BU-6644-S
1996

MINNESOTA EXTENSION SERVICE

UNIVERSITY OF MINNESOTA
COLLEGE OF AGRICULTURAL, FOOD
AND ENVIRONMENTAL SCIENCES

Tillage Best Management Practices
for the Minnesota River Basin
Based on
Soils, Landscape, Climate, Crops, and Economics

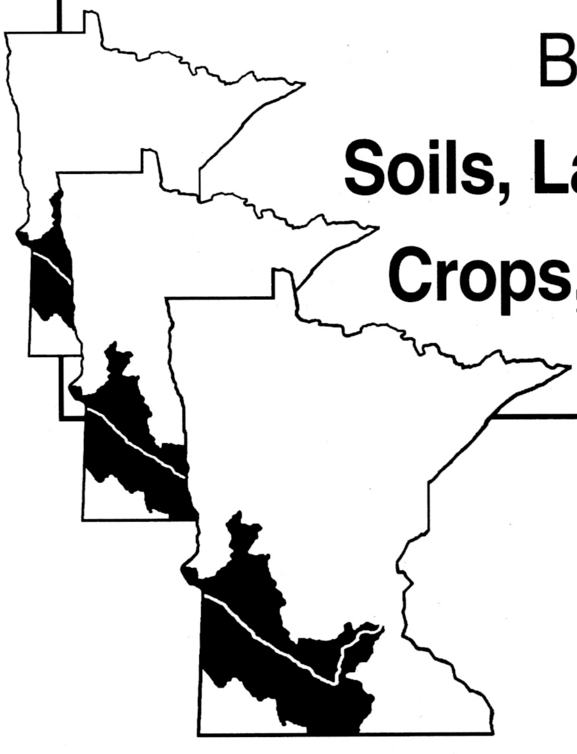


Table of Contents

These publications are available individually.

To order contact the Distribution Center at (612) 625-8173 and reference the item number (in parenthesis) after the title.

Description of the Minnesota River Basin and General Recommendations of Residue Management Systems for Sediment Control

John F. Moncrief,
Extension Specialist, Dept. of Soil, Water, and Climate

Samuel D. Evans,
Soil Scientist, West Central Experiment Station[1]

Gyles W. Randall,
Soil Scientist, Southern Experiment Station
University of Minnesota

Scope of the Problem and Description of the Watershed

The Problem

Non-point source monitoring studies conducted by Metropolitan Waste Services, MWS, (1990, 1991, 1994, formerly Metropolitan Waste Control Commission) have documented that during 1976-1992 the water quality of the Minnesota River was worse than that of the Mississippi and St. Croix Rivers. The load of total suspended solids in the lower Minnesota River was 22 times greater than that in the St. Croix River and 3.6 times greater than that in Mississippi River (MWCC, 1994). According to MWS, these numbers translate to approximately 625,000 tons per year of total suspended solids (86 20-ton truck loads per day) transported by the Minnesota River at Fort Snelling in the Twin Cities. Suspended solids, largely sediment, make the water turbid and contribute to the biochemical oxygen demand (depletion of dissolved oxygen by chemical reactions and microbial transformations).

Extent of P Load

The load of total P (phosphorus) from the Minnesota River was 5.5 times greater than from the St. Croix River and 1.5 times greater than from the Mississippi River (MWCC, 1994). This nutrient is important because lack of it limits the growth of algae. When P enters surface water algal blooms occur that then deplete dissolved oxygen as the algae decompose.

Differences among Watersheds

The differences in sediment load of the three rivers has to do with the material that the last glacier left and with human activity. Figure 1 shows the boundaries of the three watersheds that are being monitored by the MWS overlaid on a generalized soils map. Minnesota is a unique state in that within its boundaries are parts of five major watersheds draining in all compass directions: the St. Lawrence, the Hudson Bay, the Mississippi, the Minnesota, and the Missouri watersheds. On this synoptic state soils map, the type of parent material in which soil has formed is represented by different colors.

Importance of Soil Texture and Native Levels of P

Soil texture is determined by the relative amounts of sand (2-.05mm), silt (.05-.002mm), and clay (<.002mm) sized particles. The predominence of a particular particle size is largely dependent on the

---

[1] Dr. Evans is now an Emeritus Professor at Morris, MN.

mode of deposition by either wind or water. Soil scientists and geologists call this particle size sorting.

On the soils map, the blue represents fine textured (silty clay loam or finer) lake sediments from great glacial lakes. These soil landscapes are very fine textured and have very little slope because the water was still and allowed even settling of small particles (~1-2% slope). In some areas islands of glacial till rise above the lake sediments to result in greater slopes. These soils are also very poorly drained. The yellow colored soil parent material represents poorly sorted clay to boulder-size particles that were dropped in place when the ice melted. Textures are clay loam with more slope (1-6% slope generally, although end moraines on parts of the periphery of the Minnesota River Basin can have slopes of 6-18%). The orange and pink represent soil materials that are very coarse textured, sandy deposits formed at the melting edge of the ice where meltwater had enough energy to carry sandy material but dropped it out of suspension as the water slowed beyond the edge of the ice. The green represents soil material that is silt-sized and was blown (sorted by wind) from the ice sheet (Des Moines lobe of the Wisconsin glacier, generally outlined by the yellow) and deposited on its east and west edges. This wind-blown material is termed loess. Slopes generally range from 2-18%.

The Mississippi and St. Croix watersheds are predominately covered with coarse, sandy glacial deposits. This is in contrast to the Minnesota and Red River watersheds that are covered with predominately fine glacial till and lake bed deposits. In about three minutes sand-sized particles (2-.05mm) will settle about a foot in perfectly still water. It takes about twenty four hours for silt-sized particles (.05-.002mm) to settle one foot in perfectly still water. It takes days for the larger clay-sized soil particles to settle one foot in perfectly still water. In a flowing river silt and smaller-sized particles will usually not settle until a lake is encountered and the flow rate is very low. A portion of the clay particles will be bound together or become aggregated and act like larger particles in flowing water. How much clay is aggregated depends on the amount of calcium and magnesium present and the amount of cementing agents such as organic matter. They are present in fairly high quantities in the Minnesota and Red River basins, which tends to reduce the amount of clay in suspension.

Due to differences in mineralogy, the Mississippi and St. Croix watersheds also have higher native levels of soil P than the Minnesota watershed. This influence is seen with the ratio of P loads of the Minnesota River relative to the other two watersheds compared with sediment that is mentioned in the introduction. Although the Minnesota River carries higher loads of P than the other two rivers, the spread is much smaller than sediment load differences. This is in part due to native mineralogy of the watersheds.

Natural Vegetation

Most of the soils in the Minnesota River watershed have developed under prairie vegetation. The transition between forest and prairie is roughly along interstate highway I-94. Prairie soils are much darker than the soils developed under forests in the Mississippi and St. Croix watersheds. A given amount of prairie soil in suspension will make the water appear more turbid than the same amount of a forest soil.

It's a complex issue, but most scientists agree that the Minnesota River will carry a higher load of suspended soil particles and appear more turbid than the Mississippi and St. Croix Rivers just because of the type of material that the glacier left behind and the type of vegetation present.

Agricultural Activity

Agricultural activity is different among the watersheds. In the Mississippi and St. Croix watersheds there is less agriculture (mostly dairy) and forested acreage predominates. In the Minnesota watershed row crop farming with corn and soybeans predominates. When considered over the total crop rotation, historically corn and soybeans have required more intensive tillage than a rotation of corn and alfalfa for dairy enterprises. Agricultural activity makes erosive losses of soil particles more likely in the Minnesota Watershed.

Even though generally native levels of soil P were medium to low in the Minnesota River basin, most fields have been raised with manure and fertilizer additions to medium to high levels of Soil P to support crop production. Since most P that is lost from fields is associated with soil loss, this has increased the impact of sediment losses on P levels in the river.

In summary, turbidity and sediment loading of the Minnesota River is greater than the Mississippi and St. Croix due to differences in soil parent material, natural production, and agricultural activity. Differences in P loads are much smaller due to differences in the mineralogy of the watersheds. It's hard to evaluate the relative influences of these two factors on river water quality.

Physical Description of the Watershed

Precipitation and Runoff

The next three figures have been taken from Payne (1994) to characterize the climate and landscape of the Minnesota River watershed. Figure 2 shows the average annual precipitation for the basin. The 28-inch average annual rainfall line is a logical place to first divide the basin into wetter and dryer regions. This break also corresponds to the 4-inch average annual runoff contour in figure 3. The eastern third of the basin has about twice the average annual runoff intensity as the western two-thirds. This has obvious implications as to where the highest risk of runoff and sediment losses are in the basin.

High Slope Areas

Figure 4 shows the physiographic regions in the basin. This figure is important in that it shows the location of morainal areas. The landscape of this area has steeper soil slopes and the likelihood of runoff and erosion is higher. The Coteau des Prairies, Owatonna Moraine area, and Alexandria Moraine area are areas of greater soil slope.

Further Subdivision by Soil Type and Parent Material

Soil type and parent material shown in figure 1 assist in logically dividing the basin. There are three basic types of soil parent material/landforms in the basin: moraines, till plains, and glacial lake beds (lacustrine soils). There are some soils in the basin that have developed in a fourth parent material-glacial outwash (very coarse, excessively well drained soils) but they don't contribute high priority pollutants such as P, BOD, and sediment (same argument as the Mississippi and St. Croix watersheds).

A moraine is a deposit of glacial till in a linear fashion at the periphery of the ice sheet. In this case the ice was advancing at the same rate at which it was melting. You can think of it acting like a conveyor belt dropping the rock and soil material in the ice at its edge. Moraines are usually associated with a steeply sloping landscape. The morainal soils have the highest risk of erosive losses due to the slope, but the amount of sediment reaching the Minnesota River is unknown.

Till plains are deposits left when the ice retreated and dropped its load of soil parent material in place. They are sometimes rolling but not as steep as the moraines. The soils developed in till plains have intermediate risk of erosive losses but are poorly drained and need to be tiled to be cropped effectively.

The soils developed in glacial lake bed sediments are very flat and don't have much potential for water erosion. They are the most poorly drained, however, and must be extensively tiled. Surface tile inlets pose a special hazard in that they act as conduits that allow water to enter the drainage system without the benefit of soil filtering. This is particularly true when rain drop impact dislodges the fine soil particles, which remain suspended in the drainage waters.

Evaluation of Residue Management Systems

Background for Recommendations

The soils in the Minnesota River basin are quite variable from very fine-textured, poorly drained to coarse-textured, excessively well drained. The data base for evaluation of the crop response to residue management systems is very extensive for the glacial till soils, both on University Experiment Stations and on farmer cooperator fields. The data are rather sparse for evaluation of these systems on crop response on the soils developed in glacial lake sediments (lacustrine). There are no data addressing the relative contribution of sediment of these landscapes compared to glacial till soils or the effectiveness of crop residue.

There is also a considerable range in rainfall across the basin. Generally more tillage is required for ideal growing conditions during wet years. The tillage recommendations need to be tailored for climate and soil. The best tillage approach will likely not be the same every year.

Effect of Tillage Systems

With the limitations of the data base in mind, some generalizations can be made, however. Fall chisel plowing that results in 30% crop residue cover after planting can reduce the gross field erosion from 50% to 65% compared with a system without soil cover. Only a portion of the soil that moves on any given field from erosion will be delivered to the river system, however. The ratio of the watershed erosion to the amount of sediment that ends up in the river system is called the sediment delivery ratio. Estimates in the research literature range from 2% to about 19%. The smaller the watershed the greater the sediment delivery ratio.

Chisel plowing is probably the best alternative to moldboard plowing on poorly drained soils. Light spring tillage only, such as disking, has performed well, but may delay entry into the field on poorly drained soils in wet springs.

Ridge- and no-till systems provide the maximum amount of surface residue cover and thus sediment control. Ridge-till systems have performed well over a wide range of soil and climatic conditions. This system does require a banded P and K application for corn, controlled traffic (combine, cultivator, and planter), a special planter and cultivator, and sometimes herbicide applications for perennial weed control.

No-till approaches also require special fertilizer application techniques for corn, complete chemical weed control, and specially equipped planters—and controlled traffic is even more important. There has been some success with no-till drilled soybeans in the Minnesota River Basin. No-till success with corn depends on fertilizer management, stand establishment, and enhanced early growth with row-clearing, planter-mounted tillage tools. This is probably not going to be a viable option on the lacustrine soils (glacial lake beds) and on very poorly drained glacial till soils. Internal drainage is a necessary component to the success of no-till systems.

Recommendations

Details of recommendations are presented in companion publications.

Evaluation of Tillage and Manure on Sediment and P Losses

There are very little actual runoff data available designed to evaluate the effectiveness of residue management systems on pollutant losses in Minnesota. An experiment was initiated at Morris, Minnesota in the spring of 1992 with this objective in mind. It was designed to evaluate the interaction between tillage and manure on P losses.

The slope was a uniform 12% and the soil a Barnes loam. The initial soil test P was in the medium range, ~10ppm. A one-time application of 330 pounds per acre of P_2O_5 as solid beef manure (25 tons per acre) was applied in the spring of 1992. Manure was incorporated with moldboard plowing to a depth of 8 inches, or with planting and cultivation in the ridge-till plots. Runoff plots were established that allowed collection of runoff, and determination of sediment and P. The 1993 and 1994 runoff and yield data (second and third year of corn since manure application) are shown in table 1.

The soil test P in the spring of 1994 (0-6") was increased by the manure application more with the ridge-till system than the moldboard system. This is due to less mixing and greater fixation in this calcareous soil. In 1993 there was no statistically significant increase in yield due to manure with either system. Yields were decreased with the ridge-till system compared to the moldboard plowing system in this year however.

In 1994 there was no grain yield benefit to the higher soil test P levels with moldboard plowing. It does appear that the higher soil test did, however, increase grain yield 21 bushels per acre with the ridge-till system.

The effect of the higher soil test levels on P losses is also shown in table 1. As would be expected, the sediment losses were much lower with the ridge-till system. Sediment losses were reduced by about one-half by manure application with both systems. The erosion reduction associated with manure was consistent in 1992 and 1993. This is likely due to more stable soil aggregates because of the "cementing agent" properties of manure that bind clay-sized particles that act like larger particles. In 1992, the year of manure application, sediment loss was also reduced with manure application but total P was increased with the moldboard system (data not shown).

Total P is usually associated with sediment. This type of chemical analysis digests the organic matter associated with the soil and determines all of the P. Total P losses were higher with moldboard plowing compared with ridge tillage and without manure addition for both tillage systems. The trend follows the sediment results.

In summary, tillage has a large effect on sediment and P loss. In the study presented, solid beef manure reduced sediment and total P loss. Residue management systems, often with manure applied, will be an important part of sediment reduction in the Minnesota River. It appears that shallow incorporation of solid manure sources with these systems may still result in lower P losses due to increased sediment control.

Table 1. The effect of tillage and manure on corn yield and annual sediment and total P loss, Morris, MN (Ginting et al.).

	soil	Yield			Sediment loss			Total P loss		
Tillage	test P	'93	'94	avg.	'93	'94	total	'93	'94	total
Ridge	ppm	-bushels/acre-			—tons/acre—			-pounds/acre-		
Manure	32	119	193	156	.1	<.1	.2	.6	.4	1.0
No Manure	14	115	172	144	.4	.1	.5	2.3	.4	2.7
Average		117	183	150	.3	<.1	.4	1.5	.4	1.9
Moldboard										
Manure	20	146	175	161	6.4	.6	7.0	1.7	.6	2.3
No Manure	12	134	179	157	10.5	1.2	11.7	2.6	.8	3.4
Average		140	177	159	8.5	.9	8.9	2.2	.7	2.9

Literature Cited

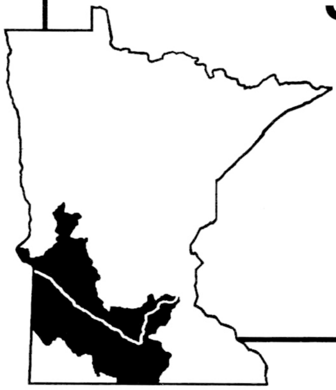
Ginting, D., J.F. Moncrief, S.C. Gupta, S.D. Evans, G.A. Nelson, B.J. Johnson, and A. Ranaivoson. 1994. Assessment of the effects on tillage and manure application on sediment and P loss due to runoff. In: Field Research in Soil Science 1994. pg74-83. MN Ag. Exp. Sta. Misc. Publ. 83-1994

Metropolitan Waste Control Commission. 1990. Annual Report Non-point Source Program (Program 6000). Report No. QC-90-182. pp 86.

Metropolitan Waste Control Commission. 1991. Annual Report Non-point Source Program (Program 6000). Report No. QC-91-221. pp 152.

Metropolitan Waste Control Commission. 1994. Water quality analysis of the Lower Minnesota River and selected tributaries: River (1976-1991) and non-point source (1989-1992) monitoring. Volume 1. Report No. QC-93-267. pp 142.

Payne, G.A. 1994. Sources and transport of sediment, nutrients, and oxygen-demanding substances in the Minnesota River basin, 1989-1992. In: Minnesota River Assessment Project Report, Vol. II, Physical and chemical assessment. USGS, Water Resources Investigations Report 93-4232



Sediment Problems and Solutions for the Minnesota River

Norman B. Senjem,
Minnesota River Basin Coordinator

John F. Moncrief,
Extension Specialist, Dept. of Soil, Water, and Climate

Gyles W. Randall,
Soil Scientist, Southern Experiment Station

Samuel D. Evans,
Soil Scientist, West Central Experiment Station University of Minnesota[1]

A Minnesota River Prognosis

The Minnesota River is in poor health. Like a heart patient's veins and arteries, its tributaries and main stem are clogged—not with cholesterol, but with sediment, nutrients, and excessive algae growth. The river, like a heart patient, needs to go on a strict diet before its health can be restored.

The river's water, clouded by sediment and contaminated by bacteria, frequently is unfit for fishing, swimming, and other uses. In fact, the lower stretch of the river has seen violations of federal and state water quality standards for turbidity, dissolved oxygen, and fecal coliform. At periods of low flow, pollution-generated algae growth and subsequent decay remove so much dissolved oxygen from the water that many aquatic life forms can't survive. At other times, a steady supply of suspended sediments keeps the river turbid—cloudy—and far below its potential as a water resource that Minnesotans can use and enjoy. This is true of the main stem, and many of the major tributaries that drain into the Minnesota River.

The good news is, the Minnesota River can be restored to health. Measures already underway promise to result in reductions of the major pollutants spoiling the river—bacteria, sediment, phosphorus, and nitrogen. Farmers are upgrading feedlots and leaving more residue on their fields. Towns and cities are reducing storm water runoff and industrial discharges while upgrading wastewater treatment plants and septic systems. New techniques.for reducing sediment losses through open tile inlets are also being tested.

Sediment: A Priority Pollutant

A significant part of the Minnesota River's water quality problems comes from sediment that enters the river and its tributaries throughout its 10-million-acre watershed. Approximately 625,000 tons per year of total suspended solids, largely sediment, are transported by the Minnesota River at its mouth at Fort Snelling, according to the Metropolitan Council. That's 86 20-ton truckloads a day.

Sediment is a pollutant in its own right, causing turbidity in the water that limits light penetration and prohibits healthy plant growth on the river bed. Sediment also covers much of the river bed with a blanket of silt that smothers life. By covering up gravel and cobble, sediment destroys the spawning grounds and habitat of desirable fish species such as bass and bluegills. Instead, less desirable species such as carp are favored by the sediment-enriched habitat.

Finally, sediment is an important carrier of a critical pollutant: phosphorus. This nutrient stimulates excessive algae growth in the water column. When the algae decomposes, it depletes dissolved oxygen from the water, reducing the quality of life forms that are able to survive.

---

[1] Dr. Evans is now an Emeritus Professor at Morris, MN.

Sediment Sources

Sediment originates from many sources within the Minnesota River basin: stream banks, construction sites, lawns and streets, and agricultural fields. Each of these sources is being addressed as part of the river restoration effort. However, given the prevalence of row-crop agriculture throughout the basin, this source generally outweighs the others, and must be significantly reduced to improve the river's water quality.

Substantial water quality improvements can result from the use of economically achievable sediment-reduction practices on farmland. One of these practices is conservation tillage, defined as tillage systems that leave at least 30 percent of the field surface area covered by crop residue after planting. Leaving the surface rough and partially covered with crop residue reduces sedimentation at its origin by preventing the detachment of soil particles by raindrops, and retarding their transport across the field surface by water runoff. Soil erosion reduction does not translate into equal reductions of sediment entering surface waters, however. Erosion refers to the transport of soil over the field by water or wind, while sedimentation refers to the deposition of soil particles into surface water. Reductions in erosion usually correspond to much smaller reductions in sedimentation.

An example illustrates the point. Switching from clean tillage to a system that leaves at least 30 percent residue cover on the surface after planting can reduce soil erosion by 50 to 65 percent. Thus, if the original average annual erosion rate on a field was 4 tons per acre, conservation tillage would result in a 2-ton reduction in soil erosion. But only a fraction of this 2 tons would translate into reduced sedimentation. On a gently sloping, typical row-cropped field in the south-central part of the Minnesota River basin, the Natural Resources Conservation Service (NRCS) estimates that about 10 to 20 percent of eroded soil typically is delivered to a surface water channel such as a drainage ditch or surface tile intake or directly into a stream. Thus, a 2-ton per acre reduction in erosion may translate into a reduction of 400 to 800 pounds of sediment entering surface water.

These sediment losses are much lower than the so-called "tolerable" level of soil loss that can be sustained without sacrificing long-term productivity — the "T" level of approximately 5 tons per acre. But sediment losses of several hundred pounds multiplied over hundreds of thousands of acres of cropland can contribute to chronic water quality problems in the Minnesota River system. This is especially true of sediment composed of fine particles from the clayey soils so prevalent in the basin. These particles may stay in suspension for days, degrading water quality for hundreds of miles before settling out.

The relative proportions of the total sediment in the river contributed by cropland, streambanks and other sources still are not well understood. Very likely, these proportions vary widely within the basin. But according to an evaluation by the NRCS, the widespread adoption of conservation tillage practices within the south-central part of the basin could reduce sediment losses by approximately 45 percent. Since conservation tillage can be practiced with minimal effect on crop yields and often at lower production costs than conventional tillage, it offers a low-risk means of achieving substantial reductions in sediment losses from cropland.

Minnesotans can aim high in their efforts to restore the quality of their namesake river. However, we need to be realistic. Even substantial reductions in sediment and other pollutants won't restore the Minnesota River to its pre-settlement state of quality, as described by early explorers and settlers. For one thing, highly productive row-crop agriculture is the dominant land use throughout most of the basin. This intensive form of land use inevitably entails sediment losses. In addition, the prairie soils throughout the Minnesota River basin are generally of a fine texture that dislodge easily, carry substantial quantities of phosphorus, and cause a high degree of turbidity.

The Benefits of a 40 Percent Sediment Reduction

The Minnesota Pollution Control Agency has established a basinwide goal of a 40 percent reduction in sediment losses. This is economically achievable throughout much of the basin, and would lead to substantial improvements in water quality.

During high-flow periods, typically in the spring, the river would begin to cleanse itself by scouring deposits from years of sediment loading. As the small spaces between pebbles on the river bed cleared out, spawning by popular game fish would increase. Species such as bluegills and largemouth bass would begin to increase in population in the lower reaches of major tributaries and in parts of the main stem.

During the rest of the year, at medium and low flow, the river and tributaries would become less turbid. A child could see his or her feet after wading in knee-deep, for example, versus only shin-deep today. But actually, light would penetrate much farther than that, all the way to the river bed of tributary streams, and up to a grown man's height in the main stem. As a result, plant growth would shift from algea at the surface to large aquatic plants at the bottom, becoming a healthy part of the biological community rather than a nuisance. Dissolved oxygen levels would rise as phosphorus levels and surface algae growth declined. The Minnesota River would be on its way to achieving the level of quality that Minnesotans expect from their major water resources.

Achieving these water quality gains through land-use changes that are consistent with a productive, profitable agriculture is the goal of the Sediment Reduction Initiative, a basinwide effort involving state and local government agencies, private businesses, landowners and nonprofit organizations. As the first stage of this initiative, the University of Minnesota has developed conservation tillage guidelines for specific soils, climate zones, and crop rotations within the basin.

Reduced Tillage Guidelines for the Minnesota River Basin

Sediment from cropland can be reduced through a variety of measures including reduced tillage, crop rotation, waterways and terraces, grassed buffers at the field edge, and catch basins. In many situations, residue management through reduced tillage can be the primary means of sediment reduction. By preventing sediment losses at the source, surface residue management reduces the need for secondary measures. Where such measures are required for secondary protection, residue management makes them less costly, more effective, and longer lasting.

Overview of Tillage Systems

A variety of tillage systems can be used in a corn-soybean rotation, or rotations including a small grain, to achieve an average surface residue cover of approximately 30 percent after planting, the goal of conservation tillage.

- Chisel plowing with straight shanks followed by very limited secondary tillage is the system most broadly applicable throughout the basin that can achieve this goal without sacrificing yield potential.

- On well-drained soils, a single pass in the spring with a disk or field cultivator can achieve still more sediment reduction, but at the possible cost of delayed planting in wet springs due to slower field drying and warm-up. Following a high residue crop like corn or small grains two passes may be necessary.

- Ridge-till achieves still more sediment reduction, usually at reduced operating costs and with no yield penalty. However, on poorly drained soils in wet years, reduced yields may occur.

- The same is true of no-till, but with greater potential for substantially reduced yields on poorly drained fields in wet, cool springs.

A Three-Stage Implementation Sequence

The Natural Resources Conservation Service (formerly Soil Conservation Service) has recommended that sediment reductions on farmland in the Minnesota River basin be pursued by introducing residue management on cropland through a three-stage process:

- First, cropland eroding at a rate higher than T, or the rate at which soil can replace itself naturally, should be treated with appropriate conservation tillage practices.

- Second, if the sediment reduction achieved through the first step is inadequate, suitable conservation tillage methods should be extended to fields adjacent to streams and field ditches—so-called riparian areas where eroded soil directly enters surface water channels.

- Third, if these two measures prove insufficient, suitable conservation tillage practices should be extended to fairly level terrain where sediment losses occur. Priority should be placed on fields with surface tile inlets, side inlets, or plow drains leading to ditches, or comparable surface drainage conduits. A range of methods can be used to reduce sediment losses through such conduits, depending on the situation. These include conservation tillage, alternative tile inlet designs, vegetative buffer zones, wetland restoration, or closer pattern tiling in areas that pond but are not classified as protected wetlands.

Critical Management Factors

The performance of reduced tillage systems depends on a wide variety of management factors that differ from those used under clean-till systems. Crop rotation, equipment selection and adjustment, fertility management, weed control, and drainage are among the critical factors required for successful use of reduced tillage systems.

The degree of management changes required depends on the extent of tillage reduction. Farmers who substitute the chisel plow for the moldboard plow face minor management changes, while those adopting no-till face systematic adjustments touching many aspects of crop management. Farmers in the eastern part of the Minnesota River basin, where annual precipitation averages 28 inches or more, will often face higher management requirements than those in the western part of the basin where rainfall is lower. Similarly, farmers with poorly drained, fairly level fields face greater challenges than those farming better drained, sloping fields.

• Crop Rotation

Each crop rotation presents distinct opportunities and challenges for residue management:

- Continuous corn and continuous small grains are the most restrictive cropping sequences for residue management. This is because of the high quantities of residue produced, increased potential for disease transmission and insect problems, and the loss of rotational advantages such as yield stimulus and improved weed control. Chisel plowing and ridge tillage are best suited to residue management under continuous cropping, but moldboard plowing may be required under high-stress conditions such as compaction. Crop residue should be removed from the seed furrow at planting.

- The corn-soybean rotation, the most prevalent cropping system in the Minnesota River basin, is much more flexible than continuous corn. Properly managed, and used in an appropriate soil and climate zone, reduced tillage systems of all types can be successful. On well-drained soils, corn can be planted into soybean residue with little risk of yield reduction if residue is evenly distributed by the combines and is cleared from the rows before or at planting, and if P and K are banded near the rows. Soybeans can be planted or drilled into fairly heavy corn residue without a yield penalty on well-drained fields. In poorly drained fields, chisel plowing often promotes higher corn and soybean yields by aerating and warming the soil, especially in cool, wet springs or in compacted soil.

- Small grain following soybeans can perform well under a wide range of tillage systems, from chisel-plowing to no-till. However, some yield reductions may occur on heavier, poorly drained soils unless full-width deep (6"-8") tillage is used. Moisture saving can be an added benefit of reduced tillage in the western part of the basin in years when soil moisture is limited. To avoid disease problems, wheat and barley should not follow corn in the rotation. Winter wheat seeded no-till into barley stubble is a promising rotation for west central Minnesota, thanks to the winter protection afforded by stubble-trapped snow cover.

• Drainage

- Choose well-drained fields for high-residue systems. Either natural or artificial drainage is a must. On soils that are naturally tight and poorly drained, tile drainage is a prerequisite to successful high-residue farming.

- Artificial drainage activity must not violate wetland preservation laws, however, and might need to be accompanied by such practices as vegetative riparian buffers around surface inlets and drainage ditches, and possibly temporary impoundment of drainage water.

• Planting

- Use planters and drills designed for heavy crop residue—not older, lightweight units designed for moldboard-plowed fields. Some modern planters and drills are flexible, designed for conventional and reduced tillage and no-till.

- For soybeans, choose varieties that are resistant to phytophthora root rot, and avoid planting when fields are too wet.

- Clear residue from the corn row or small grain furrow before or at planting, using coulters, finger wheels, and other such toolbar attachments.

- Avoid planting through piles of residue or chaff left by the combine. Use chaff spreaders and choppers to avoid residue piling.

• Fertilization

- Soil testing should be used to correct low P and K fertility problems before introducing high-residue farming systems. In addition, it should be used to manage P and K levels for optimal crop performance and minimal pollutant loading from any sediment that leaves the field. Move toward a medium to high soil test for phosphorus (about 15 to 20 parts per million). Limiting the concentration of phosphorus in the soil will reduce the pollutant content of sedimentation without limiting yield potential.

- Starter fertilizer: Band-apply starter fertilizer next to corn rows where full-width deep tillage is not used.

Either apply the full P-K requirement, or the first 20 to 30 pounds.

- Nitrogen: Inject, rather than broadcast, nitrogen fertilizer. Best options are injecting anhydrous ammonia, or injecting or incorporating 28 percent liquid nitrogen at early cultivation. If urea is broadcast, incorporate within three days.

• Weed Control

- Avoid starting very-reduced tillage systems on weed-infested fields.

- Perennial weed problems often increase with no-till or ridge-till. Be prepared to control a shifting spectrum through crop rotation, mechanical controls, and timely treatments of carefully chosen herbicides.

- Herbicide timing and choice become more critical as you rely less on tillage to control weeds. However, with today's wide choice of herbicides, excellent control with little or no tillage is highly feasible, often at little or no additional weed control cost compared with conventional tillage.

- Producers in the western part of the basin should not rely on rainfall to activate herbicides applied at or after planting time. Early pre-emergence treatments generally are activated, but may be difficult to schedule.

- Total post programs are feasible, and pre-post combinations including residual and contact products offer a range of reliable options.

- Soybeans planted into heavy corn residue generally require a burn-down treatment. This is not usually necessary for corn planted into soybean stubble in late April or early May.

- Banding of herbicides provides effective weed control with many tillage systems.

- Mechanical weed control, using the rotary hoe or cultivator, is a best management practice for corn and soybeans, and can be an economical choice under many situations.

Performance Summary of Tillage Systems

For purposes of evaluating tillage systems, the Minnesota River basin can be divided into four regions based on soil parent material and rainfall. The two soil parent materials are lacustrine and glacial till. Lacustrine soils, which are fine-textured and poorly drained, are found south of Mankato, in the Blue Earth basin, as well as to the northwest of New Ulm in Renville, Chippewa, and northern Lac Qui Parle counties, and in isolated pockets elsewhere. Most of the rest of the soils are classed as glacial till. The east-west dividing line is formed by the 28-inch annual precipitation line, which runs roughly north-to-south between Highways 71 and 15. Based on these distinctions, the following four regions have been delineated:

Lacustrine, High Rainfall (L-HR)
Lacustrine, Low Rainfall (L-LR)
Glacial Till, High Rainfall (G-HR)
Glacial Till, Low Rainfall (G-LR)

Each of the five tillage systems identified earlier are evaluated using the following four performance indicators:

1) ***Inadequate residue for sediment control*** — considerably less than 30 percent of surface covered after planting. Highest yields may be obtained, however, on poorly drained, fine-textured, high organic matter soils.

2) ***Recommended with good management*** — If the above management guidelines are observed, no yield penalty is expected, and surface residue should be 30 percent or more.

3) ***Excellent management required*** — Surface residue should be adequate for erosion control, but a slight yield penalty is possible, even if all recommended management practices are observed. Above average crop management, especially weed control without excessive herbicide use, will be needed to ensure profitability.

4) ***Reduced yield potential*** — Surface residue should be adequate for erosion control, but the potential exists for substantially reduced yields in wet years on poorly drained sites.

Soybeans Following Corn

	Lacustrine Soils		Glacial Till Soils	
	HR	LR	HR	LR
MB Plow	1	1	1	1
Chisel Plus	2	2	2	2
1 or 2 Passes	3	3	2	2
Ridge Till	3	2	2	2
No Till	3	3	3	3

Corn Following Soybeans

	Lacustrine Soils		Glacial Till Soils	
	HR	LR	HR	LR
MB Plow	1	1	1	1
Chisel Plus*	2/1	1	2/1	1
1 or 2 Passes	2	2	2	2
Ridge Till	3	3	2	2
No Till	3	3	3/2	2

* Even if straight shanks are used, this system cannot reliably achieve the 30 percent surface residue target, and must be used in a rotation where corn residue levels are at least 40 percent after planting.

Continuous Grain Corn

	Lacustrine Soils		Glacial Till Soils	
	HR	LR	HR	LR
MB Plow	1	1	1	1
Chisel Plus	3	2	3	2
1 or 2 Passes	4	3	3	3
Ridge Till	3	3	2	2
No Till	4	4	4	4

Small Grain Following Soybeans

Tillage System	Glacial till Soils	Lacustrine Soils
MB Plow	1	1
Chisel Plus	1	1
1 or 2 Passes	2	2
No Till	2	3

Tillage Best Management Practices for Corn-Soybean Rotations in the Minnesota River Basin

Gyles W. Randall,
Soil Scientist, Southern Experiment Station

William E. Lueschen,
Agronomist, Department of Agronomy and Plant Genetics[1]

Samuel D. Evans,
Soil Scientist, West Central Experiment Station[1]

John F. Moncrief,
Extension Specialist, Dept. of Soil, Water, and Climate, University of Minnesota

Summary

A corn-soybean crop rotation presents opportunities for tillage flexibility without sacrificing yields due to the lesser amounts of crop residue produced compared to continuous corn. Numerous reduced tillage practices can be used profitably, with little or no additional risk, in this crop rotation. When accompanied by good management, one-pass tillage with a field cultivator, ridge tillage, and no tillage systems are appropriate for corn in the lower rainfall area and on glacial till soils throughout the Minnesota River basin. One-pass field cultivation or fall chisel plowing plus spring field cultivation are advisable tillage systems for corn production on the flat, poorly drained lacustrine soils. Soybean production can be accomplished successfully throughout the Minnesota River basin with the chisel plow-plus tillage system. This system also allows incorporation of nutrients, lime, and herbicides. One- or two-pass disk tillage or ridge-till are also advisable on glacial till soils but may require excellent management on wet, level, fine-textured fields. Even then, modest yield penalties are possible. No-tillage for soybeans requires excellent management on all soils in the basin; even then a slight yield penalty is possible. Best results with no-till are obtained when rotated periodically with a chisel plow system. Moldboard plow tillage is not recommended in this crop rotation except when solid manure sources, nutrients, or lime are to be incorporated up to 8 inches deep following corn, or when the risk of sediment losses to surface waters are minimal.

Introduction

Tilling the soil to prepare a seedbed has been a practice used for centuries. Since the mid-1800s the moldboard plow has been used by most farmers to invert the soil, leaving the soil surface bare of residues. Because the possibility of erosion and sediment loss occurring is higher on bare soils, primary tillage tools that leave some residue on the soil surface were introduced in the 1950s and 60s to reduce soil erosion. Chisel plows and early models of ridge-till planters were the forerunners. 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. The result has been good seed-to-soil contact for consistent seedling emergence and improved erosion control. With improved herbicides and planters available in the mid-1980s for better weed control and good seed placement, some farmers began to use no-tillage in their crop production system.

Soil erosion that has resulted in sediment loss into the surface waters of the Minnesota River Basin has been identified as a key source of nutrient enrichment and turbidity (cloudiness) of the rivers. This nutrient enrichment and cloudiness promotes algal blooms, reduces oxygen levels, and interferes with 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

---

[1] Dr. Lueschen was formerly Head of the Southwest Experiment Station at Lamberton. He is now based at St. Paul, with the Department of Agronomy and Plant Genetics. Dr. Evans is now an Emeritus Professor at Morris, MN.

impact of raindrops and minimizes the dislodging of soil particles. Crop residues on the soil surface also may improve infiltration of precipitation into the soil, reducing surface runoff and resulting in more stored water in the soil profile for crop use. However, increased levels of crop residue on the soil surface insulates the soil causing decreased soil temperatures in the spring due to sunlight reflection and increased soil moisture which can reduce soil aeration.

Factors to Consider When Making a Tillage Decision

Selecting the best tillage system should involve a set of specific considerations much like those a farmer uses when selecting a hybrid. Often, certain hybrids are chosen to meet specific soil conditions. 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 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. Maintaining an adequate residue cover is a problem following soybeans. 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. Very reduced tillage, that is, no-tillage, often works well following soybeans. 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 the erosion potential is high, conservation tillage systems are highly recommended. Fields or acres considered to be highly erodible land (HEL) require 30% residue cover after planting for conservation compliance. 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.

Soil fertility level— A high level of fertility is necessary if reduced tillage systems are to perform well. Low fertility conditions offer too many obstacles and generally limit yields more severely in reduced tillage (no-till and ridge-till) systems compared to full-width, deep tillage systems. Thus, fields testing low in phosphorus (P) or potassium (K) should be brought to high P and K levels before implementing these reduced conservation tillage systems.

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 this surface soil compaction. Without primary tillage, good seed-to-soil contact and rapid root development in the spring will be more difficult.

• Nutrient Management

Management of fertilizer and manure nutrients is highly important to the success of conservation tillage systems for corn-soybean rotations. If nutrient management is poor, yields and economic return will suffer. In addition, runoff of non-incorporated nutrients applied to fields with no-tillage may actually increase nutrient enrichment of the surface waters. To reduce potential loss by volatilization and runoff, do not surface-apply urea or liquid 28% N solution UAN (urea-ammonium nitrate) unless incorporation can be completed within three days or gentle rains are imminent. Anhydrous ammonia has been the most consistent source of N, but some soybean residue will be incorporated by the knives during application. Application of ammonia is improved in all tillage systems and especially in no-till, when covering disks attached to the injection knives are used to close the knife slits and seal in the ammonia. Alternative N application methods with ridge-till and no-till systems include: (1) spoke-injecting UAN into the soil and (2) applying urea 4" to 6" to the side of the seed row with the dry starter fertilizer attachment at the time of planting.

Phosphorus and K should be maintained at high levels (16-20 and 12-15 ppm P for Bray and Olsen extractants, respectively, and 121-160 ppm K) for optimum production with all tillage systems. Grid soil sampling with variable rate fertilizer application will greatly assist farmers to keep soil test P and K within these ranges without over-fertilization of the already high-testing areas. To maintain these soil test levels, broadcast application of fertilizer P and K should be incorporated following corn if at all possible. These nutrients will be available for the corn in the second year of the rotation. Results from a 6-year no-till study at Waseca showed a significant accumulation of both P and K in the surface 0-2" layer even when no P or K was applied. Thus, unincorporated broadcast P and K would add to this surface buildup and could increase the potential for P to be lost to surface water. Recommended application methods include: (1) broadcast and incorporation with a tillage implement following corn; (2) banding 4" to 7" deep within the ridge with ridge tillage; (3) banding 4" to 7" deep randomly or with strip-till (zone-till) systems that prepare a residue-free band for corn; or (4) starter fertilizer. With no-till or ridge-till systems, starter fertilizer should be used for corn when Bray soil test P is <25 ppm. See extension bulletins "Fertilizer Management for Corn in Minnesota" (Minnesota Extension Service FO-3790, 1994) and "Fertilizer Management for Corn Planted in Ridge-Till or No-Till Systems" (Minnesota Extension Service AG-FO-6074, 1993) for more detailed information.

Livestock manure should also be incorporated for maximum benefit. However, incorporating manure when in a corn-soybean rotation presents a real dilemma. Greatest nutrient utilization occurs when the manure is applied following soybeans for corn (nitrogen is utilized); however, the small amount of "fragile" soybean residue is almost completely destroyed in the incorporation process. Incorporating manure following corn with either a chisel plow or by injection of liquid manure allows for good residue management, but nutrient utilization by the following soybean crop is inferior to corn. Liquid manure offers more tillage flexibility because it can be knife- or sweep-injected either before planting or sidedressed between the corn rows. With strict no-till this will disturb the residue similarly to a cultivation, but injection when the corn is 12+ inches tall should not increase the erosion potential greatly. 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.

• Herbicide Program

Reduced tillage and increased levels of crop residue may increase weed pressure. Thus, it is extremely important that farmers adjust their herbicide program to fit their tillage system. Herbicide timing and choice are more critical as one relies less on tillage to control weeds. However, with today's wide choice of herbicides, excellent control with little or no tillage is highly feasible, often at little or no additional weed control cost compared to conventional tillage. But starting very reduced tillage systems on weed-infested fields should be avoided. Tillage provides some weed control, offers greater herbicide flexibility, and perhaps some economic savings for weed control. Mechanical weed control, using the rotary hoe or cultivator, is a best management practice and can be an economical choice under many situations. Perennial weed problems often increase with no-till or ridge-till but can be economically and satisfactorily controlled with herbicides. Herbicide incorporation with tillage minimizes herbicide runoff and volatilization losses.

• Planting Equipment: Type and Age

Residue management systems require state-of-the-art planters that are capable of providing proper depth control, firm seed-to-soil contact, and good stands. Row cleaning devices that remove residues from a narrow band over the corn row may assist stand establishment, early plant growth, corn maturity, and yield in very reduced tillage systems and, thus, are advisable for high residue conditions. Using a light planter designed for moldboard tillage conditions generally will not give adequate stands and uniform seedling emergence when used with no-till or most conservation tillage systems. If considering solid-seeded soybean production with no tillage, it is essential that a properly designed, heavy duty drill be used that can cut through the residue, place seed at a proper depth without incorporating residue, and firm the soil over the seed. In summary, matching planting equipment with the desired tillage system is very important.

• Management Ability and Risk

Economical risk can be increased somewhat as less tillage is used in a corn-soybean rotation. This is especially true over the long term with very-reduced tillage systems. Crop development may be delayed and yields decreased under adverse growing conditions. This long-term risk can be reduced through occasional use of primary tillage and close attention to crop management requirements of very-reduced tillage systems.

In summary, various factors including soil characteristics, erosion potential, nutrient and herbicide management, planting equipment, management ability, and risk must be considered when selecting a residue management system for a corn-soybean rotation. Because crop residue levels are lower in this rotation, tillage options are numerous and reduced tillage systems are practical for a corn-soybean rotation in most areas of the Minnesota River basin. Good tile drainage, high soil fertility levels, a herbicide program that is targeted to the dominant weeds and applied in a timely fashion, and modern planters equipped with row cleaning and/or coulter devices for good seed-to-soil contact are critical management aspects that need to be practiced to optimize performance of conservation tillage systems in this rotation.

Yield Results from Long-Term Tillage Research

Long-term tillage experiments on corn-soybean rotations have been conducted at the University of Minnesota agricultural experiment stations at Lamberton, Morris, and Waseca. These experiments allow us to see interactions with climate or trends that may occur during a period of years. These experiment stations are located on glacial till soils.

There are no data addressing tillage performance (crop response and soil erosion control) on lacustrine soils (see publication in this series that address soil types- "Description of the Minnesota River Basin and General Recommendations of Residue Management Systems for Sediment Control". The recommendations for lacustrine soils are based on the anticipated performance of tillage systems based on experience on other soils that have similar characteristics but have textures that are somewhat coarser and drainage that may be better.

- **Low Rainfall, Glacial Till Sites**

Corn

A tillage study comparing moldboard plow, chisel plow, spring disk, ridge planting, and no-till systems for corn following soybeans was started in 1979 at the West Central Experiment Station at Morris and the Southwest Experiment Station at Lamberton. Each year the experiment was moved to a new site. On the somewhat poorly drained Hammerly clay loam at Morris, 6-year average corn grain yields for the 5 tillage systems varied by only 2 bu/A (136 to 138 bu/A) and were not significantly different (Table 1). Within any one year yield differences among the tillage systems ranged from only 4 bu/A in 1979 to 18 bu/A in 1984. However, no single tillage system was consistently better or poorer than another. On the well drained Ves soil at Lamberton, a similar yield response to tillage was shown (Table 2). Four-year average yields differed by only 1 bu/A with no consistent year-to-year pattern.

Table 1. Corn yield in a corn-soybean rotation as influenced by tillage on a somewhat poorly drained Hammerly clay loam at Morris.

	Year						
Tillage	1979	1980	1981	1982	1983	1984	Avg.
	Yield (bu/A)						
Moldboard	137	134	141	148	126	134	137
Chisel	138	124	149	155	130	121	136
Spr. disk	136	127	138	154	124	139	136
Ridge[1]	135	128	143	151	134	134	138
No-till[1]	139	127	136	153	126	136	136

1. All treatments were cultivated. The planter used was not equipped with sweeps, disks, or fluted coulters.

Table 2. Corn yield in a corn-soybean rotation as influenced by tillage on a well drained Ves clay loam soil at Lamberton.

	Year				
Tillage	1979	1980	1981	1982	Avg.
	Yield (bu/A)				
Moldboard	128	135	124	146	133
Chisel	130	131	135	138	134
Spr. disk	131	138	126	143	135
Ridge[1]	138	130	121	148	134
No-till[1]	127	135	127	151	135

1. All treatments were cultivated. The planter used was not equipped with sweeps, disks, or fluted coulters.

Another tillage study for corn after soybeans was started on a well-drained Barnes loam soil at Morris in 1980. Again, 5-year yield averages show no difference among the moldboard, chisel, or no-till systems (Table 3). Yields among the three tillage systems never varied by more than 9 bu/A in any year.

In all three of these studies row cleaning devices and fluted coulters were not used, but all tillage systems received cultivation. Under these conditions, when a long-term tillage system had not been in place, corn yields following soybeans were unaffected by tillage.

Table 3. Corn yield in a corn-soybean rotation as influenced by tillage on a well-drained Barnes loam soil at Morris.

	Year					
Tillage	1980	1981	1982	1983	1984	Avg.
	- - - - - - - - - - - - Yield (bu/A) - - - - - - - - - - - -					
Moldboard	129	139	147	103	139	131
Chisel	131	134	146	105	141	131
No-till[1]	134	130	145	106	147	132

1. No-till treatment was cultivated. The planter used was not equipped with sweeps, disks, or fluted coulters.

A 7-year study was started in 1986 on a well-drained Ves soil at Lamberton to evaluate long-term tillage systems in a corn-soybean rotation (Table 4). Three continuous tillage systems—ridge-till (RT), paraplow (PP), and no-till (NT)—were compared to two tillage systems where the tillage varied with the crop. Row cleaners were not used and weed control was a problem in some years. Significant yield differences among tillage systems occurred in 5 of 7 years. Seven-year average yield was highest with the system that involved chisel plow (CP) after soybean and moldboard plow (MP) after corn. Lowest average yields were obtained with continuous paraplowing, continuous no-tillage, and with the system where no-tillage was used after soybean and chiseling was used after corn. Ridge-till yields were intermediate. The performance of the tillage systems did not appear to be related to growing season rainfall. However, a trend of poorer performance with increasing years of continuous no-till use was apparent. In the fourth through seventh years, yields with continuous NT and the NT/CP system averaged 15 and 12 bu/A less, respectively, than with the CP/MP system. These data suggest that corn yields in a corn-soybean rotation may be reduced with the use of no-till systems over time. The reason for this yield reduction is not known. Yields from the spring field cultivation after soybeans and spring disk after corn system averaged 3 bu/A better than the NT/CP system during the last four years.

Table 4. Corn yield in a corn-soybean rotation as influenced by tillage and rainfall on a well-drained Ves clay loam soil at Lamberton.

	Tillage System[1]					Apr. - Oct.
Year[2]	CP/MP	NT/CP	RT/RT	PP/PP[3]	NT/NT	Rainfall
	- - - - - - - -Yield (bu/A) - - - - - - - -					inches
1986	141	138	145	132	142	34.7
1987*	136	125	125	120	132	15.8
1988*	77	70	82	65	74	13.2
1989*	139	128	133	132	122	14.7
1990*	137	120	118	123	114	20.7
1991	132	134	129	133	133	25.4
1992*	154	131	145	137	134	23.9
Avg.	131	121	126	—	122	

1. Tillage for corn after soybean/tillage for soybean after corn.
2. *Indicates that yields among tillage treatments were significantly different at the 95% level for that year.
3. PP abandoned after 1988 and replaced by spring disk after corn and spring field cultivate after soybeans.

Summarizing the yield data from these 22 site-years indicates little effect of tillage following soybean on corn production. The only exception, but one that is very important, is the reduced yields after three years when no-tillage is used continuously or as part of a reduced tillage system.

Soybean

A comprehensive study to evaluate tillage systems for soybeans in a corn-soybean rotation was started in 1982 at the Morris, Lamberton, and Waseca experiment stations (Table 5). The soils were primarily moderately and well-drained Aastad and Barnes clay loams at Morris and moderately and well-drained Normania and Ves clay loams at Lamberton. Each year a new site was used; thus the tillage methods were one year in length and were not repeated as part of a long-term tillage system. Stalks were chopped in the spring for the ridge-till and no-till treatments. Cultivation was not done on any of the plots. Both 10" and 30" rows were planted in the moldboard, chisel, and disk plots. A planter equipped with fluted coulters was used to plant all plots except the ridged plots where a ridge planter, which scalped 1" to 2" from the ridge, was used. Weed control was perfect with a combination of herbicides and hand weeding.

Yields shown in Table 5 indicate no significant difference among tillage systems in 2 of 4 years at Morris and 2 of 3 years at Lamberton. In the 3 years when differences existed, yields among the 5 tillage treatments never varied by more than 4.5 bu/A. Four-year average yields at Morris were slightly lower with the double spring disk treatment compared to the chisel, ridge, and no-till treatments. Average yield with moldboard plowing was intermediate probably a result of the low yield in 1982, a very dry spring. At Lamberton, 3-year average yields were not different among the tillage treatments. A tillage by row spacing interaction was not found at either location, which indicates that yields among the tillage systems were not affected by row spacing. Surface residue coverage after planting averaged about 14% for the fall moldboard plow treatment, 40% for fall chiseling, 50% for spring disking, 59% for ridge-planting, and 76% for no-tillage at the two sites.

Table 5. Soybean yield in a corn-soybean rotation and surface residue cover as influenced by tillage at three locations in the Minnesota River Basin, 1982-85.

		Year					Surface Residue[1]
	Tillage	1982	1983	1984	1985	Avg.	Cover
		--- Yield (bu/A) ---					%
Morris	Moldboard	30.0	55.5	39.4	49.8	43.7	14
	Chisel	32.3	55.4	41.2	49.2	44.5	37
	Spr. disk	32.9	52.5	38.9	45.8	42.5	51
	Ridge	32.4	54.6	40.7	49.2	44.2	58
	No-till	34.5	55.5	40.6	47.7	44.5	74
	LSD (.05)	2.3	NS	NS	2.4	1.4	
Lamberton	Moldboard	45.5	41.1	36.8	-	40.7	15
	Chisel	46.2	40.3	33.2	-	39.3	43
	Spr. disk	45.9	42.0	34.7	-	40.4	48
	Ridge	43.9	46.0	33.0	-	41.0	60
	No-till	42.0	43.5	35.3	-	39.6	79
	LSD (.05)	2.2	NS	NS	-	NS	
Waseca	Moldboard	44.0	43.4	42.1	40.0	42.4	14
	Chisel	44.0	41.5	41.9	38.2	41.4	40
	Spr. disk	44.6	40.3	42.3	40.6	41.9	48
	Ridge	41.8	43.0	40.1	39.2	41.0	40
	No-till	43.0	40.7	40.2	38.8	40.7	84
	LSD (.05)	2.0	2.1	1.6	NS	1.0	

1. Between 30" rows after planting and averaged over years.

Table 6. Soybean yield in a corn-soybean rotation and surface residue cover as influenced by tillage at three locations in the Minnesota River Basin, 1986-88.

		Year				Surface Residue[1]
Location	Tillage[2]	1986	1987	1988	Avg.	Cover
		--- Yield (bu/A)[3] ---				%
Morris	MP/CP	45.5	39.2	15.8	33.5	12
	CP/NT	44.3	40.0	22.3	35.5	52
	RT/RT	42.0	40.3	24.3	35.5	62
	PP/PP	45.3	36.9	23.4	35.2	62
	NT/NT	45.2	40.0	25.1	36.7	80
	LSD (.05)	2.5	NS	4.9	2.1	
Lamberton	MP/CP	47.9	38.8	32.0	39.6	6
	CP/NT	46.7	39.5	26.3	37.5	50
	RT/RT	47.3	38.7	26.7	37.6	40
	PP/PP	48.9	37.0	26.2	37.4	68
	NT/NT	47.4	39.3	26.9	37.9	84
	LSD (.05)	2.0	NS	2.4	1.3	
Waseca	MP/CP	46.6	42.0	38.8	42.1	11
	CP/NT	45.1	42.3	36.3	40.9	42
	RT/RT	40.2	42.4	34.6	38.9	51
	PP/PP	44.1	42.6	34.7	40.1	72
	NT/NT	44.5	42.0	37.6	41.1	82
	LSD (.05)	4.6	NS	NS	2.0	

1. Between 30" rows after planting and averaged over years.
2. Tillage for soybean after corn/tillage for corn after soybean. MP = moldboard plow, CP = chisel plow, RT = ridge tillage, PP = paraplow, and NT = no tillage.
3. Each yield is an average of 8 varieties.

Another study was started at these same three locations in 1986 to evaluate the effect of five tillage systems for a corn-soybean rotation on both corn and soybean yields (Table 6). Soils were similar to those described in the previous study. Stalks were chopped in the fall for the ridge-till and chisel treatments only. Eight soybean varieties were planted in 30" rows on each tillage plot. Weeds were controlled with herbicides applied to all plots; cultivation of the moldboard, chisel, and ridge plots; and by hand-weeding all plots.

Yields shown in Table 6 indicate significant differences among the five tillage systems in 4 of 6 site-years at Morris and Lamberton. Three-year soybean yield averages at Morris show a significantly lower yield with moldboard plow tillage primarily because of 1988 (a very dry year in which yields from the moldboard plots were 6 to 8 bu/A poorer than from the other tillage treatments). Yields among the chisel, ridge, paraplow, and no-till treatments were not different. At Lamberton, 3-year average yields contradicted those from Morris and were significantly higher for the moldboard treatment compared to the other treatments. Again, this difference was due primarily to 1988 which was dry at Lamberton but not quite as dry as at Morris. Surface residue coverage after planting averaged 9% for moldboard plowing, 51% for chiseling and ridging, 65% for paraplowing, and 82% for no tillage.

The study described above and shown in Table 6 was continued at Lamberton for four additional years. The only change was substituting the spring disk after corn/spring field cultivate after soybean treatment for annual paraplowing. Yields shown in Table 7 indicate significant differences among the tillage systems in three of four years. Beginning in 1989 (the fourth year of the study) and continuing through 1991, soybean yields with continuous no-tillage were 5.2 bu/A lower than for the other tillage systems. In 1992 (year 7) when yields were relatively low, yield differences among the tillage systems were not found. Four-year averages show highest yields with the moldboard plow/chisel and chisel/no-till systems, intermediate yields with the ridge till and spring disk/spring field cultivate systems, and lowest for the continuous no-tillage system.

Based on the 17 site-years of data from these two low rainfall, glacial till locations, it is very clear that little yield difference exists among any tillage methods for soybeans after corn until at least three years into continuous no-tillage. After three years, yields from the continuous no-till began to decline. Although the exact reason for this decline is not known, we can speculate that surface soil compaction may be at least partially responsible. Surface residue coverage was ideal with all tillage systems except moldboard plow.

Table 7. Soybean yields in a corn-soybean rotation as influenced by tillage on a well-drained Ves clay loam soil at Lamberton.

Tillage[1]	Year[2]				
System	1989*	1990*	1991*	1992	Avg.
	- - - - - - - - - - Yield (bu/A) - - - - - - - - - - - -				
MP/CP	48.8	51.8	48.0	37.3	46.5
CP/NT	45.8	51.6	46.2	37.7	45.3
RT/RT	49.2	48.7	41.4	35.4	43.7
SD/SFC	47.1	45.4	44.4	36.5	43.4
NT/NT	40.9	44.7	40.3	35.9	40.4

1. Tillage for soybean after corn/tillage for corn after soybean. SFC = spring field cultivate.
2. * Indicates that yields among tillage treatments were significantly different at the 95% level for that year.

- **High Rainfall, Glacial Till Sites**

Corn

A 5-year study was started in the fall of 1972 on a poorly drained Webster clay loam at Waseca to compare time and methods of tillage for a corn-soybean rotation (Table 8). Fluted coulters were used to plant the treatments that did not receive primary tillage, but were removed for the rest of the treatments. Nitrogen as ammonium nitrate was broadcast at a rate of 150 lb. N/A each spring. Starter fertilizer was not used on this high-testing soil. All tillage treatments were cultivated once in 1975-1977. However, high surface residues prevented cultivation of the no-till plots in 1973 and 1974.

Four-year average yield data shown in Table 8 indicate substantially lower corn yields with continuous no-tillage, and somewhat lower yields when primary tillage (moldboard plow or chisel) was done in the spring.

Table 8. Corn and soybean yields in a corn-soybean rotation as influenced by time and method of tillage on a poorly drained Webster clay loam at Waseca.

Tillage for:[1]		Yield Average	
		1974-77	1973-77
Corn after Sb	Sb after Corn	Corn	Soybean
		- - - - - bu/A - - - - -	
No-till	No-till	113	38.6
Fall moldboard	Fall moldboard	135	45.5
Fall chisel	"	138	46.4
Spr. chisel	"	129	44.8
No-till	"	137	45.2
Spr. moldboard	Spr. moldboard	124	45.3
Fall chisel	Fall chisel	130	43.2
No-till	"	125	43.9
Spr. chisel	Spr. chisel	128	43.2
Spr. disk	Spr. disk	136	44.0
LSD (.05)		10	2.5

1. Corn was grown on all plots in 1972.

Periodic poor weed control with continuous no-tillage and a poor, cloddy seedbed resulting from spring primary tillage in some years were the primary causes of these reduced yields. Highest yields were obtained with the fall chisel/fall moldboard and the no-till/fall moldboard tillage combinations and the continuous spring disk system for the corn-soybean rotation.

Table 9. Corn yields and surface residue cover in a corn-soybean rotation as influenced by tillage on a poorly drained Webster clay loam soil at Waseca.

Tillage	Yield[2]				Residue cover[3]		
System[1]	1986	1987	1988	Avg.	1986	1987	1988
	- - - - - - - bu/A - - - - - - -				- - - - - % - - - - - -		
CP/MP	134	161	92	129	9	11	8
NT/CP	141	151	100	131	32	59	49
RT/RT	137	158	98	131	4	36	14
PP/PP	136	154	90	127	21	45	41
NT/NT	135	148	92	125	29	76	58
LSD (.05)	NS	7	NS	-	-	-	-

1. Tillage for corn after soybean/tillage for soybean after corn.
2. Average of 5 hybrids grown each year.
3. Average of 16 measurements taken after planting but before anhydrous ammonia application.

Tillage systems similar to those discussed earlier for Lamberton (Table 4) were also evaluated on a poorly drained Webster clay loam at Waseca (Table 9). After soybean, only the chisel plow plots received a field cultivation before planting. Five hybrids were planted on each plot. Nitrogen as anhydrous ammonia was sidedress-applied at the 4-leaf stage at a rate of 160 lb. N/A each year. None of the treatments were cultivated except to build the ridges when the corn was about 30" high in the ridge treatment. Weed control was excellent.

Yields shown in Table 9 indicate no significant difference among tillage systems for corn after soybeans in 2 of 3 years. However, in 1987 yields with no-tillage and paraplowing were lowest. Three-year average yields were highest with the no-till/chisel plow system and ridge-till system and were 6 bu/A lower with the continuous no-till system. A companion study indicated yields were optimized at rates of 80 lb. N/A in 2 years and 120 lb. N/A in the third with no tillage by N rate interaction. Surface residue coverage was poor in all 3 years when the moldboard plow was part of the tillage system. Ridge tillage also gave inadequate residue cover, largely because scalping the ridge buries most of the fragile soybean residue. In 1986, when the tillage treatments for corn had not been in place earlier (1984), residue coverage was marginal for all tillage systems. However, in 1987 and 1988 (corn was grown in 1985 and 1986, respectively, on these plots), residue coverage was much higher and averaged 43% with paraplowing, 54% with the no-till/chisel system, and 67% with continuous no-tillage.

From the results of these two studies (7 site-years), adequate residue coverage and optimum corn yields can be obtained with no tillage after soybeans as long as some primary tillage (chiseling or moldboard plowing) is done following the corn. Ridge till or a single spring one-pass tillage operation (field cultivator or disk) would also result in optimum yields but residue coverage could be less than desired. Continuous no-tillage results in somewhat poorer yields but does give excellent surface coverage.

Soybean

Soybean yields were also obtained in the 1973-77 study conducted at Waseca and described above (Table 8). Lowest yields were obtained with continuous no-tillage partially due to inadequate weed control in some years. Those tillage systems that contained either fall or spring moldboard plowing yielded 2 bu/A higher than those that contained either fall or spring chiseling.

Five tillage methods described in the low rainfall discussion for Morris and Lamberton were also compared at Waseca on a poorly drained Webster clay loam (Table 5). Yields were affected by tillage in 3 of 4 years with the 4-year average showing highest yield (42.4 bu/A) with moldboard plow tillage and the lowest yield (40.7 bu/A) with no-tillage. Surface residue coverage ranged from 40% with the chisel and ridge systems to 84% with no-tillage while moldboard plowing only had 14% coverage.

The five tillage systems for a continuous corn-soybean rotation described for Morris and Lamberton were also compared at Waseca on a poorly drained Webster clay loam (Table 6). Very little yield difference was found among the tillage systems during the 3-year period except for the ridge-till yields being about 5 bu/A lower in 1986. The 3-year average yields reflected this with a ridge-till yield of 38.9 bu/A compared to yields from 40.1 to 42.1 bu/A with the other tillage systems. Surface residue coverage was inadequate for the moldboard plow/chisel system, averaged about 45 to 50% with the chisel/no-till and ridge-till systems, and over 70% with the continuous paraplow and no-till systems.

In summary, these studies also indicate that excellent soybean yields and surface residue coverage can be obtained on high rainfall, glacial till soils with very little or no tillage in a corn-soybean rotation as long as good weed control is practiced.

Managing Crop Residue with Tillage

Tillage implements combined into tillage systems can be used very effectively to create various levels of corn residue remaining on the soil surface. However, any tillage following soybeans almost completely destroys the residue because of the small amount present and its fragile nature. As seen from the previous discussion, corn and soybean yields in a corn-soybean rotation are not impacted greatly by the amount of crop residue present.

Five tillage systems shown below are categorized in Tables 10 and 11 according to the residue management/yield performance indicators also shown below:

Tillage Systems

Moldboard Plow: Fall moldboard plowing followed by one or two secondary tillage operations before planting.

Chisel Plow-Plus: Fall chisel plowing plus spring secondary tillage.

One or Two Pass: No fall primary tillage. Single pass in spring with field cultivator before planting corn. Single or double pass with tandem disk in spring before planting soybeans.

Ridge-Till: Tillage is limited to that performed by the planter (ridge-leveling) and one or two in-season cultivations (ridge-building).

No-Till: All seedbed preparation is performed by the planter. Starter fertilizer placement and clearing residue from the rows usually are done with the planter for corn, but may be performed separately, sometimes in combination with anhydrous ammonia injection or other fertilizer injected into a band.

Residue Management/Yield Performance Indicators

1) Inadequate Residue to Minimize Erosion (less than 30 percent of surface covered after planting). Highest yield may be obtained, however, on poorly drained, fine-textured, high organic matter soils.

2) Recommended with Good Management. No yield penalty is expected if the farmer observes all relevant recommended management practices for high residue systems.

3) Excellent Management Required. Slight yield penalty is possible, even if all recommended management practices are observed. Above average crop management will be needed to ensure good performance.

4) Reduced Yield Potential. The potential exists for substantially reduced yields especially on poorly drained soils in wet years.

Corn

The matrix of performance indicators shown in Table 10 indicates that corn following soybeans is not very sensitive to tillage system when grown on medium- and fine-textured glacial till and lacustrine soils. ***Moldboard plowing*** does not result in higher corn yields than other tillage systems and leaves inadequate surface residue (often <10%) to minimize soil erosion. Thus, this tillage system should not be used for corn after soybean in the Minnesota River basin. The ***chisel plow-plus system*** will also leave inadequate amounts of surface residue in all soil-rainfall scenarios, and will not give higher corn yields than other reduced tillage systems. This tillage system should be used only on level (0 to 3% slope) soils when broadcast manure is to be incorporated or if severe surface soil compaction occurred during the last year when soybeans were grown.

Table 10. Matrix of residue management/yield performance indicators for corn following soybean on glacial till and lacustrine soils under high annual precipitation (>28") or low annual precipitation (<28") conditions in the Minnesota River Basin.

	Glacial till		Lacustrine	
Tillage system Rainfall:	High	Low	High	Low
Moldboard plow	1	1	1	1
Chisel plow plus[1]	2/1	1	2/1	1
One pass	2	2	2	2
Ridge-till	2	2	3	3
No-till	3/2	2	3	3

1. Even if straight shanks are used, this system cannot reliably achieve the 30 percent surface residue target, and must be used in a rotation where corn residue levels are at least 40 percent after planting.

One-pass, field cultivator tillage in the spring levels the field, provides a good seedbed, incorporates surface-applied fertilizers and preplant herbicides, and kills early-germinating weeds. However, little soybean residue is left on the soil surface, and erosion control is minimal. Use of flat, wide, low-crown cultivator shovels can help to minimize destruction of fragile surface residues. Corn residue left on the soil surface from the previous crop can be helpful in attaining slightly higher surface residue coverage. A disk should not be used unless absolutely necessary because more residue will be incorporated and soil cloddiness can develop under wet conditions in these fine-textured soils. This tillage system performs best on 0 to 4 percent slopes.

Ridge-till also maintains inadequate surface residue coverage when corn follows soybeans, especially when soil is removed (scalped) from the ridge at planting. The accumulation of residue between the ridges/rows from the previous corn crop will not be helpful because it will have been destroyed in the ridge-building process. However, the ridges themselves which act like mini-terraces every 30-36", allows this tillage system to be used successfully on 0 to 6 percent slopes provided that the row orientation is not consistently up and down the slopes. Maintaining high soil test P and K with band injection of fertilizer 4" to 7" deep into the ridge is necessary for optimum yield and profit. This practice also minimizes loss of soluble P from the landscape. Ridge tillage can be practiced on glacial till soils without a yield penalty.

Although we do not have long-term yield data with ridge-till on lacustrine soils, we speculate that greater management may be required and some yield loss could occur on these very flat, poorly drained landscapes.

No-tillage leaves all of the residue on the soil surface, which may result in wetter and slightly colder soils at planting. Row cleaners attached to the planter may be necessary to minimize these potential negative effects on crop growth. This system has been successful when used up to three consecutive years in this rotation or where primary tillage (moldboard plow or chiseling) has been used following corn. However, the consolidated nature of the surface soil with long-term continuous no-till appears to slow root growth when the plant is small. This results in slower plant growth, delayed maturity, and lower yields, especially on wet, poorly drained soils. Soil test P and K also needs to be high and fertilizer must be injected for optimum efficiency. Starter fertilizer should be applied when Bray soil test P is <25 ppm. Burndown herbicides should be applied before crop emergence to minimize weed competition and optimize yield. This practice works best on fields with 0 to 8 percent slopes.

In summary, characteristics such as slope of the field, soil test levels, condition of the field following soybeans, and previous years' tillage must be considered when choosing a tillage system for corn after soybeans. On flat, poorly drained, fine-textured soils, a one-pass secondary tillage is usually best. On the other hand, no tillage can be used on those landscapes with 0 to 8 percent slopes, but management is generally more critical for this system to perform consistently well.

Soybeans

The matrix of performance indicators shown in Table 11 indicates that soybean following corn is only slightly sensitive to tillage system when grown on medium and fine-textured glacial till and lacustrine soils. ***Moldboard plowing*** generally does not result in higher soybean yields than other tillage systems and leaves inadequate surface residue (often <10%) to minimize soil erosion. Thus, this tillage system should not be used in the Minnesota River basin unless manure or fertilizer P and K are to be incorporated into the surface 8-inch layer. The ***chisel plow-plus system*** will leave adequate residue in all soil-rainfall scenarios, will minimize surface compaction, will allow incorporation of nutrients and herbicides, and will result in optimum yields when good management is practiced. Residue clearing attachments mounted on the planter may be helpful but are not usually necessary to optimize yield. This tillage system also facilitates the use of narrow soybean rows and no tillage in alternate years when corn follows soybeans. Fields or landscapes with 0 to 8 percent slopes are ideal for this tillage system.

One or two pass, tandem disk tillage can be used successfully for soybean after corn especially on glacial till soils. This system kills early spring weed growth and evenly distributes a large amount of corn residue across the soil surface but does little seedbed preparation below 2" to 3". Soybean yields may suffer some on poorly drained, wet, flat lacustrine fields. This tillage system performs best on 3 to 8 percent slopes.

Table 11. Matrix of residue management/yield performance indicators for soybean following corn on glacial till and lacustrine soils under high annual precipitation (>28") or low annual precipitation (<28") conditions in the Minnesota River Basin.[1]

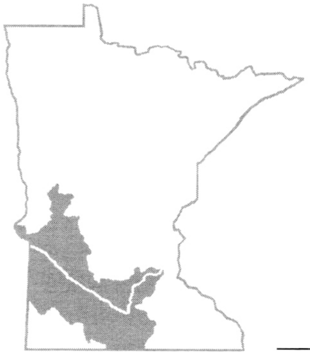
	Glacial till		Lacustrine	
Tillage system Rainfall:	High	Low	High	Low
Moldboard plow	1	1	1	1
Chisel plow plus	2	2	2	2
One or two pass	2	2	3	3
Ridge-till	2	2	3	2
No-till	3	3	3	3

1. When following silage corn, inadequate amounts of surface residue will exist for all tillage systems.

Ridge-till maintains excellent surface residue coverage when soybeans follow corn, especially when very little soil is removed (scalped) from the ridge at planting. The accumulation of residue between the ridges/rows coupled with the ridges themselves every 30-36", which act like mini-terraces, allows this tillage system to be used very successfully on 0 to 6 percent slopes. Soil erosion is minimal because infiltration is optimized and runoff is minimized. Ridge tillage can be practiced on glacial till soils without a yield penalty. Although we do not have long-term yield data with ridge-till on lacustrine soils, we speculate that greater management may be required and some yield loss could occur on these very flat, poorly drained landscapes, especially under wet conditions. The opportunity to use narrow rows, unless no-till drills or special planters are used, is a disadvantage of this tillage system.

No-tillage leaves all of the residue on the soil surface, which often results in wetter and cooler soils at planting. Soybean yields with both wide and narrow rows can be optimal with this system if excellent management is used. However, the consolidated nature of the surface soil with long-term, continuous no-till may lead to some stand reductions and disease problems. This may result in slightly lower yields, especially on wet, poorly drained soils. Burndown herbicides coupled with post-emergence herbicides are necessary to control weeds. Soil test P and K also need to be high. Starter fertilizer and stalk chopping are not necessary for soybeans. This practice works best on fields with 2 to 10 percent slopes.

In summary, soil characteristics such as slope, drainage, texture, and condition of the field after corn must be considered when choosing a tillage system for soybeans. On flat, poorly drained, fine-textured, lacustrine soils, chisel plow plus tillage is usually best, but with excellent management, one- or two-pass, ridge-till, or no-till systems can be used successfully. These latter conservation tillage practices can be used on glacial till landscapes with 0 to 10 percent slopes, but good management is necessary for these systems to perform consistently well. For continued long-term success with reduced tillage systems for a corn-soybean rotation, farmers are encouraged to practice tillage rotation. Research on glacial till soils suggests that no-till planting of corn into soybean stubble and fall chiseling corn ground for either wide or narrow row soybean production is a good example of this rotation. The tillage choice must be based on the current soil properties, that is, wet and compacted vs. dry and non-compacted, the crop to be grown, and the soil/field characteristics. Properly matching the tillage system with the soil and cropping conditions will lead to successful conservation tillage systems that minimize erosion losses and optimize profit.



Tillage Best Management Practices for Continuous Corn in the Minnesota River Basin

Gyles W. Randall,
Soil Scientist, Southern Experiment Station

Samuel D. Evans,
Soil Scientist, West Central Experiment Station[1]

John F. Moncrief,
Extension Specialist, Dept. of Soil, Water, and Climate

William E. Lueschen,
Department of Agronomy and Plant Genetics, University of Minnesota[1]

Summary

A continuous corn cropping sequence can present severe challenges to conservation tillage systems, owing to the extremely high amounts of residue produced. Reduced tillage practices that can be used profitably, with little or no additional risk, in the corn-soybean rotation must be approached with caution with continuous corn. When accompanied by good management, chisel plowing and ridge tillage systems are appropriate for lower rainfall areas and on moderately or steeply sloping fields throughout the Minnesota River basin. However, on fairly level, poorly drained fields with fine-textured soils, chisel plowing or disc-chisel operations are advisable only with excellent management. Even then, modest yield penalties are possible. Moldboard plowing performs best in such conditions, but leaves inadequate residue for erosion protection. Thus, in fairly level, poorly drained, high-rainfall areas where sedimentation is a problem, management practices other than tillage (i.e., vegetative filter strips along rivers, streams, drainage ditches, and other runoff pathways to surface waters) may be required to reduce sediment losses.

Introduction

Tilling the soil to prepare a seedbed has been a practice used for centuries. Since the mid-1800s the moldboard plow has been used by most farmers to invert the soil— leaving the soil surface bare of residues. Because the possibility of erosion and sediment loss occurring is higher on bare soils, primary tillage tools that leave some residue on the soil surface were introduced in the 1950s and 60s to reduce soil erosion. Chisel plows and early models of ridge-till planters were the forerunners. 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. The result has been good seed-to-soil contact for consistent seedling emergence and improved erosion control. With improved herbicides and planters available in the mid-1980s for better weed control and good seed placement, some farmers began to use no-tillage in their crop production system.

Soil erosion that has resulted in sediment loss into the surface waters of the Minnesota River basin has been identified as a key source of nutrient enrichment and turbidity (cloudiness) of the rivers. This nutrient enrichment and cloudiness promotes algal blooms, reduces oxygen levels, and interferes with biological and aesthetic well-being of the rivers. Improved crop residue management on these 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 residues on the soil surface also may improve the infiltration of the rain into the soil, reducing surface runoff and resulting in more stored water in the soil profile for crop use. However, increased levels of crop residue on the soil surface insulate the soil, causing decreased soil temperatures in the spring due to sunlight reflection and increased soil moisture.

---

[1] Dr. Evans is now an Emeritus Professor at Morris, MN. Dr. Lueschen was formerly Head of the Southwest Experiment Station at Lamberton. He is now based at St. Paul, with the Department of Agronomy and Plant Genetics.

Factors to Consider When Making a Tillage Decision

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

• Cropping System

The amount of residue present in a field before tillage depends on the crop previously grown and the level of production. Corn generates more residue than soybeans; thus it is easier to maintain higher residue levels following corn with a variety of tillage systems. However, corn has a low tolerance to high levels of crop residue on the soil surface, especially under cool and wet conditions, that is, on poorly drained soils. Therefore, continuous corn requires more tillage for residue incorporation. On the other hand, a corn-soybean rotation generates less residue and allows greater tillage flexibility. Little residue exists following soybeans and very reduced tillage, that is, no-tillage, often works well.

• Soil Characteristics

***Erosion potential*—**Erosion potential mostly depends on the length and steepness of slope and soil texture. If the erosion potential is high, conservation tillage systems are highly recommended. Fields or acres considered to be highly erodible land (HEL) require 30% residue cover after planting for conservation compliance. 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.

***Soil fertility level*—**A high level of fertility is necessary if reduced tillage systems are to perform well. Low fertility conditions offer too many obstacles and generally limit yields more severely in reduced tillage systems. Thus, fields testing low in phosphorus (P) or potassium (K) should be brought to high P and K levels before implementing these reduced conservation tillage systems.

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

• Nutrient Management

Management of fertilizer and manure nutrients is critical to the success of conservation tillage systems with continuous corn. If nutrient management is poor, yields and economic return will suffer. In addition, runoff of non-incorporated nutrients applied to fields with no-tillage may actually increase nutrient enrichment of the surface waters. Do not surface-apply urea sources of N without incorporation unless gentle rains are imminent. Urea and UAN should be incorporated within three days to reduce potential loss by volatilization and runoff. Anhydrous ammonia has been the most consistent source of N. Application of ammonia is improved in all tillage systems, and especially in no-till, when covering disks attached to the injection knives are used to close the knife slits and seal in the ammonia. Alternative N application methods with ridge-till and no-till systems include: (1) spoke-injecting UAN into the soil and (2) applying urea 4" to 6" to the side of the seed row with the dry starter fertilizer attachment at the time of planting.

Phosphorus and K should be maintained at high levels (16-20 and 12-15 ppm P for Bray and Olsen extractants, respectively, and 121-160 ppm K) for optimum production with all tillage systems for continuous corn. Fertilizer P and K should be incorporated if at all possible. Results from a 6-year no-till study at Waseca showed a significant accumulation of both P and K in the surface 0-2" layer even when no P or K was applied. Thus, unincorporated broadcast P and K would add to this surface buildup and would increase the potential for P to be lost to surface water. Recommended application methods include: (1) broadcast and incorporation with a tillage implement; (2) banding 4" to 7" deep within the ridge with ridge tillage or randomly with other tillage systems; or (3) starter fertilizer. With no-till or ridge-till systems, starter fertilizer should be used when soil test P is <25 ppm. See extension bulletins "Fertilizer Management for Corn in Minnesota" (MES FO-3790, 1994) and "Fertilizer Management for Corn Planted in Ridge-Till or No-Till Systems" (MES AG-FO-6074, 1993) for more detailed information.

Livestock manure should also be incorporated for maximum benefit. Liquid manure offers more tillage flexibility because it can be knife- or sweep-injected either before planting or sidedressed between the rows with all tillage systems. With strict no-till this will disturb the residue similarly to a cultivation, but injection when the corn is 12+ inches tall should not increase the erosion potential greatly. Solid manure sources should be incorporated by moldboard or chisel plowing or disking.

• Herbicide Program

Reduced tillage and increased levels of crop residue may increase weed pressure. It is extremely important that farmers adjust their herbicide program to fit their tillage system. Tillage provides some weed control and offers greater herbicide flexibility and perhaps some economic savings for weed control. Perennial weeds are often economically controlled very satisfactorily with tillage. Herbicide incorporation with tillage minimizes herbicide runoff and volatilization losses.

• Planting Equipment: Type and Age

Reduced tillage systems require state-of-the-art planters that are capable of providing good seed-to-soil contact and good stands. Row cleaning devices that remove residues from a 6" to 10" band over the row may assist stand establishment, early plant growth, maturity, and yield in most reduced tillage systems. Using a light planter designed for moldboard tillage conditions generally will not give adequate stands and uniform seedling emergence when used with no-till or most conservation tillage systems. Thus, matching planting equipment with the desired tillage system is very important.

• Management Ability

Management of all the inputs in a manner that fits the soil, climate, and cropping system of the grower is critical if conservation tillage systems are to be profitable. Each of the components must be examined carefully. Seeking information by asking questions and reading educational background material is helpful for improving management.

• Risk

Economical risk is increased as less tillage is used for continuous corn, especially over the long term. Crop development can be delayed and yields reduced in wet and cool years. The degree of risk is highly dependent on some of the preceding factors. With today's tight farm economy, risk is a factor that needs to be strongly considered by crop producers.

In summary, various factors including soil characteristics, erosion potential, fertilizer and herbicide management, planting equipment, management ability, and risk must be considered when selecting a residue management system for continuous corn. Because corn is sensitive to high levels of crop residue, especially in the cool and wet conditions so common in poorly drained soils, tillage options are limited for continuous corn production in most areas of the Minnesota River basin. Good tile drainage, high soil fertility levels, a herbicide program that is targeted to the dominant weeds and applied in a timely fashion, and modern planters equipped with row cleaning and/or coulter devices for good seed-to-soil contact are critical management aspects that need to be practiced for conservation tillage systems to succeed for continuous corn.

Yield Results from Long-Term Tillage Research

Long-term tillage experiments on continuous corn have been conducted at the University of Minnesota agricultural experiment stations at Lamberton, Morris, and Waseca. These experiments along with good rainfall records allow us to see interactions with climate or trends that may occur over a period of years. These experiment stations are located on glacial till soils.

There are no data addressing tillage performance (crop response and soil erosion control) on lacustrine soils (see publication in this series that addresses soil types-"Description of the Minnesota River Basin and General Recommendations of Residue Management Systems for Sediment Control." The recommendations for lacustrine soils are based on the anticipated performance of tillage systems based on experience on other soils that have similar characteristics but have textures that are somewhat coarser and drainage that may be better.

• Low Rainfall, Glacial Till Sites

A tillage study comparing moldboard plow (MP), chisel plow (CP), a spring disking (DK), ridge planting (RT), and no-till (NT) for continuous corn was started

Table 1. Effect of tillage on continuous corn grain yields on a somewhat poorly drained Hammerly clay loam soil at Morris

	Tillage System				
Year	MP	CP	DK	RT[1]	NT[1]
	Yield (bu/A)				
1979	132	132	126	127	120
1980	119	109	114	108	108
1981	139	121	120	117	95
1982	143	137	133	128	126
1983	113	102	101	111	98
1984	131	133	128	134	130
Avg.	130	122	120	120	113

1. All treatments were cultivated. The planter used was not equipped with sweeps, disks, or fluted coulters.

in 1979 at the West Central Experiment Station at Morris and the Southwest Experiment Station at Lamberton. On the somewhat poorly drained Hammerly clay loam soil at Morris, grain yields were highest in 5 of 6 years with moldboard plow tillage and averaged 8 to 10 bu/A higher than chisel plow, disk, or ridge tillage systems during the 6-year period (Table 1). No-till yields were lowest in 5 of 6 years and averaged 7 to 9 bu/A lower than the chisel, disk, and ridge till systems. On the well drained Ves clay loam soil at Lamberton, 4-year average grain yields from the moldboard plow and ridge-till systems were similar and were 8 to 12 bu/A higher compared with the chisel, disk, and no-till systems (Table 2). Yields were not different among the chisel, disk, and no-till systems. The absence of row cleaning devices (sweeps or disks) and fluted coulters on the planter used for all tillage systems in this study should be noted. However, all treatments were cultivated, which may have assisted the performance of the no-till system compared with strict no-tillage where cultivation is not practiced.

A 6-year (1984-1989) study conducted on a moderately well-drained Tara silt loam soil at Morris showed significant effects of rainfall and substantial differences among tillage systems (Table 3). It should be noted that the 6-month growing season rainfall was above normal and exceeded 15" in 4 of the 6 years. Under these conditions, ridge tillage produced higher yields than the other three tillage systems in three years, and over the six years averaged 6 bu/A higher than the next highest yielding tillage system (chisel plow). Yields with ridge tillage were consistently high in both wet and dry years with the exception of 1988 when yields were very low with all tillage systems. Lowest yields were found with no-tillage in 3 of 6 years. Surprisingly, no-till gave the lowest yield in 1987 (a year with only 8.5" of growing season rainfall) while lowest yields in the wettest year (1986 with over 26" of growing season rainfall) were obtained with moldboard plow tillage. In summary, large yield differences (up to 47 bu/A) were seen among the tillage systems each year, but clear-cut trends during the 6-year period or relationships to growing season rainfall were not apparent.

Table 2. Effect of tillage on continuous corn grain yields on a well-drained Ves clay loam soil at Lamberton.

	Tillage System				
Year	MP	CP	DK	RT[1]	NT[1]
	Yield (bu/A)				
1979	137	125	121	133	124
1980	117	109	119	124	113
1981	122	117	116	109	112
1982	148	137	125	152	125
Avg.	131	122	120	130	119

1. All treatments were cultivated. The planter used was not equipped with sweeps, disks, or fluted coulters.

Table 3. Continuous corn yields as influenced by tillage and rainfall on a moderately well drained Tara silt loam at Morris.

	Tillage System[1]				Rainfall
Year	Fall MP	Fall CP	RT	NT	Apr-Sep
	Grain Yield(bu/A)				-inches-
1984	135	128	140	115	18.8
1985	91[2]	98[2]	88	81	19.0
1986	102	139	149	129	26.2
1987	161	150	167	145	8.5
1988	59	49	49	67	9.2
1989	155	160	167	168	15.7
Avg.	117	121	127	118	15.7[3]

1. 160 lb N/A.
2. Spring MP and CP due to wet conditions (10.6") in October, 1984.
3. 100-Yr average

• High Rainfall, Glacial Till Sites

A 10-year study (1970-79) comparing four tillage systems—fall moldboard plow (MP), fall chisel plow (CP), a one-pass spring tandem disking (DK), and no tillage (NT)—was conducted on a somewhat poorly drained Nicollet soil at Waseca. The site had very high soil P and K tests, tile lines at a 75-foot spacing, and a 2-5% south facing slope. A planter equipped with 2" inch wide fluted coulters was used. Nitrogen was broadcast-applied as ammonium nitrate at 175 lb N/A. Starter fertilizer was not used.

Grain yields averaged over the 10-year period were 12 to 16 bu/A higher with the moldboard, chisel, and disk systems compared with the no-till system (Table 4). Although a hard, compacted soil layer (disk pan) was found at the 3" to 4" depth at the end of the study with the continuous disk tillage system, yield was not affected. Yield differences among tillage systems in the first few years of the study were not large, probably due to the favorable site characteristics of a south-facing slope and close tile spacing. However, in the last two years of the study, under both average and wet conditions, yields with no-till were dramatically less than with the other three systems. Weed control, with the exception of some late-emerging fall panicum in the disk and no-till plots, was good in all years.

Table 4. Continuous corn yields as affected by tillage and rainfall on a moderately well drained Nicollet clay loam soil at Waseca.

	Tillage System				Rainfall
Year	MP	CP	DK	NT	Apr-Oct
	- - - - - Grain Yield (bu/A) - - - -				-inches-
1970	164	157	158	156	29.6
1971	103	110	104	96	19.2
1972	136	133	131	130	25.4
1973	144	146	146	133	30.5
1974	100	92	94	86	21.4
1975	53	49	49	50	18.3
1976	68	67	79	83	13.6
1977	131	128	125	122	32.0
1978	157	155	152	130	24.0
1979	177	169	169	132	32.0
Avg.	139	136	135	123	24.6

Another study comparing ridge tillage with fall moldboard plowing, fall chiseling, and no tillage was started on a poorly drained (but tiled) Webster clay loam at Waseca in 1975. All plots received 175 lb. N/A as broadcast ammonium nitrate each year and 150 lb. 9-23-30/A as starter fertilizer in 1975-1978. Beginning in 1979, one-half of each plot did not receive starter fertilizer, while the other half received 12 gal. of 7-21-7/A. Soil test P and K were high at the beginning of the study and tested very high at the conclusion of the study due to broadcast P and K additions. Weeds were controlled with a pre-emergence application of Lasso + atrazine plus post-emergence atrazine and oil in 1979 and 1980. Weed control was excellent on the moldboard plow, chisel, and ridge-till plots, which were cultivated each year, but weed pressure and lack of control increased with time in the no-till plots. Corn yield results shown in Table 5 indicate a 5 bu/A average yield advantage for moldboard plowing compared with ridge tilling and a 10 bu/A advantage over chisel plowing. Lowest yields occurred with no tillage. This was primarily due to slow early plant growth, which delayed maturity, and inadequate weed control due to foxtail pressure. Yields of the chisel, ridge-till, and no-till plots were increased by 5 to 6 bu/A with starter fertilizer, but starter fertilizer did not increase yield with moldboard plowing.

Table 5. Continuous corn yields as affected by tillage and starter fertilizer on a poorly drained Webster clay loam at Waseca.

Treatment		Period	
Tillage	Starter Fert.	1975 - 82	1979 - 82
		- - - Yield (bu/A) - - -	
Moldboard plow	Yes	154	171
	No	—	171
Chisel plow	Yes	144	162
	No	—	156
Ridge plant	Yes	149	162
	No	—	156
No tillage	Yes	129	141
	No	—	136

Table 6. Continuous corn yields as affected by tillage and rainfall on a poorly drained Webster clay loam at Waseca.

	Tillage		Rainfall
Year	MP	NT	Apr - Oct
	- Grain Yield (bu/A) -		-inches-
1982	146	144	25.1
1983	106	102	31.0
1984	118	106	25.0
1985	160	145	23.5
1986	143	136	30.5
1987	158	153	22.4
1988	101	83	16.4
1989	153	128	15.9
1990	147	105	30.2
1991	163	121	36.8
1992	121	64	37.8
Avg.	138	117	26.2

Moldboard plow tillage was compared with no tillage to determine if tillage for continuous corn affected nitrate losses from tile lines. This study was conducted on a poorly drained Webster clay loam at Waseca from 1982-1992. Soil test P and K were very high. Starter fertilizer and row cleaners were not used. Nitrogen was broadcast-applied as ammonium nitrate just prior to planting at 180 lb. N/A. The moldboard plots were cultivated. Weed control with the pre-emergence herbicides was excellent in all plots up until 1992, when some grasses and milkweed were found in the no-till plots. Average corn yields for the 11-year period showed a 21 bu/A advantage for moldboard plowing compared with no-till (Table 6). Each year, no-till yields were less than with moldboarding, even in the drier years when no-till was expected to perform better. The yield advantage for moldboarding increased as the study aged. In the 8th through 11th years of the study, yields averaged 42 bu/A lower with no tillage. These extreme differences occurred under both wet and dry conditions. Early plant growth was much slower with no tillage and resulted in a 5-to 7-day average delay in silking date and higher grain moisture at harvest. Nitrate losses in the tile drainage were not different for the two tillage systems.

In summary, yield results from these long-term continuous corn studies indicate clear advantages for moldboard plow and ridge tillage on the normally drier glacial till soils at Morris and Lamberton, while moldboard plowing was superior on the flatter, poorly drained soils at Waseca. The sloping, somewhat poorly drained soil at Waseca produced almost equal yields among the moldboard, chisel, and disk systems, indicating greater tillage flexibility under these soil conditions.

Managing Crop Residue with Tillage

Tillage implements combined into tillage systems can be used very effectively to create various levels of corn residue remaining on the soil surface. However, as seen from the previous discussion, corn yields following a previous crop of corn may be impacted greatly, depending on the amount of crop residue, internal drainage of the soil, soil texture, and growing season rainfall.

Five tillage systems shown below are categorized in Table 7 according to the residue management/yield performance indicators also shown below:

Tillage Systems

Moldboard Plow: Fall moldboard plowing followed by one or two secondary tillage operations before planting.

Chisel Plow-Plus: Fall chisel plowing plus spring secondary tillage.

One or Two Pass: Single or double pass with tandem disk in spring before planting corn.

Ridge-Till: Tillage is limited to that performed by the planter (ridge-leveling) and one or two in-season cultivations (ridge-building).

No-Till: All seedbed preparation is performed by the planter. Starter fertilizer placement and clearing residue from the rows usually are done with the planter, but may be performed separately, sometimes in combination with anhydrous ammonia injection or other fertilizer injected into a strip.

Residue Management/Yield Performance Indicators

1) ***Inadequate Residue to Minimize Erosion*** (less than 30 percent of surface covered after planting). Highest yield may be obtained, however, on poorly drained, fine-textured, high organic matter soils.

2) ***Recommended with Good Management.*** No yield penalty is expected if the farmer observes all relevant recommended management practices for high residue systems.

3) ***Excellent Management Required.*** Slight yield penalty is possible, even if all recommended management practices are observed. Above average crop management will be needed to ensure good performance.

4) ***Reduced Yield Potential.*** The potential exists for substantially reduced yields especially on poorly drained soils in wet years.

Table 7. Matrix of residue management/yield performance indicators for corn following corn on glacial till and lacustrine soils under high annual precipitation (>28") or low annual precipitation (<28") conditions in the Minnesota River Basin[1].

	Glacial till		Lacustrine	
Tillage system Rainfall:	High	Low	High	Low
Moldboard plow	1	1	1	1
Chisel plow plus	3	2	3	2
One or two pass	3	3	4	3
Ridge-till	2	2	3	3
No-till	4	4	4	4

1. For corn following silage corn, inadequate amounts of surface residue will exist for all tillage systems.

The matrix of performance indicators shown in Table 7 indicates that corn following corn is very sensitive to tillage system when grown on medium- and fine-textured glacial till and lacustrine soils.

Moldboard plowing often results in highest corn yields, especially on poorly drained soils, but leaves inadequate surface residue (often <10%) to minimize soil erosion. Thus, this tillage system should be restricted to the flat, poorly drained, fine-textured soils if both yield/profitability and erosion are to be optimized. The ***chisel plow-plus system*** will leave adequate residue in all soil-rainfall scenarios, but will require excellent management and may result in a slight yield penalty in the higher annual precipitation area (>28") of the Minnesota River basin. Residue clearing attachments should be mounted on the planter to minimize yield loss. Fields that are better drained in lower rainfall areas, or landscapes with 3 to 8 percent slopes, are ideal for this tillage system.

One or two pass, tandem disk tillage is usually a rescue spring tillage treatment for continuous corn because conditions the previous fall were either too wet or cold for fall tillage. This system evenly distributes a large amount of corn residue across the soil surface but does little seedbed preparation below 2" to 3". Delayed planting may be a problem, and corn yields can suffer markedly, especially on poorly drained, flat fields. This tillage system performs best on 3 to 8 percent slopes and when row cleaners are used.

Ridge-till maintains excellent surface residue coverage in continuous corn cropping systems, especially when very little soil is removed (scalped) from the ridge at planting. The accumulation of residue between the ridges/rows coupled with the ridges themselves every 30-36", which act like mini-terraces, allows this tillage system to be used very successfully on 3 to 10 percent slopes. Soil erosion is minimal because infiltration is optimized and runoff is minimized. Maintaining high soil test P and K with band injection of fertilizer 4" to 7" deep into the ridge is necessary for optimum yield and profit. This practice also minimizes loss of soluble P from the landscape. Ridge tillage can be practiced on glacial till soils without a yield penalty. Although we do not have long-term yield data with ridge-till on lacustrine soils, we speculate that greater management may be required and some yield loss could occur on these very flat, poorly drained landscapes.

No-tillage leaves all of the residue on the soil surface, which often results in wetter and colder soils at planting. Row cleaners attached to the planter are necessary to minimize these negative effects on crop growth. However, the consolidated nature of the surface soil with continuous no-till appears to slow root growth when the plant is small. This results in slower plant growth, delayed maturity, and lower yields, especially on wet, poorly drained soils. Soil test P and K also need to be high and fertilizer must be injected for optimum efficiency. Starter fertilizer is usually necessary. This practice works best on fields with 4 to 10 percent slopes.

In summary, soil characteristics such as slope, drainage, and texture must be carefully considered when choosing a tillage system for continuous corn. On flat, poorly drained, fine-textured soils, moldboard plow tillage is usually best. On the other hand, conservation tillage practices can be used on those landscapes with 2 to 10 percent slopes, but management is critical for these systems to perform well.

Tillage Best Management Practices
for
Small Grain Production
in the Upper Minnesota River Basin

Samuel D. Evans,
Soil Scientist, West Central Experiment Station[1]

John F. Moncrief,
Extension Specialist, Dept. of Soil, Water, and Climate

Gyles W. Randall,
Soil Scientist, Southern Experiment Station

William E. Lueschen,
Department of Agronomy and Plant Genetics, University of Minnesota[1]

Introduction

Management of crop residues with reduced tillage is the most cost-effective method of controlling sediment losses and reducing farming impacts on water quality. Crop residues can also help reduce wind erosion and can enhance snow entrapment. One of the primary water quality concerns for the Minnesota River and its tributaries is sediment, which contributes increased phosphorus (P) to the system. This increased P stimulates algae growth, which is followed by an increased biological oxygen demand when the algae die and decompose. This can deplete dissolved oxygen levels, resulting in game fish stress or kill.

In addition to affecting sediment loss, tillage influences many interacting physical, chemical, and biological properties of soils that can have major impacts on crop production. These properties include temperature, moisture, aeration, bulk density, structure, nutrient distribution, organic matter levels, and microbial populations. Various crops respond to these changes differently. The range of these changes can be amplified by extremes in tillage reduction associated with some residue management alternatives. Small grain is insensitive to temperature changes but may respond to changes in the seed furrow environment and to differing weed species present.

Small grain is a prominent part of the agriculture in the upper Minnesota River Basin. Following is a discussion of residue management tillage system effects on small grain production.

Factors To Consider When Making A Tillage Decision

• Soil Characteristics

On soils classified highly erodible land (HEL) the general requirement is 30% residue cover after planting. On non-HEL soils the steepness and length of the slopes will indicate the potential for significant erosion. A second soil factor that must be considered is internal drainage. Poorly drained soils warm up more slowly than well-drained soils, so may require more tillage. Tile drainage may improve this situation, but in some cases this may not be enough to insure consistent success with little or no tillage. A third factor is soil fertility level. Having a high level of fertility is necessary if reduced tillage systems are to perform well. Low fertility conditions offer too many obstacles and generally limit yields in reduced tillage systems. It is important to effectively control sediment at high soil test P levels. Research has shown that this can be done effecectively with crop residues in conjunction with other conservation techniques.

---

[1] Dr. Evans is now an Emeritus Professor at Morris, MN.
Dr. Lueschen was formerly Head of the Southwest Experiment Station at Lamberton. He is now based at St. Paul, with the Department of Agronomy and Plant Genetics.

• Crop Rotation

The amount of residue present in a field depends on the crop rotation and the level of production. Corn generates more residue than small grains or soybeans; thus it is easier to maintain higher residue levels with a variety of tillage systems. The durability of the residue is also crop dependent. Soybean residue is classified as "fragile," or in other words is easily destroyed. Corn and small grain residues, on the other hand, are classified as "non-fragile."

Spring wheat and soybeans appear to be a viable crop rotation in a no-till system for Minnesota conditions. Other crops that fit well in a small grain rotation are sunflowers, sugar beets, and field beans. Maintaining a sufficient residue cover may be a problem following these crops. Soybean yields after small grain have generally not been affected by tillage. With more intensive tillage systems, crop sequence becomes less important. In summary, both the crops in the rotation and the sequence of the crops are important in tillage management.

• Residue Management

Tillage for small grain production requires the management of residue to allow for effective stand establishment. Planting when surface crop residues are relatively dry and are cut more easily with coulters is advisable. Experience has shown that planting in the direction of stubble orientation reduces the effectiveness of coulters and disc openers. Small grain residue pushed into the seed furrow by coulters "cradles" the seed and often results in stand loss and delayed emergence. This is primarily because of slower absorption of soil water due to poor seed-to-soil contact and allelopathic inhibition. Small grains are not as temperature sensitive as corn, so residue effects are mainly due to in-furrow seed-soil contact or phytotoxicity.

• Fertilizer Management

Do not surface-apply urea sources of nitrogen (N) without incorporation unless air temperatures are cool or rain is imminent. Urea left on the surface in proximity to residue has a high potential of volatilization losses. With residue management tillage systems, less N is released from soil organic matter due to less physical disturbance. In addition, soil organic matter may increase under some reduced tillage systems, and this will act as a sink for nitrogen. Anhydrous ammonia has been the most consistent source of N. Drill-applied diammonium phosphate (18-46-0) places N and P below the soil surface and close to the seed. This has been very effective in the western Minnesota River basin with calcareous soils that can tie up P. In addition to being a very efficient method of P fertilizer application, it also minimizes the risk of erosive losses of P.

• Disease Management

The effects of tillage on the development and severity of crop diseases are variable, depending on the disease, the specific type of tillage system used, and the effectiveness of the other disease management practices used. Conservation tillage usually reduces soil temperatures, conserves soil moisture, and leaves crop residue on the soil surface. Of particular concern are crop diseases that are favored by cool, wet soils. Diseases most troublesome in high-residue tillage systems are those that have inoculum associated with crop residues left on the soil surface. In many cases the diseases are most noticeable when monoculture cropping is practiced. Diseases of most concern are scab and tan spot, both of which are associated with plant residue. However, in addition to the disease inoculant supplied by residue, the proper environment and susceptible varieties must be present for economic infestations.

• Seeding Equipment

Controversy exists over what type of seed openers (disk vs. hoe vs. sweep) deal with small grain residue most effectively. Generally, hoe openers work better in drier soil. Hoe-type openers operate below residue, making "in furrow" residue less probable. Sweep or air seeders, placing seeds below sweeps, also reduce the probability of intimate contact of seed with crop residue. Depth control is the challenge with sweep seeders. Press wheels should also be used for good stand establishment under dry conditions. Disk-type openers require the most caution in this respect, but work better under wet conditions. If considering no-till small grain production, it is essential to use a properly designed, heavy duty drill that can cut through the residue, place seed in contact with the soil without incorporating residue, and firm the soil over the seed. Selecting a drill with fertilizer capability is also important.

Summary

Various factors including soil characteristics, crop rotation, residue management, disease problems, seeding equipment, and management ability must be considered when selecting a residue management system including small grains. In rotations with moderate amounts of residue, many systems will work on a variety of soils. With higher residue levels, the importance of proper residue management and heavy duty reduced tillage drills will ensure proper seed-to-soil contact without significant residue in contact with the seed. In the upper Minnesota River Basin, higher levels of residue may contribute to increased soil moisture and subsequent yield increases in dry years. Crop rotation is a major factor in minimizing the disease problems in small grains.

Yield Results from Tillage Research

Spring and Winter Wheat

The results of studies in Douglas, Norman, and Becker Counties are shown in table 1. In these studies tillage plots were split, with winter and spring wheat planted into barley stubble.

On average, spring wheat yields following barley were not affected by tillage. Only in one site year (1986 in Becker County) did tillage significantly affect spring wheat yields. A bindweed problem at this site was the likely cause. At most sites an increase in foxtail (pigeon weed) was associated with chisel and no-till systems.

Table 1. The effect of tillage on spring and winter wheat yields (bu/A) following barley.

	Spring Wheat			Winter Wheat		
Year	NT	Chs	Mldbd	NT	Chs	Mldbd
1987[1]	34a[4]	33a	39a	38a	37a	33a
1986[2]	27a	31a	35a	51a	47a	53a
1987[2]	47a	41a	42a	35a	44b	42b
1988[2]	30a	26a	24a	21a	13b	19b
1986[3]	24a	25a	30b	30a	38b	35b
Avg.	**33**	**31**	**34**	**35**	**36**	**35**

1. Douglas County, Barnes loam-Langhei loam soils
2. Norman County, Fargo silty clay-Hegne silty clay soil
3. Becker County, Hamerly clay loam-Winger silty clay loam soils
4. Data followed by the same letter in the same row for a given wheat type are not significantly different at the 10% level.

Table 2. The effect of tillage on spring wheat yields (bu/A) and protein content (%) following soybeans in Ottertail County.

	Yield				Protein			
Year	NT	Spr Disc	Chs	Prplw	NT	Spr Disc	Chs	Prplw
1992[1]	56a[7]	56a			13.0a	14.0b		
1992[2]	47a		49a		13.6a		13.7a	
1993[3]	43a		45a		14.4a		15.3a	
1993[4]	48a		53a		13.8a		14.0a	
1994[5]	45a		51b	46a	13.8a		13.6a	14.2a
Avg.[6]	**46**		**50**		**13.9**		**14.2**	

1. Chappet, Chappet-Sisseton, and Friberg loam soils
2. Sandberg loamy sand soil
3. Formdale-Buse, Formdale-Langhei, and Aazdahl clay loam soils
4. Fordum fine sandy loam, Sandberg loamy sand, and Langhei loam soils
5. Barnes-Langhei, Langhei-Barnes, and Lake Park loam soils
6. Only the four years in common are averaged to compare the no-till and chisel plowing tillage systems
7. Data followed by the same letter in the same row are not significantly different at the 10% level

Results of some recent studies near the headwaters of the Pomme de Terre River in Ottertail County are shown in table 2. Tillage affected spring wheat yields at only one site year out of five (in 1994). The yield reduction in 1994 was linked in part to stand reduction with the no-till system. The drill used had a single disk opener. At the other site years spring wheat yields following soybeans were not affected by tillage.

The Paraplow is a unique type of subsoiler which leaves surface residue minimally disturbed. Even though soils were very dense in the fall of 1993, subsoiling that fall reduced spring wheat yields the next year. Paraplowing reduced stand compared to a chisel plowing system. On average there was a 4 bu/acre yield reduction with the no-till system compared to the chisel plow-based system.

In a continuous wheat study on a Barnes loam near Morris (table 3) there were no significant effects of tillage on yield in the three years measured. Sometimes protein content can be used as an indicator of reduced N availability. For this reason it is presented in tables 2 and 3. Protein contents appeared to more affected by environment than by tillage system. Protein differences between tillage systems were very small.

Table 3. Effect of tillage on spring wheat yields[1] (bu/A) and protein content1 (%) following wheat on a Barnes loam at Morris, MN.

	Yield[2]			Protein[3]		
Year	NT	Chs	Mldbrd	NT	Chs	Mldbrd
1987	54a[4]	54a	52a	10.9	10.9	11.6
1989	57a	50a	57a	14.9	15.1	14.7
1990	58a	58a	59a	12.5	12.7	12.6
Avg.	**56**	**54**	**56**	**12.8**	**12.9**	**13.0**

1. Average of 8 varieties at 120 lb. N/A as ammonium nitrate broadcast in early spring before any secondary tillage
2. Average of three replications
3. Analysis of samples from only one replication
4. Data followed by the same letter in the same row are not significantly different at the 10% level.

Traditionally there has been very little winter wheat grown in Minnesota. This is primarily due to the harshness of the winters. In some years lower prices (vs. spring wheat) and the lack of a suitable crop sequence may also be a factor. In most years, with a clean tillage system there will be substantial winter kill. This limits varietal selection to only the most winter hardy. In some instances this is at the expense of intrinsic yield potential, protein content, and disease resistance.

The studies in table 1 illustrate the potential for winter wheat production when stubble is managed for snow catch in an effort to insulate the soil. North Dakota research has shown that if 4 inches of snow are caught by stubble, winter wheat is protected to -30°F. In the three-year study at three locations, winter wheat yields were slightly higher than spring wheat and there was little effect of tillage. Disease management is more important with winter wheat, however.

Spring Barley

Data from six trials in northwestern Minnesota where barley was grown after soybeans with spring-applied urea showed no difference in yield or protein due to tillage (Table 4).

Table 4. Effect of tillage on barley yields (bu/A) and protein content (%) following soybeans.

	Yield			Protein		
Year	NTI	Chs	Mldbrd	NT	Chs	Mldbd
1986[1]	63a[5]	63a	62a	11.2a	11.4a	11.2a
1986[2]	20a	20a	18a	12.9a	12.9a	13.5a
1987[2]	55a	59a	57a	10.8a	11.1a	11.3a
1988[2]	62a	60a	56a	13.5a	13.7a	13.0a
1988[3]	71a	76a	75a			
1989[1]	58b	61ab	65a	10.6a	11.5a	11.6a
1994[4]	58a	54a		13.3a	13.9a	
Avg.[6]	**55**	**57**	**56**	**11.8**	**12.1**	**12.1**

1. Douglas County, Barnes-Langhei loam soils
2. Norman County, Fargo and Hegne silty clay soils
3. Becker County, Hamerly clay loam and Winger silty clay loam soils
4. Ottertail County, Formdale-Buse, Formdale-Langhei, and Aazdahl clay loam soils. At this site, barley followed wheat.
5. Data followed by the same letter in the same row are not significantly different at the 10% level.
6. Only the years in common are averaged to compare the no-till, chisel plow, and moldboard plow tillage systems.

Summary

Success of reduced tillage approaches to small grain production have been higher when preceded by a low residue crop such as soybeans. Spring wheat and barley following soybeans have generally not been affected with most alternative tillage approaches. A no-till system resulted in more variability in yields (higher or lower than a moldboard plowing system). No tillage sometimes posed challenges in stand establishment, N management, and weed control.
By catching snow with barley stubble, no-till systems allow winter wheat to be grown in Minnesota with less "overwintering" risk. Winter and spring wheat resulted in comparable yields, although performance was more variable for winter wheat. This provides an opportunity for growers to reduce their labor during peak labor demand periods (spring and fall). It also allows for more flexibility to accommodate variations in weather.

Managing Crop Residue With Tillage

Tillage passes with different implements can be used very effectively to create various levels of residue remaining on the soil surface. Four tillage systems shown below are categorized in the following tables 5-8 according to the residue management/yield performance indicators also shown below:

Tillage Systems

Moldboard Plow: Fall moldboard plowing followed by one or two secondary spring tillage operations before seeding.

Chisel Plow: Fall chisel plowing plus secondary spring tillage before seeding. Special attention should be paid to use of proper shaped/width shovels and implement speed in order to maintain proper residue cover.

Spring Disc/Field Cultivator: One or two passes in the spring prior to seeding.

No-till: All seedbed preparation is performed by the drill.

Residue Management/Yield Performance Indicators

1) ***Inadequate Residue to Minimize Erosion*** (less than 30 percent of soil surface covered after planting). Where erosion is not a concern, fall moldboard plowing may be the best practice.

2) ***Recommended with Good Management***
No yield penalty is expected if the farmer observes all relevant recommended management practices for high residue systems.

3) ***Excellent Management Required.***
Slight yield penalty is possible, even if all recommended management practices are observed. Above average crop management will be needed to ensure good performance.

4) ***Reduced Yield Potential.***
The potential exists for substantially reduced yields, especially on poorly drained soils in wet years.

A number of tables have been developed which estimate residue management/yield performance of various crop rotations involving corn, soybeans, and/or small grains. Continuous corn and corn-soybean sequences are discussed in other publications. In those publications the Minnesota River Basin was divided into high annual rainfall (> 28 inches) and low rainfall (< 28 inches) areas. This north-south line is approximately halfway between Highways 71 and 15. Since most small grain is grown in the low rainfall segment of the Minnesota River Basin, indices were developed only for that section of the basin. In each crop sequence, separate indices were developed for glacial till (deposited in place by melting glacier, poorly sorted) and lacustrine (deposited in glacial lakes, well sorted) soils.

Table 5. Matrix of residue management/yield performance indicators for corn following small grain on glacial till and lacustrine soils under low annual rainfall (< 28 inches) conditions in the Minnesota River Basin.

Tillage System	Glacial Till	Lacustrine
Moldboard plow	1	1
Chisel plow	2	2
Spring Disc/Field Cult.	2	3
No-Till	3	4

Table 6. Matrix of residue management/yield performance indicators for small grain following soybeans on glacial till and lacustrine soils under low annual rainfall (< 28 inches) conditions in the Minnesota River Basin.

Tillage System	Glacial Till	Lacustrine
Moldboard plow	1	1
Chisel plow	1	1
Spring Disc/Field Cult.	2	2
No-Till	2	3

Table 7. Matrix of residue management/yield performance indicators for soybeans following small grain on glacial till and lacustrine soils under low annual rainfall (< 28 inches) conditions in the Minnesota River Basin.

Tillage System	Glacial Till	Lacustrine
Moldboard plow	1	1
Chisel plow	2	2
Spring Disc/Field Cult.	2	3
No-Till	2	3

Table 8. Matrix of residue management/yield performance indicators for small grain following small grain[1] on glacial till and lacustrine soils under low annual rainfall (< 28 inches) conditions in the Minnesota River Basin.

Tillage System	Glacial Till	Lacustrine
Moldboard plow	1	1
Chisel plow	2	2
Spring Disc/Field Cult.	2	3
No-Till	3	4

[1] In order to minimize residue-borne diseases, barley, oats, or wheat should not follow themselves in rotation. The use of various small grains in rotation will minimize this problem, but producers must be aware of diseases that are common to more than one crop.

Discussion

Moldboard Plow: This system generally results in high yields but leaves inadequate surface residue to minimize soil erosion. For this reason it should not be used except on level soils where erosion is not a concern, to alleviate surface soil compaction, to incorporate P and K fertilizer, or to incorporate manure.

Chisel Plow: This tillage system generally results in high yields but care must be taken to insure adequate surface residue cover. In most cases straight chisel shanks should be used to achieve 30 percent residue cover. For small grain following soybeans this system will result in less than 30 percent cover, so it is not recommended.

Spring Disc/Field Cultivate: On glacial till soils this tillage system will result in good yields and will leave adequate residue if the implement is properly set. On lacustrine soils this system will probably result in some yield loss due to delayed planting for small grain following soybean. It will also require a high level of management on other crop sequences with higher residue production.

No-till: On glacial till soils this system will work well for small grain following soybeans or soybeans following small grains. For corn following small grain or small grain following small grain, some yield loss would probably result. On the lacustrine soils the no till system will likely result in yield loss (even with good management) for small grain following soybean or soybean following small grain due to delayed planting. For the other crop sequences substantial yield loss would occur.

Economic Comparison of Incremental Changes in Tillage Systems

in the Minnesota River Basin

Kent D. Olson,
Dept. of Applied Economics,
University of Minnesota

Norman B. Senjem,
Minnesota River Basin
Coordinator

Crop residue management through reduced tillage is a cost-effective, best management practice for reducing sediment losses into the Minnesota River. The Minnesota River Assessment Project recommended widespread adoption of conservation tillage, meaning systems that leave at least 30 percent of the surface covered with crop residue after planting, to help achieve the basinwide goal of a 40 percent reduction in sedimentation. It is believed that farmers can reduce tillage to this degree without endangering crop yields or profitability if they choose appropriate tillage systems for their crop rotations, climate, and soils, and adopt necessary changes in crop management. Tillage guidelines for specific rotations and regions within the Minnesota River basin, developed by the University of Minnesota, are described in other documents.

In this paper, an economic comparison is made between several tillage systems in distinct regions of the basin. We limit our evaluation to incremental changes that have no expected yield penalties, based on University of Minnesota reduced tillage guidelines. We explicitly avoid discussion of extreme solutions, where predicted yield penalties need to be compensated for by savings in operating costs through superior crop management, such as low-cost weed control. We intentionally focus on changes that offer the potential for reduced costs and increased net profits.

The Minnesota River basin can be divided into four regions based on soil parent materials and rainfall for purposes of tillage system evaluation. The two soil parent materials are glacial till and lacustrine. Lacustrine soils, which are heavy and poorly drained, are found south of Mankato and to the northwest of New Ulm in Renville, Chippewa, and northern Lac Qui Parle Counties, and isolated pockets elsewhere. Most of the rest of the soils in the basin are classified as glacial till, which tend to be better drained and not as level. The division between high- and low-rainfall areas of the basin is formed by the 28-inch annual precipitation line, which runs roughly north to south between highways 15 and 71.

In this paper we compare the same tillage systems in both the high- and low-rainfall regions. On lacustrine soils, we compare the switch from using a moldboard plow to using a chisel plow. On glacial till soils, we compare both the switch from using a chisel plow to a one-pass-and-plant system and the switch from using a chisel plow to a ridge-till system. All of the changes are designed to result in a rotation average of 30 percent surface crop residue, the definition of conservation tillage. This will be achieved through straight points on chisel plows and avoiding secondary tillage beyond operations listed.

To compare these systems, we are basing our estimates on an example farm which has 800 crop acres evenly divided between corn and soybeans with a 400-acre corn base. The current, on-farm equipment line includes a moldboard plow, 8-row planter, chisel plow, field cultivator, tandem disk, row cultivator, and three tractors (75hp, 120hp and 160hp) as well as other equipment not pertinent to this analysis. The planter is assumed to be new enough and rugged enough to be readily adapted to high-residue use with row attachments.

We use this example farm knowing that every farmer will see something that is different from his or her own farm. However, this does not mean our analysis is not applicable to other farms. Each farmer can use this example as a starting point to study the switch to a different tillage system on their own farm. We have laid out our process and numbers in a straightforward manner so they can be adjusted to fit individual conditions.

In the next section, we present the changes in machinery and the associated up-front investment costs that would be needed to switch from one tillage system to another system. Then we estimate the costs of growing corn and soybean using the various tillage systems. In the last section of this paper, we compare the up-front investment costs of switching machinery to the changes in annual operating costs.

Switching Costs

The up-front costs of adapting (or switching) the equipment line to higher residue use are obtained from current market information.

Moldboard to Chisel. To switch from a moldboard to a chisel plow is expected to have a minimal cost since most farms already have both kinds of plows. To increase residue and thus reduce erosion, the chisel needs straight shovels. To replace the twisted shovels with 2-inch straight shovels is estimated to cost $250; the straight shovels are cheaper than the twisted shovels.

Chisel to One-Pass-and-Plant. To switch from a chisel plow to a one-pass-and-plant system involves the use of two tillage methods. The first method is for corn following soybeans and would not require purchasing any new equipment; the current field cultivator could be used for the required tillage following soybeans. The second method, which is appropriate for soybeans following corn, would require, in our example, the purchase of a new tillage implement which combines two or three light tillage operations in the spring. One such implement (which combines the functions of a disk, field cultivator, and a drag) is available for $10,500 in a 15' width. (An alternative to purchasing the new implement for soybeans is one or two passes with the tandem disk.)

Chisel to Ridge-till. To switch from a chisel plow to a ridge-till system, would require the conversion of a modern planter and the purchase of a heavy-duty cultivator. The cost of the planter conversion is estimated to be $7,000 for an 8-row, 30" planter. The price of a new heavy-duty, 8-row, 30" cultivator is estimated to be $11,500. The cost of converting a combine's wheels to run between the rows is not included in this analysis but would need to be included if it was required in a specific situation.

Operating Costs

In this section, we estimate and compare the operating costs for a corn-soybean rotation. Since the yields are equal in the comparisons, any difference in net returns is caused by the differences in the costs. To facilitate comparisons between systems, standard tillage, herbicides, fertilization, and other operations were defined for each basic tillage system following University recommendations (Table 1). The costs of operating under the different systems are estimated using the SCS (NRCS) CARE program (Cost and Return Estimator). All machinery is assumed to be owned; no custom work is hired. Prices of products and inputs (except herbicides) are taken from recent historical information. Herbicide costs are from "Cultural and Chemical Weed Control in Field Crops, 1995" (BU-3157-S, Minnesota Extension Service, University of Minnesota).

Lacustrine Soils

Moldboard to Chisel. In both the eastern and western parts of the basin, the average annual return from the corn-soybean rotation is estimated to be $10 per acre higher for the chisel system compared to the moldboard system (Tables 2 and 3). Lower machinery operating costs and lower labor costs are the major reasons for the chisel system's lower operating costs. Operating costs per acre are estimated to be $7 lower for corn and $5 per acre for soybeans in both parts of the basin.

Glacial Till Soils

Chisel to One-Pass-and-Plant. In the eastern part of the basin, the average annual return from the corn-soybean rotation is estimated to be $10 per acre higher for the one-pass-and-plant system compared to the chisel system (Table 4). In the western part of the basin, the average return is estimated to be $9 per acre higher for the one-pass-and-plant system (Table 5). Most of the lower cost for the one-pass system is due to lower herbicide costs for soybeans. Machinery operating costs, diesel fuel use, and labor use are also lower for the one-pass system. Operating costs per acre are estimated to be $4 lower for corn and $11 per acre for soybeans in the eastern part of the basin. In the western part of the basin, they are $3 lower for corn and $11 lower for soybeans.

Chisel to Ridge-till. In both the eastern and western parts of the basin, the ridge-till system's average annual return from the corn-soybean rotation is estimated to be $10 per acre higher than the chisel system (Tables 6 and 7). Lower herbicide costs due to banding with ridge-till is the main reason for the decrease. The ridge-till system requires less machinery use and diesel fuel; but since the ridge-till equipment is more expensive to purchase and, thus, operate, the machinery operating costs do not decrease as much as may be expected. Operating costs per acre are estimated to be $15 lower for corn in the eastern part of the basin and $14 lower in the western part of the basin. Operating costs are $7 lower for soybeans in both parts of the basin.

If the post-emergence herbicides were banded with the chisel system, the herbicide costs decrease by $5 for corn and $9 for soybeans. Thus, the cost relationships change. The operating costs for corn are then $10 lower in the eastern part and $9 lower in the western part. For soybeans, the chisel system would have lower operating costs in both regions, lower by $2 per acre.

Investment Costs versus Operating Cost Savings

In this section we compare the required machinery investment cost to switch tillage systems to the estimated annual cost savings. For this example, the farm has 800 acres: 400 planted to soybeans and, with 7.5% setaside, 370 acres actually planted to corn. We also assume that the estimated cost savings will continue at the same level into the future.

Lacustrine Soils

Moldboard to Chisel. In both parts of the basin, operating costs are estimated to decrease by $7 per acre for corn and $5 per acre for soybeans. Thus, total savings for the farm is estimated to be $4,590. Since we expect this example farm already to have a chisel plow, there is no investment expense to be paid in order to make the switch from moldboard to chisel plow. The $250 cost of switching to straight shovels to leave more residue on top of the soil and reduce erosion would be paid for easily. If a chisel plow had to be purchased, these savings in operating costs indicate that its purchase price would be paid back in fewer than two years.

Glacial Till Soils

Chisel to One-Pass-and-Plant. In the eastern part of the basin, operating costs per acre are estimated to be $4 lower for corn and $11 lower for soybeans. In the western part of the basin, operating costs are estimated to be $3 lower for corn and $11 lower for soybeans. As mentioned earlier, a farmer could switch to one-pass-and-plant without making any additional equipment investment. However, the farmer in this example may want to use a combination tillage rig instead of two disk passes before planting soybeans. Since the new combination implement would be used only following corn, total savings for the farm on the soybeans is estimated to be $4,400 in both parts of the basin. Compared to the $10,500 purchase cost of the disk-cultivator-drag implement, these savings would give the farm a payback period of fewer than three years (not counting interest expenses).

Chisel to Ridge-till. Operating costs per acre are estimated to be $15 lower for corn in the eastern part of the basin and $14 lower in the western part of the basin. Operating costs are $7 lower for soybeans in both parts of the basin. Total savings for the example farm is estimated to be $8,350 in the eastern part of the basin and $7,980 in the western part of the basin. Compared to the $7,000 to convert the planter and the $11,500 purchase cost of the new, heavy-duty cultivator, these savings would give the farm a payback period of fewer than three years (not counting interest expenses). If combine conversion is required, the payback period would be lengthened.

If banding is done with the chisel system, the cost relationships change and, thus, the profitability of changing to a ridge-till system also changes. Compared to the chisel system, operating costs for corn in the ridge-till system are estimated to be $10 lower in the eastern part of the basin and $9 lower in the western part. But the operating costs for soybeans under the chisel system is estimated to be $2 lower in both areas. Thus, by switching to ridge-till, the example farmer would expect to lower corn costs by $3,700 in the eastern part of the basin and $3,330 in the western part. This cost savings on corn would be partially offset by soybean costs increasing by $800. This lower savings would extend the payback period for the ridge-till equipment to over six years in the eastern part and over seven years in the western part without counting for any interest costs. Since interest can become significant over this many years, the decision to switch to ridge till from a chisel system that bands the post-emerge requires more analysis and is questionable. If combine conversion is required, these costs would extend the payback period and make the switch to ridge till from chisel even more questionable.

Table 1. Machinery operations and herbicides used in the comparison of tillage systems in the Minnesota River Basin.

Tillage:	Moldboard	Moldboard	Chisel	Chisel	1-pass	1-pass	Ridge-till	Ridge-till
Crop:	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean
FALL MACHINERY OPERATIONS								
Moldboard plow Nov, 7-16, 160 hp	1	1						
Chisel plow Nov, 19', 160 hp			1	1				
SPRING MACHINERY OPERATIONS								
Field Cultivator Apr, 28', 160 hp	2	2	1	2	1			
Disk-cult-drag Apr, 15', 120 hp						1		1
Sprayer Apr, 30', 75 hp	1	1	1	1	1		1	1
Apply Anhydrous Apr, 160 hp	1		1		1		1	
Planting May, 8-30, 120 hp	1	1	1	1	1	1	1	1
Sprayer May, 30', 75 hp	1	1	1	1	1	1	1	1
Row cultivator June, 8-30, 120 hp	1	1	1	1	1	1		
Ridge cultivator June, 8-30, 120 hp							2	2
HARVEST OPERATIONS								
Combine, large	1	1	1	1	1	1	1	1
Trucking	1	1	1	1	1	1	1	1
MATERIALS (lbs. a.i.)								
Pre-emerge herbicide								
Dual	3		3		3		1.5	
Treflan		1		1				
Lexone								0.18
Roundup							0.19	0.19
2,4-D							0.18	0.18
Post-emerge herbicide								
Banvel	0.5		0.5		0.5		0.25	
Pursuit		0.055		0.055		0.047		0.0275
Cobra						0.063		
Pinnacle								0.001

Summary

These cost estimates show that there are potential savings to be made by switching from tillage systems that leave less crop residue on the soil surface, potentially contributing to erosion, to systems that leave more surface residues and minimize erosion. These savings we have estimated are private benefits in the sense that they will be seen by the individual farmer; they do not count society's benefit of a cleaner river.

In this paper, we have used an example farm that we think is similar to many farms in the Minnesota River basin. We know it is not the same as every farm in the Minnesota River Basin. Any example farm we had chosen would have that same problem. However, this example farm shows that a farmer could likely benefit by a switch in tillage system. Therefore, we encourage individual farmers to take our example calculations, modify those items which are different, and make a more exact comparison for their own farm.

Table 2. Cost and return estimates for the moldboard and chisel tillage systems on lacustrine soils in the EASTERN part of the Minnesota River Basin.

Tillage: Crop:	MBplow Corn	MBplow Soybean	Chisel Corn	Chisel Soybean
Yield (bu/A)	130	37	130	37
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	58		58	
TOTAL REVENUE ($/A)	334	202	334	202
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	29	0	29	0
Herbicide	33	24	33	24
Machinery operation	17	15	13	12
Labor cost	15	14	12	12
Trucking	20	6	20	6
Operating Interest	7	4	6	3
Drying costs	23	0	23	0
TOTAL OPER. COSTS	168	73	161	68
FIXED COSTS				
Machinery Ownership	34	28	29	25
Land Charges	80	80	80	80
TOTAL COSTS	282	181	270	173
NET RETURNS:	51	21	63	29
AVERAGE CORN & SOYBEAN NET RETURNS	36		46	
OPERATING COSTS /bu	1.29	1.96	1.24	1.83
Diesel Fuel (gal)	6.1	5.8	4.8	4.8
Labor (hrs)	1.3	1.2	1.1	1.1

Costs and returns may not add up exactly due to rounding.

Table 3. Cost and return estimates for the moldboard and chisel tillage systems on lacustrine soils in the WESTERN part of the Minnesota River Basin.

Tillage: Crop:	MBplow Corn	MBplow Soybean	Chisel Corn	Chisel Soybean
Yield (bu/A)	110	33	110	33
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	43		43	
TOTAL REVENUE ($/A)	276	180	276	180
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	28	0	28	0
Herbicide	33	24	33	24
Machinery operation	17	15	13	12
Labor cost	15	14	12	12
Trucking	17	5	17	5
Operating Interest	7	3	6	3
Drying costs	20	0	20	0
TOTAL OPER. COSTS	160	72	153	67
FIXED COSTS				
Machinery Ownership	34	28	29	25
Land Charges	80	80	80	80
TOTAL COSTS	274	180	263	172
NET RETURNS	2	-1	14	8
AVERAGE CORN & SOYBEAN NET RETURNS	1		11	
OPERATING COSTS /bu	1.46	2.18	1.39	2.03
Diesel Fuel (gal)	6.1	5.8	4.8	4.8
Labor (hrs)	1.3	1.2	1.1	1.1

Costs and returns may not add up exactly due to rounding.

Table 4. Cost and return estimates for the chisel and one-pass-and-plant tillage systems on glacial till soils in the EASTERN part of the Minnesota River Basin.

Tillage:	Chisel	Chisel	1-pass	1-pass
Crop:	Corn	Soybean	Corn	Soybean
Yield (bu/A)	130	37	130	37
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	58		58	
TOTAL REVENUE ($/A)	334	202	334	202
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	29	0	29	0
Herbicide	33	24	33	18
Machinery operation	13	12	12	10
Labor cost	12	12	11	10
Trucking	20	6	20	6
Operating Interest	6	3	6	2
Drying costs	23	0	23	0
TOTAL OPER. COSTS	161	68	157	56
FIXED COSTS				
Machinery ownership	29	25	27	23
Land Charges	80	80	80	80
TOTAL COSTS	270	173	265	159
NET RETURNS	63	29	69	42
AVERAGE CORN & SOYBEAN NET RETURNS	46		56	
OPERATING COSTS /bu	1.24	1.83	1.21	1.52
Diesel fuel (gal)	4.8	4.8	4.0	3.8
Labor (hrs)	1.1	1.1	1.0	0.9

Costs and returns may not add up exactly due to rounding.

Table 5. Cost and return estimates for the chisel and one-pass-and-plant tillage systems on glacial till soils in the WESTERN part of the Minnesota River Basin.

Tillage:	Chisel	Chisel	1-pass	1-pass
Crop:	Corn	Soybean	Corn	Soybean
Yield (bu/A)	110	33	110	33
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	43		43	
TOTAL REVENUE ($/A)	276	180	276	180
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	28	0	28	0
Herbicide	33	24	33	18
Machinery operation	13	12	12	10
Labor cost	12	12	11	10
Trucking	17	5	17	5
Operating Interest	6	3	6	2
Drying costs	20	0	20	0
TOTAL OPER. COSTS	153	67	150	56
FIXED COSTS				
Machinery ownership	29	25	27	23
Land Charges	80	80	80	80
TOTAL COSTS	263	172	257	159
NET RETURNS	14	8	19	21
AVERAGE CORN & SOYBEAN NET RETURNS	11		20	
OPERATING COSTS /bu	1.39	2.03	1.36	1.68
Diesel fuel (gal)	4.8	4.8	4.0	3.8
Labor (hrs)	1.1	1.1	1.0	0.9

Costs and returns may not add up exactly due to rounding.

Table 6. Cost and return estimates for the chisel and ridge tillage systems on glacial till soils in the EASTERN part of the Minnesota River Basin.

Tillage: Crop:	Chisel Corn	Chisel Soybean	Ridge-till Corn	Ridge-till Soybean
Yield (bu/A)	130	37	130	37
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	58		58	
TOTAL REVENUE ($/A)	334	202	334	202
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	29	0	29	0
Herbicide	33	24	20	21
Machinery operation	13	12	13	11
Labor cost	12	12	12	11
Trucking	20	6	20	6
Operating Interest	6	3	5	2
Drying costs	23	0	23	0
TOTAL OPER. COSTS	161	68	146	61
FIXED COSTS				
Machinery ownership	29	25	31	25
Land Charges	80	80	80	80
TOTAL COSTS	270	173	257	166
NET RETURNS	63	29	77	36
AVERAGE CORN & SOYBEAN NET RETURNS	46		56	
OPERATING COSTS /bu	1.24	1.83	1.13	1.65
Diesel Fuel (gal)	4.8	4.8	4.4	3.8
Labor (hrs)	1.1	1.1	1.1	1.0

Costs and returns may not add up exactly due to rounding.

Table 7. Cost and return estimates for the chisel and ridge tillage systems on glacial till soils in the WESTERN part of the Minnesota River Basin.

Tillage: Crop:	Chisel Corn	Chisel Soybean	Ridge-till Corn	Ridge-till Soybean
Yield (bu/A)	110	33	110	33
Price ($/bu)	2.12	5.45	2.12	5.45
Gov't ($/A)	43		43	
TOTAL REVENUE ($/A)	276	180	276	180
OPERATING COSTS ($/A)				
Seed cost	24	10	24	10
Fertilizer	28	0	28	0
Herbicide	33	24	20	21
Machinery operation	13	12	13	11
Labor cost	12	12	12	11
Trucking	17	5	17	5
Operating Interest	6	3	5	2
Drying costs	20	0	20	0
TOTAL OPER. COSTS	153	67	139	60
FIXED COSTS				
Machinery ownership	29	25	31	25
Land Charges	80	80	80	80
TOTAL COSTS	263	172	249	165
NET RETURNS	14	8	27	15
AVERAGE CORN & SOYBEAN NET RETURNS	11		21	
OPERATING COSTS /bu	1.39	2.03	1.26	1.83
Diesel Fuel (gal)	4.8	4.8	4.4	3.8
Labor (hrs)	1.1	1.1	1.1	1.0

Costs and returns may not add up exactly due to rounding.

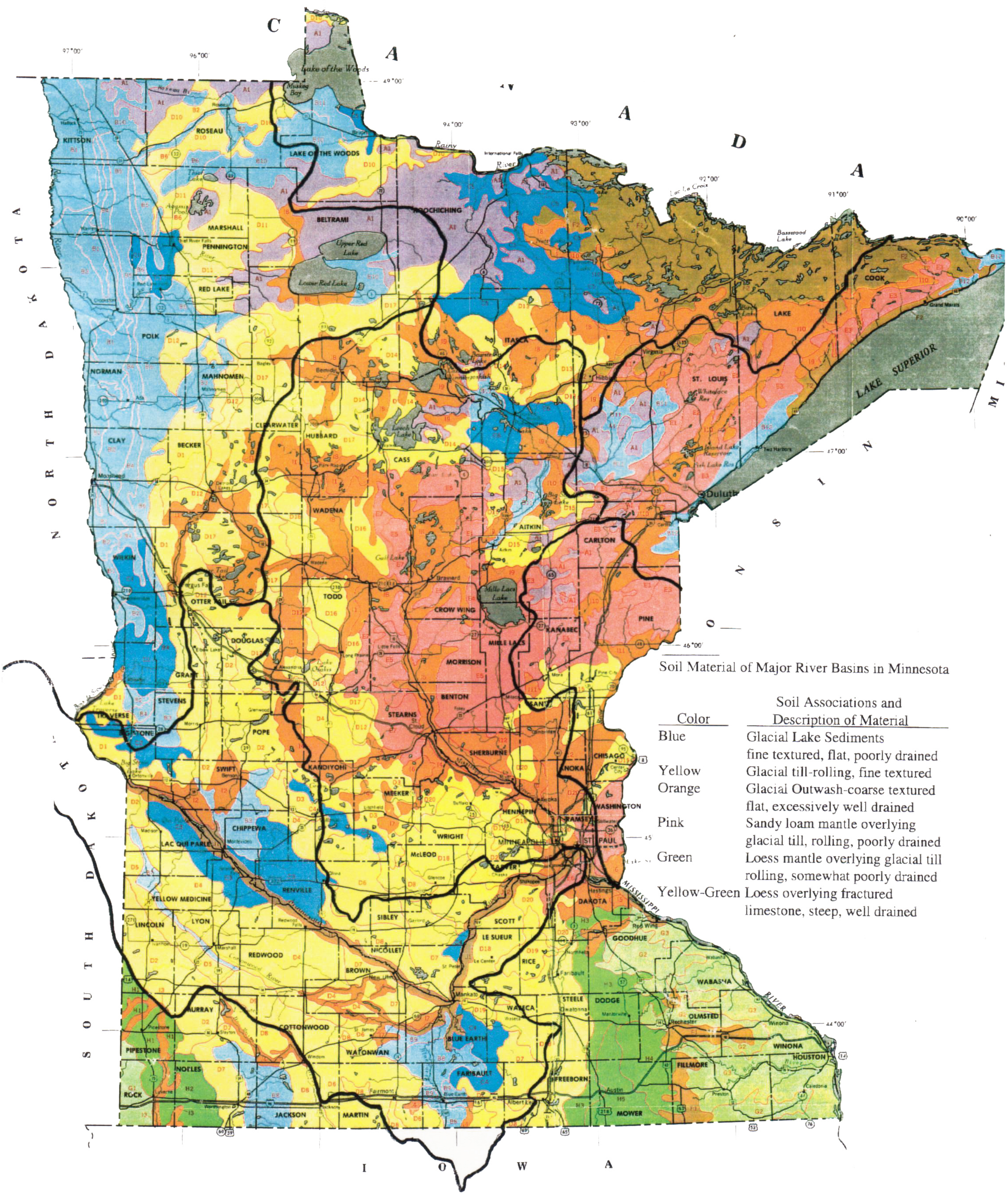
This publication was the result of a joint effort between Minnesota Extension Service, Minnesota Agricultural Experiment Station, and Minnesota Pollution Control Agency. This information was first presented February of 1995 at the Sediment Control Solutions Conferences in Mankato and Montevideo, MN.

Printed on recycled paper with minimum of 10% postconsumer waste, using agribased inks.

Produced by the Educational Development System, Minnesota Extension Service.

NOTES

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE



Soil Material of Major River Basins in Minnesota

Color	Soil Associations and Description of Material
Blue	Glacial Lake Sediments fine textured, flat, poorly drained
Yellow	Glacial till-rolling, fine textured
Orange	Glacial Outwash-coarse textured flat, excessively well drained
Pink	Sandy loam mantle overlying glacial till, rolling, poorly drained
Green	Loess mantle overlying glacial till rolling, somewhat poorly drained
Yellow-Green	Loess overlying fractured limestone, steep, well drained