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Water Quality: The Tillage Component

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Tillage practices greatly affect water resources, particularly surface water. Tillage management is an important factor to be considered when attempting to reduce soil erosion and sedimentation. Tillage practices that control soil erosion also protect surface water quality.

What types of water quality problems may be traced to soil erosion and sedimentation?

Sediment

- High amounts of suspended solids in water can choke out aquatic life.
- Removal of suspended solids increases water treatment costs.
- Suspended solids contribute to increased temperatures that reduce dissolved oxygen.

Nutrients

- Increased nitrogen and phosphorus cause excessive weed growth and algal blooms. Some algae produce toxic chemicals.

Organic matter

- Provides energy for microbial growth that depletes dissolved oxygen.
- Mineralization of organic matter produces ammonia, which is extremely toxic to aquatic animals and plants.

Pesticides

- Pesticides may be dissolved in runoff water or are adsorbed to detached soil particles. Although it rarely happens, they can be toxic to aquatic plants and animals if present at high enough concentrations.
- Some pesticide levels may be built up over time in aquatic plants and animals. This is called bioconcentration and may pose a risk to consumers of those animals, humans or otherwise. This type of behavior is more common to the older, more persistent pesticides such as DDT, which are no longer in use.

Soil management practices that protect soils from detachment and movement by wind and water also protect surface water quality by reducing the amount of material that flows into the water body. Practices that help to reduce nutrient and pesticide movement to water resources include timing of fertilizer and pesticide applications. If possible, producers should avoid leaving nutrients and pesticides on the soil during erosive periods of the year.

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Soil and Crop Management Practices

Continuous cropping:

Continuous cropping has been adopted in North Dakota where rainfall and spring stored soil moisture are generally adequate for profitable crop yields each year. Successful continuous cropping depends on winter snow trapping and conservation of non-growing season rains for efficient soil moisture recharge.

In a continuous cropping system, eliminating fall tillage is most effective in reducing soil erosion losses and protecting water quality. Stubble left standing over winter will trap snow and allow spring precipitation and snow melt to infiltrate into the soil profile instead of running off (Table 1).

Fall tillage provides no advantage to increasing stored soil moisture but is often performed to reduce spring field work, apply nitrogen fertilizer, apply granular herbicides, reduce residue, and control weed populations. These are important agronomic practices that have economic benefits for the producer. In some instances, limited fall tillage can accomplish these major objectives and still leave adequate upright stubble.

TABLE 1. Research comparisons of overwinter soil water storage for standing stubble versus stubble flattened or incorporated by tillage in the Northern Great Plains (2).

Years of Study	Upright Stubble	No Stubble	Reference
	Water Stored (inches)		
20	2.01	.43	Staple. et al., 1960
4	2.03	-.12	Smika, et al., 1966
4	3.00	1.90	Black, et al., 1965
3	2.39	1.16	Bauer, et al., 1978
2	5.60	4.00	Black, et al., 1977
12	4.10	2.50	Bauer, et al., 1990

Crop rotation:

Another important cropping practice to consider is crop rotation. A proper crop rotation contributes to the success of continuous cropping. Crop rotations are absolutely necessary to maximize profits, reduce disease cycles, diversify weed control options, and efficiently use stored soil moisture.

A good crop rotation will have diversity in grass and broadleaf crops, planting dates, and harvest times. This diversity has economic benefits and allows the work load to be spread out.

Effective crop rotations will vary with location and each producer's overall goals. For the most up-to-date information on rotations applicable to your area, contact your local county extension agent or extension area agronomist. County Soil Conservation District offices have information about rotation practices that are acceptable to the federal farm program. Crop rotation is a management option each producer should consider for profitable farming and maintenance of natural resources.

Soil organic matter and tillage:

Loss of soil organic matter content is directly related to tillage method and frequency (1). Organic matter loss has two distinct disadvantages:

1) loss of soil moisture holding capacity and permeability and 2) loss of a natural source of nitrogen and phosphorus.

Loss of moisture holding capacity and permeability. Organic matter acts as the "glue" to hold the framework of soil particles and pores together. Organic matter stabilizes aggregates of soil particles. A stable system of soil pores allows exchange of oxygen and carbon dioxide through plant roots. Stable soil aggregates promote soil pores of size and distribution that hold soil water and allow its release to plants when they need it. When soils are tilled, organic matter is lost through mineralization or soil erosion (Figure 1). Excessive organic matter loss will reduce the soil's ability to store water and exchange water and gases, adding risk to economic crop production.

Both moisture holding capacity and permeability are directly related to crop yields. Research has shown that in North Dakota, every inch of stored soil moisture translates to about a 5-bushel-per-acre increase in wheat yield.

Loss of a natural source of nitrogen and phosphorus. Nitrogen and phosphorus become available to the plant when organic matter is "broken down" or mineralized by soil microorganisms. Organic matter, therefore, is a natural reservoir for these nutrients. Organic matter cannot provide all of the needed nutrients for today's high production agriculture, but it is an important source for some of the nitrogen and phosphorus needed for crop production. If this source of nutrients is depleted, additional fertilizer input will be needed to meet crop needs.

Reducing erosion and tillage help maintain and enhance organic matter levels. Management plans that conserve organic matter protect water quality and maintain crop productivity.

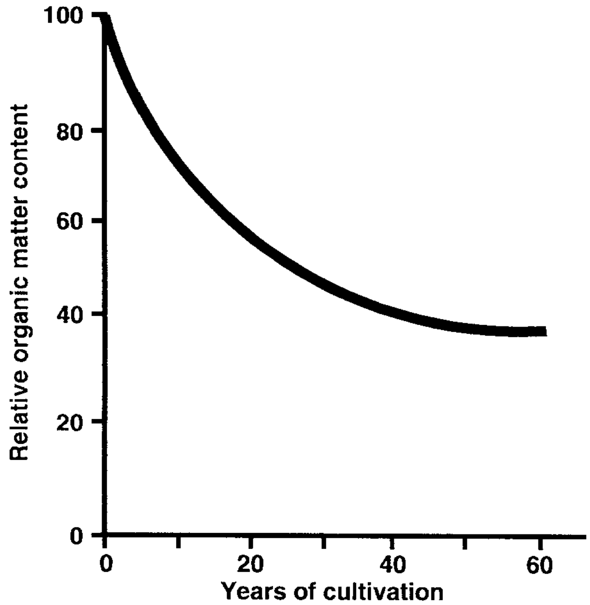


Figure 1. Change in soil organic matter content with cultivation.

Summerfallow:

For years, farmers throughout North Dakota have relied on black summerfallow as a crop production tool. Advantages of black summerfallow include weed control, nitrogen accumulation and soil moisture recharge. However, bare soil is highly erodible and topsoil loss is a major disadvantage of black summerfallow.

Water storage in soil is important to crop production, as average rainfall in North Dakota is usually insufficient to produce economic crop yields. Plants depend on stored soil water to meet their growth needs during dry periods.

The amount of water stored in the soil during a fallow period does add some stability to crop yields the following year. However, sandy soils that have limited moisture holding capacity (Figure 2) store little or no additional soil moisture over the fallow period compared to continuous cropping.

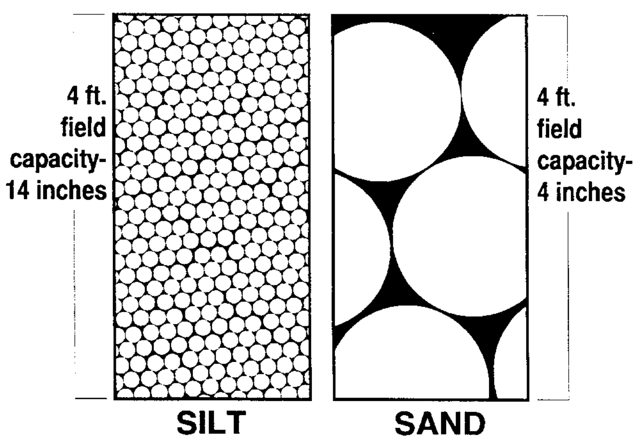


Figure 2. Approximate relationship between soil texture and field capacity.

Fallow provides a smaller advantage in areas with higher precipitation, because stored moisture is usually adequate for seed germination and initial crop growth.

Implementation of reduced tillage practices that conserve soil moisture and trap winter snow may eliminate black fallow as a soil water storage practice. Practices such as no-till, reduced-till, and ridge-till generally increase the amount of stored soil moisture.

Chemical fallow:

For low rainfall areas, where summerfallow provides an economic advantage, there are ways to control weeds without tillage. Chemical fallow is an alternative to tillage. Chemical weed control increases residue and surface water protection by reducing tillage and soil exposure to erosion. However, increased use of herbicides also increases the potential for contamination of water resources with pesticides. Risk to water resources can be minimized by using the following practices (9):

- Use herbicides with short residual and limited mobility in soil.
- Calibrate sprayers so that application rates of herbicide are uniform and at label recommended rates.
- Apply herbicides only when necessary and follow all herbicide label recommendations and guidelines.
- Use good agronomic practices that minimize weed competition and maximize herbicide performance such as crop rotation, herbicide rotation, and cover crops.
- Avoid use of persistent and/or mobile herbicides if possible.

Options such as reduced-tillage and chemical fallow are alternatives to black summerfallow that reduce soil erosion. Standing, upright residues and conserving surface residue are effective tools to protect soil surfaces from wind and water erosion.

Tillage Systems

Each type of tillage system has a different effect on surface water runoff and erosion. A tillage system that aids in moisture retention and decreases soil erosion will benefit surface water quality. That tillage system may or may not improve crop yield and profitability.

Some producers who have compared different tillage alternatives have found economic benefit to practices that also protect water quality. Others have found tillage practices that protect water quality have no effect on their economic situation.

For some producers, the economic impact of changing to tillage practices that protect water quality may be negative.

Every farm is different, and the tillage system that works well on one farm may not be the best choice for another. Producers should consult with the county agent and SCD office to select tillage practices that have the best economic impact and that are in compliance with federal farm programs. Recommended tillage systems are generally categorized as either **conservation tillage** or **conventional tillage**.

Conventional tillage:

Conventional tillage systems are designed to prepare a seedbed by eliminating most of the residue that is left on the soil surface. Conventional drills and seeders cannot penetrate greater than 10 percent surface residue cover. Another goal is to bury residue to reduce diseases such as scab, tanspot, wheat streak mosaic virus, and take-all (5). Also, conventional double disk drills operate best in a clean, tilled soil. Generally, moldboard plowing, chisel plowing, and field cultivation are the main tillage operations used in a conventional tillage system.

Moldboard plow. Plowing in North Dakota is generally done in the fall after the crop has been harvested, which leaves the soil surface bare and unprotected during winter months. Plowed fields allow snow to blow from uplands into low areas. This process contributes to limited capture and storage of water in upland soils during spring melt. Instead, excess moisture concentrates in low areas or swales.

Plowing may improve water infiltration for a short period of time after an initial tillage operation. However, the long term result of plowing is generally a steady decline in soil porosity and permeability. Plowing degrades soil structure and reduces soil porosity. Soil permeability, the natural capacity of soil to conduct water, depends on the amount and stability of soil pores. Therefore, long term reduction in porosity and permeability cause increased surface runoff and soil erosion.

Chisel plow. In comparison to moldboard plowing, chisel plowing gives the producer more control over surface roughness and the amount of surface residue. By using various shovels, greater amounts of stubble and residue can be left on the surface.

Chisel plowing can also be combined with application of granular herbicides and nitrogen fertilizer (anhydrous ammonia). Combined operations help reduce trips across the field and conserve energy and time.

Field cultivator. Field cultivation is generally done in the spring as a final operation for seedbed preparation. Field cultivation does leave a good seedbed for double-disc opener drills. However, it also leaves the soil with little protection before the crop develops a protective canopy.

Disk. Two common types of disks used are an offset disk and the tandem disk. Both implements can be used for primary or secondary tillage operations. However, offset disks are generally heavier and used more for primary tillage. About 40-70 percent residue remains on the surface after a single disking of wheat or corn residue. Residue cover will vary with diameter of disks used and spacing between disks. Disks that have a large diameter (more than 22 inches) and are spaced more than 9 inches apart will cause more residue to be buried. Tillage depth is usually one-quarter of the disk diameter (6), the larger the disk, the more residue that is buried.

The type of tillage implement used affects the amount of surface residue remaining on the soil surface (Table 2). Slower tillage speeds tend to leave more residue on the soil surface. Frequency of tillage is also important. The more you till, the more residue is buried (8).

Table 2. Influence of tillage and other practices on residue cover (7).

Operation	% Residue Left After A Single Operation
Spraying (Chem-fallow)	100
Undercutter (Sweeps 24" or wider)	70-90
Chisel plow	
Sweeps	50-80
Straight spikes	40-70
Twisted spikes	20-50
Disk (tandem or offset)	
Blade less than 23" diameter	40-70
Blade 23" to 28" in diameter	20-50
Blade over 28" diameter	10-40
Field cultivator	40-70
Knife fertilizer applicator	50-70
Moldboard plow	5-10
Drill	
Hoe opener drill	50-80
Single disk drill	80-90
Double disk drill	70-80
Air seeder	50-80
Overwinter weathering	70-80

Conservation tillage:

Conservation tillage is defined as any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting, or a system that maintains at least 1,000 pounds of small grain residue on the soil surface during the critical wind erosion period (6). Soil cover refers to vegetative growth or plant residues protecting the soil surface. Plant materials protect the soil surface from the erosive impact of wind and raindrops and slow downslope water movement (4). In addition to tillage management, conservation practices such as terraces, grass waterways and strip cropping may also be required to effectively control soil erosion.

Because soil cover is an important factor that affects soil erosion, differences in field management translate to significant differences in erosion potential even on the same soil. Just the simple factor of increased yield may have a pronounced influence on erosion, because increased yield results in greater residue.

Although it seems contrary to the goal of water quality protection, increased application of nitrogen fertilizer may be a recommendation that benefits water quality.

In North Dakota, many fields continue to underachieve yield potential because of lack of available nitrogen. Achieving a maximum yield means the amount of residue available for erosion protection is also maximized. Considering that spring wheat generally produces 100 pounds of residue per bushel harvested, just a few extra bushels of wheat means that several hundred pounds of extra residue would be available for soil and water protection.

An example of the impact of yield differences on the amount of residue and its management can be seen by comparing yields from western and eastern North Dakota. The five year (1987-1991) average production of spring wheat in the Southwest district (Adams, Billings, Bowman, Golden Valley, Hettinger, Slope and Stark counties) was 20.4 bushels per acre. The five-year average production for the East Central district (Red River Valley) was 35.0 bushels per acre. An average of 1,500 pounds per acre of extra residue must be managed in eastern North Dakota. This may give eastern producers more management problems, but it also provides them with considerably more flexibility for resource protection.

There are many different types of tillage that fall under the definition of conservation tillage.

No-till. The soil is left undisturbed from harvest to planting, except for nutrient injection in some instances. Planting is accomplished by planters or seeders equipped with coulters, row cleaners, disk openers, or in-row chisels. Weed control is accomplished with herbicides. Emergency tillage is sometimes used when weed populations cannot be controlled by herbicides.

Mulch-till. The soil is disturbed prior to planting. Tillage tools such as chisel plows, cultivators, disks, or wide blades are then used to prepare the soil for planting. Weed control is accomplished with herbicides and/or light cultivation. The number of tillage operations must be limited to maintain an adequate amount of surface residue.

Ridge-till. The soil is left undisturbed from harvest to planting except for nutrient injection. Ridges are formed during the previous growing season. Planting is completed in a seedbed prepared on ridges with sweeps, coulters, or disk openers. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/ or cultivation. Ridges are rebuilt during cultivation.

Undercutter. The soil is left undisturbed except for the undercutting operation. Undercutting is used primarily to cut roots of weeds and leaves most of the residue on the soil surface. V-shaped sweeps 2-6 feet wide are mounted on standards which are attached to a tool bar or frame. Operating depth varies from 2 to 5 inches; generally, the

V-shaped sweeps of an undercutter can vary from 2½ to 6 feet wide.

Residue remaining after one operation of an undercutter.

wider the sweep, the greater the soil depth needed to operate the implement (6). Approximately 90 percent of the original residue cover can remain after an undercutting operation.

The undercutter blade can be controlled best at the proper depth in sandy or coarse textured soils. In fine textured soils, particularly clay soils, it is more difficult to control blade depth and more power is usually required to pull the implement.

If soils are moist, sheared weed roots will fall back into an environment that allows regrowth. Undercutter depth is also more variable in a moist soil. Often the blade will work deeper than necessary and require more power to pull. An undercutter will perform best when soils are dry. However, if soils are extremely dry and hard, problems with controlling proper blade depth are likely to occur.

Seeding Equipment

Conventional small grain seeding equipment is designed to operate on a firm, residue-free seedbed. Successful planting in conservation tillage systems requires specially designed equipment that can uniformly place seed through heavy residue and into a firm, moist soil.

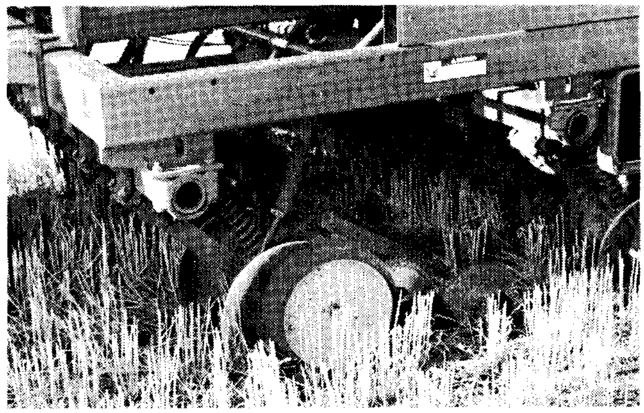
Conventional seeding:

Double disk press drills have a hard time penetrating untilled soil. "Hairpinning" of residue occurs if heavy residue is present. Disadvantges of double disk drills are the lack of positive depth control and the residue-free seedbed left after seeding.

Residue-free seedbed left after conventional double-disk seeding operation.

Conservation seeding:

No-till disk drills are commonly used in conservation tillage systems (6). No-till disk drills usually have few problems seeding into uniformly spread residue. The disks consist of either single or double disk units.

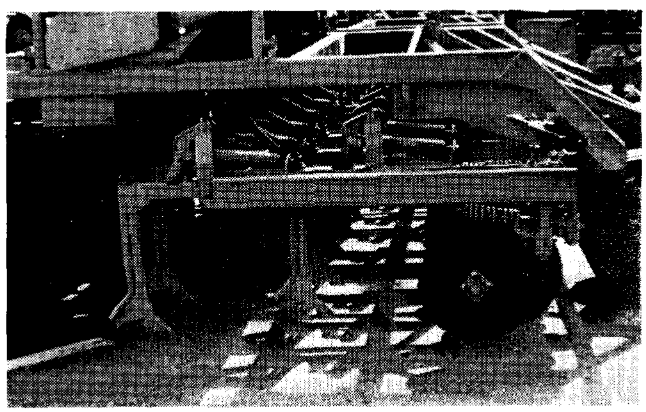


No-till disk drill with fertilizer applicator.

In addition, some drills use a cutting coulter in front of the seeding coulters. Newer models of no-till disk drills have the ability to exert pressure sufficient to cut through heavy residues.

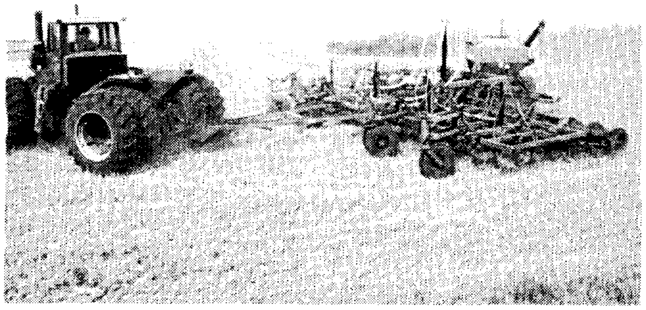
Seeding difficulties may develop with disk-type no-till drills when the straw is extremely wet. Straw and chaff that is not adequately spread also reduces the performance of disk-type no-till drills.

Another type of drill used in conservation tillage systems is the hoe drill. Hoe drills work best in dry soil conditions. Openers on a hoe drill push dry soil and residue aside and allow for better seed placement. Hoe drill speeds can be reduced to help minimize soil disturbance.



Hoe drill.

Air seeders allow farmers to seed into residue at relatively high speeds. Speed combined with easy transport between fields allows the producer to cover large areas of land with this implement. Air seeders also usually have good residue clearance. Depending on shank spacing and type of opener used, adequate residue cover for soil protection can be maintained.



Air seeder.

Using a cutting coulter ahead of the openers helps reduce residue plugging. Improved designs with flexible sections, floating drawbars, and weight-carrying press wheels provide better seeding depth and placement compared to older models of air seeders.

Does Conservation Tillage Have Economic Benefits for Your Farm?

Aside from the long term soil and water benefits, does conservation tillage have economic benefits to the individual producer? Because each farming operation is different with respect to natural factors and individual goals, the answer to this question varies.

Soil properties play an important role in determining whether certain management practices will be effective. Soil types that have low average annual rainfall, high evapotranspiration, coarse texture, or steep slopes tend to be the driest. Yield benefits from soil moisture conservation will generally be greatest on dry soil types. However, most North Dakota soils have irregular drought periods, during which soil moisture conservation will also have measurable yield benefit to the producer.

Water storage benefits from conservation tillage are not as likely to show significant yield increases on naturally moist soils with medium to high available water holding capacity. Although conservation tillage on these soils will probably benefit water quality, economic benefits to the producer may not be obvious.

Summary

In some areas, solutions to local water quality problems may include changes in tillage practices. Changing to a tillage system that benefits water quality could also benefit the producer economically. However, each producer needs to weigh the advantages and disadvantages of the various tillage options before selecting a system that best fits his operation.

Tillage is just one component of farming management that affects both farm economics and water quality. Some of the more recent advances in equipment and cropping management are making it possible for many producers to meet both economic and environmental goals.

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