Dec 2nd, 12:00 AM

Conservation Tillage, Soil Erosion and Water Quality

John M. Laflen
Iowa State University, jmlaflen@iastate.edu

Follow this and additional works at: https://lib.dr.iastate.edu/icm
Part of the Agriculture Commons, and the Bioresource and Agricultural Engineering Commons

https://lib.dr.iastate.edu/icm/2004/proceedings/29

This Event is brought to you for free and open access by the Conferences and Symposia at Iowa State University Digital Repository. It has been accepted for inclusion in Proceedings of the Integrated Crop Management Conference by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
CONSERVATION TILLAGE, SOIL EROSION AND WATER QUALITY

John M. Laflen, Agricultural Engineer
USDA-ARS (Retired), Adjunct Professor
Iowa State University

Introduction

Conservation tillage has a great effect on soil erosion and water quality. This effect is perhaps best understood by understanding of the runoff, erosion and sediment delivery processes, and how these are impacted by conservation tillage.

Tillage is an operation that disturbs the soil. Each tool acts differently. Major impacts of tillage may be to invert the soil, to bury residue, to mix materials on the surface with materials below the surface, to change soil density at various levels within the soil depth, to apply materials on and into the soil.

Wind erosion and groundwater quality will not be covered here, the focus will be on water erosion and surface runoff water quality.

Runoff and Erosion Processes

Runoff

Runoff occurs when rainfall intensity exceeds infiltration rate-after interception by plants and residue and after an initial abstraction required to fill small depressions (surface storage) within the field. These volumes are related to the roughness of the soil surface and the fraction of the surface covered by crop canopy and crop residue. They can be appreciable or small, depending on the latest tillage, handling of residue, and smoothing of the surface since the last tillage.

When the initial abstraction due to interception and filling of small depressions is satisfied, if rainfall intensity is greater than the infiltration rate, surface runoff will occur. The higher the infiltration rate, the lower the runoff rate.

The driving force in infiltration is the capillary potential in the soil. The rate of infiltration depends on this potential and the hydraulic conductivity of the soil through which the infiltrating water must pass. Both of these can be influenced greatly by tillage.

Surface sealing is greatly affected by tillage and residue. The seal formed by raindrops drastically reduces infiltration rates. Residue eliminates surface sealing under residue.

On the other hand, crop residue cover also reduces surface evaporation, and on the average, increases soil moisture content, reducing infiltration rate by reducing capillary potential. On the average, the elimination of surface sealing overrides the impact of residue on soil moisture content. The effect of tillage on surface runoff volumes is on the average fairly small. There can be some major exceptions.

In a rainfall simulation study on three different Iowa soils, each with 6 different tillage system, Laflen et al. (1978) found runoff reductions as residue cover increased of about a third on two
high silt soils, and essentially no reduction on a third high sand soil. Ghidiey and Alberts (1996) on small plots located on a claypan soil in central Missouri found that over an 11 year period, there was an increase in runoff for no-till as compared to spring plowed and spring chiseled treatments.

At Treynor IA, unpublished runoff measurements have been made on two contour planted continuous corn small watersheds, and on a nearby ridge tilled continuous corn small watershed. Surface water yields were greater over a 14 year period on the contour planted watersheds than on the ridge tilled watershed. Subsurface water yields were greater on the ridge tilled watershed. These were very steep watersheds on loessial soil, and contouring would be expected to have a minimal impact on flow from the watershed unless ridges were tall.

Erosion

Soil erosion is a process of detachment and transport. We visualize soil erosion as the detachment of soil particles by the direct action of raindrops and the transport of these by splash and very shallow flowing water to small channels called rills. When these rills join together and form even larger channels, we call them gullies—either temporary (ephemeral gullies), or permanent gullies (classical).

The direct action effects of raindrops and transport to rills is termed interrill erosion, while the detachment in rills is called rill erosion (Figure 1). One can visualize these processes in terms of row crops, with water flowing down the row middles in rills, and the delivery of interrill material from the adjacent rows (Figure 2).

Interrill detachment is best expressed as the product of flow rate and rainfall intensity. It is affected by soil, canopy, residue, interrill slope, and compaction. Interrill erosion is not affected by position on the landscape—when all other conditions remain constant. The interrill erosion rate has been shown to be constant down a slope (Young and Wiersma, 1973). Interrill erosion is usually not apparent. When one notes that a field has had a lot of erosion—it is usually not interrill erosion that is observed.
Interrill areas contribute runoff and eroded soil to rills. Rills transport this water and soil to channels downstream. Soil detachment in rills is a function of the hydraulic shear of the flowing water (Figure 3). Hydraulic shear is a function of the depth of runoff water and the rill slope. Rills can be a very significant source of eroded sediment, and can be quite visible.
Flowing water transports sediment, but for a given flow rate and a given channel, there is a limit to how much sediment can be transported. Current theory also indicates that as sediment transport increases in a channel, soil detachment is reduced. When flow conditions in a channel reduce sediment transport capacity, the amount of material being transported to that point may exceed the sediment transport capacity, and deposition will occur. This is most visible when slopes flatten, or when flow velocities are reduced due to changes in vegetation or some other flow obstruction.

Channels are very similar to rills—just larger. Again, the soil detachment is assumed to be due to hydraulic shear, but this is not necessarily accurate at the headcuts of gullies.

In rills and channels, conservation tillage may have a major impact by reducing runoff velocities, and by decreasing the soil surface area where hydraulic shear can detach soil. It has been shown (Figure 4) that even a very small amount of residue can drastically reduce runoff velocities (Kramer and Meyer, 1969)—greatly reducing the sediment transport capacity. Sediment transport capacity of runoff increases at nearly the square of the runoff velocity. The increase of runoff velocity between 1/8 of a ton per acre and no residue would be expected to more than double sediment transport capacity.

Residue acts as a small impoundment in affecting soil loss from conservation tillage. Brenneman and Laflen (1982) modeled the transport of sediment down a row using a model that incorporated Stokes law as applied in settling tank theory (Clark et al., 1977) for the settling of particles in a fluid above the crop residue (Figure 5).
Figure 4. Runoff flow velocity versus mulch rate (Kramer and Meyer, 1969).

Figure 5. Ponding of water above crop residue, resulting in sedimentation above the residue. Modeled by Brenneman and Laflen (1982) using Stokes Law as applied in settling tank theory (Clark et al., 1977).

Channels are the most visible form of soil erosion in a field. Small channels that you can cross and fill with farm implements generally form in high runoff periods. The mechanism of formation is that a channel will erode to the depth of the last tillage operation, and then widen until the hydraulic shear on the channel is below the critical shear for the material in which the channel formed. Shallow tillage can result in very wide shallow channels. No tillage can essentially eliminate the formation of these channels because of high critical shears, and low
rill erodibilities (see Figure 3). Franti et al. (1999) found that sediment detachment rates due to high discharge concentrated flow such as might occur in a small channel was an order of magnitude greater on tilled soil than on un-tilled soil. They found that rill erodibilities were 7 times greater, and critical hydraulic shear was twice as great.

There are a wide variety of studies reported on the effect of tillage on runoff and erosion. The results are generally consistent—the less tillage, the more residue remains on the surface, and the lower the soil loss. The magnitude of the impact can vary quite widely, depending on soil, climate and topography.

Generally, we express the effect of crop residue on soil erosion as shown in Figure 6. These are also the relationships one would use if the “residue” were rocks, sagebrush, or other material visible in direct contact with the soil surface. The determination of appropriate curves would be based on soils, management and topography.

![Figure 6. Effect of residue on soil erosion.](image)

The relationship shown in Figure 6 reflects the results of numerous studies, plus additional modeling analysis. These results are incorporated into models used to predict erosion on the nations lands (Yoder et al., 1997)

**Water Quality Processes**

Chemicals are transported from a field in solution in surface runoff and attached to sediment in surface runoff. Chemicals in solution in surface runoff, and much of the material attached to sediment in surface runoff moves from fields during and shortly after rainfall. Some material attached to sediment may be deposited, and moved at a later date, perhaps in a larger event.
Chemical losses are determined by the mass of the carrier (water and/or sediment) and the concentration of the chemical in the carrier.

The concentration of chemical in the soil profile, and its location in the profile, influences the concentrations of the chemical in the carriers. Studies have shown that increasing application rates of phosphorus and nitrogen have increased losses in surface runoff (Rompkins and Nelson, 1974). During rainfall and runoff, at the soil surface, rainfall mixes with the soil and water in a shallow depth (Figure 7 - after Baker and Laflen, 1983). The runoff water and the sediment begin to assume concentrations based on the concentrations of the chemical in this zone. For a given chemical, higher concentrations would be expected to result in higher concentrations in runoff and eroded soil. Baker and Laflen (1983) discussed this in considerable detail.

![Figure 7. Illustration of mixing zone concept for runoff and eroded soil chemical concentrations as affected by concentration of chemicals near the soil surface.](image)

Conservation tillage impacts both the volumes of the carriers—eroded soil and runoff water, and the chemical concentrations in the carriers. As tillage and mixing of the soil decreases, stratification of chemicals in the soil profile occurs (Erbach, 1982). In a 5 year study, P and K were fall applied as granular fertilizers prior to fall tillage. At the end of 5 years, Phosphorus levels were well distributed throughout the plow layer for a moldboard plow system, but stratification increased as tillage decreased. The stratification was well established after only 1 year of the study.

Laflen and Tabatabai (1984) found that for a similar study but with spring tillage, and with N and P added just prior to spring tillage (including for no-till), N and P concentrations were much higher in runoff water from no-till than for either a spring plow or spring chisel plow system (Table 1). This was a rainfall simulation study, with measurements made about 7 weeks after tillage and planting for one soil, and 3 weeks after tillage and planting for another soil.

For the same study, while eroded material from the no till treatment had a higher concentration
of both N and P in runoff water and eroded soil than did the spring plow or spring chisel plow system (Table 1), total losses in sediment were much less for no till than for the other treatments because soil erosion was much less. And, because the dominant pathway of loss was in the sediment, total losses were much less for no-till than for the other tillage systems.

Table 1. Nutrient concentrations and nutrient losses as affected by tillage system (Laflen and Tabatabaai, 1984).

<table>
<thead>
<tr>
<th>Nutrients in Runoff Water</th>
<th>Clarion</th>
<th>Monona</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring Plow</td>
<td>Spring Chisel</td>
</tr>
<tr>
<td>NH₄-N (ppm)</td>
<td>0.19</td>
<td>0.58</td>
</tr>
<tr>
<td>NO₃-N (ppm)</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>PO₄-P (ppm)</td>
<td>0.08</td>
<td>0.17</td>
</tr>
<tr>
<td>Total N loss (kg/ha)</td>
<td>0.024</td>
<td>0.076</td>
</tr>
<tr>
<td>Total P loss (kg/ha)</td>
<td>0.027</td>
<td>0.027</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrients in eroded soil</th>
<th>Clarion</th>
<th>Monona</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N (ppm)</td>
<td>2370</td>
<td>1620</td>
</tr>
<tr>
<td>Total P (ppm)</td>
<td>718</td>
<td>771</td>
</tr>
<tr>
<td>Total N loss (kg/ha)</td>
<td>5.21</td>
<td>75.43</td>
</tr>
<tr>
<td>Total P loss (kg/ha)</td>
<td>1.65</td>
<td>35.87</td>
</tr>
</tbody>
</table>

Conservation tillage may significantly impact water quality by changing the concentrations of chemicals near the surface, and by decreasing soil erosion. Practices that increase concentrations of nutrients near the surface would be expected to increase the concentration and losses of chemicals in surface runoff, and would also increase the concentration of chemicals in eroded soils. However, if soil erosion is significantly reduced, losses of chemicals in eroded soils would also likely be significantly reduced.

Summary

Conservation tillage has a profound effect of soil erosion and water quality. There is little doubt that practices that leave crop residue on the surface will visibly reduce soil erosion. Most research data show that conservation tillage may increase concentrations of chemicals in runoff water and eroded soil, but, depending partially on the chemical, will likely lead to decreases in losses of chemicals, particularly if soil erosion is a problem.

References


