Effective Conservation Farming Systems
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The Authors

The authors are Roger Veseth, STEEP Extension Conservation Tillage Specialist with the University of Idaho and Washington State University, located at the University of Idaho, Moscow; James Vomocil, Extension Soil Scientist with the Soil Science Department, Oregon State University, Corvallis; Bob McDole, Extension Soil Scientist, with the Department of Plant, Soil and Entomological Sciences, University of Idaho, Moscow; and Carl Engle, Extension Soil Scientist with the Department of Agronomy and Soils, Washington State University, Pullman.

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This PNW Extension publication is part of a crop management series on minimum tillage and no-till systems. The development of successful conservation tillage systems in the Northwest has been greatly accelerated through a comprehensive research program called STEEP (Solutions to Environmental and Economic Problems). The crop management series is a cooperative effort between STEEP Extension personnel and participating STEEP researchers in Idaho, Oregon and Washington. Purpose of the series is to help make the latest developments in STEEP conservation research available to Northwest growers.
Summary

About 65 to 75 percent of the annual precipitation in the Northwest comes during winter. Warm, moisture-laden storms move in from the Pacific Ocean, commonly when soils are frozen. Precipitation and rapid snowmelt on frozen soils with little or no surface residue can result in significant surface runoff and soil erosion.

Loss of topsoil by water erosion seriously affects soil productivity in the Northwest, degrades water quality and causes costly sedimentation problems. Yield potentials are also reduced because of the reduced soil water storage. One of the most severe runoff and erosion problems is from winter wheat seeded on a fine, conventionally tilled seedbed with little or no surface residue. Water and soil losses are especially high after conventional summer fallow. Compacted soil layers can significantly increase runoff and erosion potential. Tillage erosion contributes to topsoil loss on ridge tops and upper slopes as well.

Conservation tillage systems such as minimum tillage or no-till maintain a higher level of residue on the soil surface. Surface residue, as well as rough soil surface, slows downslope water movement and reduces runoff by 60 percent or more compared to low-residue conventional tillage. If compacted soil layers are present or runoff on frozen soils is common, deep chiseling can increase water movement into soils and reduce runoff. Surface residue also reduces soil freezing, allowing more water movement into the soil. If runoff does occur, no-till and minimum tillage can still reduce soil erosion by 90 percent or more compared to conventional tillage.

A number of options are available for developing minimum tillage and no-till systems. Existing drills can often be modified to improve residue penetration and fertilizer placement. Equipment can be rented or purchased, or custom seeding can be arranged. Minimum tillage and no-till reduce runoff and erosion and also potentially reduce costs while maintaining or increasing production. More producers should begin experimenting to develop efficient conservation tillage systems adapted to individual farming conditions. Contact your County Extension Agent and local Conservation District or Soil Conservation Service office for more information.

Fig. 1. Topsoil loss from water erosion can be severe on sloping, conventionally tilled cropland where little or no crop residue remains on the soil surface.
Fig. 2. Yield potential can be drastically reduced where less productive subsoils are exposed or near the surface because of topsoil erosion.

Introduction

Recent advances in management technology and equipment design have created new opportunities for Northwest producers to decrease soil erosion and to maintain or, potentially, to increase net income. Minimum tillage and no-till farming effectively decrease soil erosion through efficient residue management. These conservation tillage systems also have the potential to reduce production costs while maintaining or increasing yields. However, they require an understanding of up-to-date production technology and management skills. These conservation farming systems have been successful and should be considered for use by more producers.

High rates of topsoil erosion and low efficiencies in soil water storage are serious production problems on much of the conventionally tilled cropland of the Pacific Northwest (Fig. 1). Besides contributing to surface water pollution and sedimentation problems, topsoil erosion is sharply lowering present and future soil productivity. Loss of winter precipitation by runoff and evaporation significantly reduces crop yield potentials in areas of intermediate and low precipitation.

Annual soil erosion rates in the dryland cropping areas of the Northwest range from 2 to 27 tons per acre (McCool et al., 1976). Losses of over 150 tons per acre are not uncommon on steep slopes in one winter season. This is equivalent to about 1 inch of topsoil. About 85 percent of this erosion occurs during the winter months.

Erosion has significantly reduced topsoil depth in the region since extensive farming began near the turn of the century. In the Palouse area of eastern Washington and northern Idaho, for example, all of the original topsoil has been lost from 10 percent of the cropland (USDA, 1978), exposing less productive clayey or highly calcareous subsoils (Fig. 2). One-fourth to three-fourths of the topsoil has been lost from another 60 percent of that cultivated area.

Factors Contributing to High Runoff and Erosion Rates

Several factors contribute to high runoff and soil erosion in the Northwest. Some are environmental factors which must be adapted to. Others, such as the selection and use of tillage equipment and residue management practices, can be modified by growers to help reduce runoff and erosion.

Precipitation Distribution — The Pacific Northwest has a Mediterranean-type climate with cool, wet winters and warm to hot, dry summers. Approximately 65 to 75 percent of the annual precipitation comes between November and April. Under conventional tillage systems, this precipitation comes at a time when there is little surface residue or crop canopy to protect the soil from runoff and erosion.

During the winter months, snow cover is variable with several cycles of accumulation and melt due to wide variations in daily air temperatures. Warm, moisture-laden storms from the Pacific Ocean are common in the winter months, with precipitation or snowmelt often occurring on frozen soils.
Freeze-Thaw Cycles — Freeze-thaw cycles are a major factor contributing to high surface runoff and soil erosion in much of the Pacific Northwest. A frozen soil layer greatly reduces water movement into soils. This causes serious surface runoff and soil erosion in sloping areas and increases evaporative water loss. A thawed, saturated soil layer overlying frozen soil is extremely vulnerable to erosion where it is not sufficiently anchored by plants or crop residue, even on gentle slopes (Fig. 3).

Soil freeze-thaw cycles are common to most of the Pacific Northwest cropland areas each winter. In a review of 30 years of weather records for northeastern Oregon from 1948 to 1978, STEEP researchers at Pendleton (Zuzel et al., 1985) found that the number of major freeze-thaw cycles each year ranged from one to seven with an average of three.

In four northcentral Oregon counties, researchers at Pendleton measured runoff-erosion events between January 12 and February 25, 1980 (Zuzel et al., 1982). Of the 14 runoff-erosion events, 12 involved rainfall, rain on snow or rapid snowmelt on frozen soils.

Besides severely reducing water infiltration into the soil, soil freezing also increases the erodibility of surface soil. Ice crystal formation in the soil tends to de-
Soil compaction can be a significant factor in runoff and erosion on Northwest cropland, but it has often gone unnoticed. Compaction affects runoff events in two main ways. First, compaction reduces water infiltration into soils, directly increasing the amount of surface runoff. Second, reduced infiltration and drainage create a temporary "perched water table" above the compacted layer. When this wet soil layer freezes, it forms an impermeable, concrete-like frozen layer which completely prevents water infiltration into the soil and further increases runoff. Evaporative water loss is also increased.

Where the moldboard plow has been used as a primary tillage tool, compacted "plow pans" can severely reduce downward water movement into the soil. Other tillage implements can also create compacted layers at shallower depths. Traffic compaction from increasingly larger, heavier equipment is a problem as well, particularly if tillage is done when soils have a relatively high water content.

A tillage-residue management study was initiated in 1931 near Pendleton. After 52 years, a thin, compacted plow pan about 8 inches deep was found to be the most restrictive layer to water movement into soils (Pikul et al., 1983). Researchers measured a saturated hydraulic conductivity of less than 1.5 inches per day through the plow pan at 8-inch depth compared to 6 inches per day through the soil below the plow pan.

Alternative Tillage and Residue Management Practices

Description — Major advances in equipment design and production technology in recent years provide alternative tillage and residue management systems which offer effective conservation options and economic production. Advances such as deep-banding fertilizer near the seed row, new herbicides, longer crop rotations, disease control strategies and uniform residue distribution from combines have greatly increased the success of minimum tillage and no-till.

Conservation tillage systems which leave more crop residue on the soil surface can effectively reduce soil erosion and water loss caused by runoff and evaporation. Two conservation tillage systems that are rapidly gaining popularity in the Northwest are minimum or reduced tillage and no-till. Besides reducing soil erosion, these conservation tillage systems can reduce production costs and increase yield potential through increased soil water storage and improved production technology.

Minimum tillage simply means either reducing the number of tillage operations or selecting tillage equipment that maintains a higher percentage of the previous crop residue on the soil surface. For example, chisels and sweeps bury less residue per operation than inversion-type implements such as the moldboard plow and large offset discs. Generally, about 30 percent surface residue cover should remain after seeding with minimum tillage (Fig. 6). Extension publications (Engle et al., 1984; McDole and Vira, 1983; Ramig and Maxwell, 1984) are available to help individuals estimate the amount of residue remaining on the surface after tillage with various implements. The local Conservation District and SCS office can provide field assistance. In addition to increasing surface residue, minimum tillage also leaves a rougher soil surface that helps reduce runoff.
No-till systems do not require any seedbed preparation before seeding. No-till drills place the seed directly through the previous crop stubble (Fig. 7). Most no-till drills can also deep-band all or part of the fertilizer in one operation with seeding. Nearly all the crop residue remains on the surface, and the amount of soil disturbance is minimal. Commercial no-till drills give a range of soil disturbance and surface residue levels, however, depending on the type and size of openers, depth and speed of operation and other factors. The number of different types of commercial no-till drills available in the Northwest has grown from none in 1970 to 4 in 1980 and over 14 in 1986.

Tillage-Residue Effects on Soil Freezing — Tillage and surface residue affect soil freezing and consequently influence the level of runoff and erosion. In the absence of snow cover, crop residue on the soil surface provides thermal insulation to the soil. The frequency, depth and duration of soil freezing are reduced compared to a bare soil surface. By reducing soil freezing, surface residue helps maintain water infiltration into the soil. This reduces runoff and erosion potential and increases the amount of stored soil water. Reducing soil freezing and frost heaving also reduces root injury and winterkill of fall-seeded cereals. Root injury can provide plant infection sites for some soil-borne disease pathogens.
How It Works

Surface residue, particularly standing stubble, helps reduce soil freezing in four main ways which are described by STEEP researcher Joe Pikul, USDA-ARS soil scientist at Pendleton (Vomocil et al., 1984). First, soil gives off radiant heat during the night. Surface residue reflects part of this heat back to the soil surface, and this reduces nighttime cooling of the soil and reduces the chance of freezing. Second, surface residue lowers daytime soil temperatures up to 10°F or more which reduces evaporation losses. Consequently, surface soils are generally wetter than a bare soil surface. Because moist soils have a larger heat capacity than dry soils, more heat must be lost to allow a sufficient temperature drop for soil freezing. Third, residue reduces air movement near the soil surface, creating a "windbreak" effect which reduces evaporation and heat losses. Finally, crop stubble can effectively trap snow, providing additional insulation and soil water storage.

Research on Soil Frost Control

Comparisons of soil frost formation under different tillage and residue systems have been made by STEEP researchers at the Columbia Plateau Conservation Research Center at Pendleton. In one study between January 5 and February 10, 1980, frost depth was measured on winter wheat under conventional tillage and no-till (Vomocil et al., 1984). Where winter wheat was seeded on a fine, conventionally tilled seedbed, with less than 100 pounds per acre cereal residue on the surface, soils were continuously frozen to a depth of at least 2 inches during the period. On no-till plots with 4 to 5 tons of residue per acre, no soil freezing was detected during the 36-day period.

Fig. 8 compares the effects of conventional tillage and no-till treatments on the depth and duration of soil freezing during an 11-day freeze-thaw cycle in the winter of 1982-83 (Greenwalt et al., 1983). Both treatments were winter wheat on summer fallow. The fall-plow treatment represents a conventional tillage sequence of fall moldboard plowing and spring discing followed by two rod weeder operations before fall seeding. The no-till treatment was chemically fallowed, and winter wheat was seeded directly into standing stubble with a modified John Deere HZ deep furrow drill with 16-inch row spacing. Surface residue amounts after planting were 78 pounds per acre on the conventional fall-plow treatment and 5,500 pounds per acre on the no-till.

Soil frost developed three days earlier in the conventional fall-plow treatment and remained two days longer than in the no-till. Maximum frost penetration was three times greater in the fall-plow treatment than in the no-till.

In four winters of soil frost measurements between 1979 and 1985 in northeastern Oregon, researchers found that soil frost depth under standing stubble was consistently less than 35 percent of the frost depth with no surface residue (Pikul et al., 1986). Under thaw conditions of clear skies and warm air temperatures, stubble and bare soil treatments thawed on the same day even though the bare treatment was frozen to a deeper depth. In contrast, standing stubble thawed four days earlier than the bare surface treatment when thawing conditions
were characterized by low air temperatures and cloudy skies. These conditions are typically associated with the advance of moisture-laden cyclonic storms from the Pacific Ocean, which are common during winters in the Northwest. Appreciable rainfall and snowmelt during these storms can cause serious erosion if a thawed soil surface is underlain by frozen soils.

Non-Uniform Frost Depth with Chiseling

In areas where runoff on frozen soil is common, deep chiseling can reduce runoff losses. Minimum tillage practices such as fall chiseling of cereal stubble generally result in frost depths intermediate between standing stubble and a bare soil surface at Pendleton (Pikul et al., 1985). Frost depth with chiseling is not uniform, however, and this provides an additional advantage. The boundary between frozen and unfrozen soil may be nearly a straight line under both standing stubble and a residue-free surface. Chiseled stubble typically creates a non-uniform frost boundary because of its rough surface with residue mats, large clods and chisel marks. The rough surface slows surface water movement and allows more time for water infiltration through large, vertical pores and thin portions of the frost layer. In shallow frost situations, the frost layer is often discontinuous in rough chiseled stubble, but continuous under a residue-free surface.

Chiseling for Break-up of Compacted Plow Pans

Deep chiseling can also be beneficial for soils with tillage compacted layers. In a field study on Walla Walla silt loam soil near Pendleton (Zuzel, 1983), chiseling about 10 inches deep increased saturated hydraulic conductivity at the 8-inch plow pan depth from 1.2 inches per day to 6.7 inches per day, similar to that of the underlying soil.

In another field study where a plow pan was present at 8 inches, a rainfall simulator was used to compare water infiltration rates between different tillage treatments (Pikul et al., 1985). The field had a history of conventional tillage winter wheat-fallow, with moldboard plowing as primary tillage. On unfrozen soil in the fall of 1984, water infiltration rate was 5 inches per day under undisturbed standing stubble, compared to 8 inches per day where the stubble was chiseled to a depth of 10 inches. When the soil was frozen to a depth of 4 to 5 inches later in the winter, infiltration rates decreased to 1.2 inches per day for standing stubble and 3.4 inches per day for chiseled stubble. Where winter wheat was conventionally seeded on fallow with almost no surface residue, water infiltration rate in unfrozen soil was 2.2 inches per day. No water infiltration occurred when soils were frozen.
Tillage-Residue Effects on Runoff and Erosion

Palouse Conservation Field Station — Two STEEP research projects compare tillage and surface residue effects on runoff and erosion under different crop rotations. One of the research sites is located at the Palouse Conservation Field Station near Pullman (Fig. 9), where surface runoff and soil erosion have been monitored under different winter wheat rotations and tillage systems from November through March since 1978 (D.K. McCool, unpublished data). The plots are 12 feet wide and 73 feet long, located on a 20 to 25 percent slope.

Crop rotations and tillage systems include: (1) winter wheat after summer fallow under conventional tillage; (2) winter wheat after cereals under reduced tillage and no-till; (3) winter wheat after spring pea under reduced tillage and no-till, and (4) rough-tilled cereal stubble, to be planted to peas in the spring.

Table 1 summarizes the runoff and soil erosion comparisons from 1978 through 1985. Winter wheat planted on conventional summer fallow, with only 10 percent surface residue cover on the soil, lost an average of 2.9 inches of water in surface runoff and 8.5 tons per acre of soil. Where winter wheat was seeded after cereals, average surface residue cover was 35 percent under reduced tillage and 96 percent under no-till. Runoff from winter wheat after cereals with less than 1 inch under both reduced tillage and no-till. This was less than 30 percent of the runoff under winter wheat on conventional summer fallow. Soil loss averaged 0.4 ton per acre under reduced tillage and 0.1 ton per acre under no-till. This is almost 95 and 99 percent reduction from winter wheat on conventionally tilled fallow. Runoff from winter wheat after cereals with less than 1 inch under both reduced tillage and no-till. This was less than 30 percent of the runoff under winter wheat on conventional summer fallow. Soil loss averaged 0.4 ton per acre under reduced tillage and 0.1 ton per acre under no-till. This is almost 95 and 99 percent reduction from winter wheat on conventionally tilled fallow. This clearly illustrates just how effective surface residue can be in reducing runoff and erosion. The rougher soil surface under reduced tillage is also an important factor.

Where winter wheat was seeded after spring pea, surface residue averaged 30 percent under reduced tillage and 50 percent under no-till. Runoff was slightly higher than from winter wheat after cereals. This is because spring pea produces little residue (500 to 1,500 pounds per acre), barely enough for adequate soil cover without any tillage. Even with this low amount of residue, soil loss was reduced to less than 0.7 ton per acre with these conservation tillage practices.

For comparison, the last entry in Table 1 is from rough tilled wheat stubble for planting to peas in the spring. This is the average of three plots each year consisting of a standard chisel, soil saver chisel and moldboard plow (with furrows turned uphill). The high residue level and rough soil surface were very effective in reducing runoff and erosion over the winter.

Frozen soil has been a significant factor in runoff-erosion events on the plots. From 60 to 90 percent of the plot runoff and erosion occurred on frozen soils each year during the 7-year monitoring period. In one runoff event after a particularly severe frost period where the soil had frozen to depths of 8 to 10 inches, McCool measured 4-inch average runoff from no-till, rough-tilled and reduced tillage plots compared to 5-inch average for conventionally seeded winter wheat on fallow plots. More importantly, erosion averaged 0.1 ton per acre from no-till seeded and rough-tilled stubble plots and 1.9 tons per acre from reduced tillage seeded, compared to 10 tons per acre for conventional winter wheat on fallow.

With frost depths less than 4 inches or with no frozen soil, runoff and erosion were much less under all management systems. However, runoff and erosion rates were still significantly lower under no-till and reduced tillage treatments compared to conventional winter wheat on fallow.

Table 1. Runoff and soil erosion from November through March under winter wheat with different crop rotations and tillage systems, 1978-85, Palouse Conservation Field Station, Pullman, WA.

<table>
<thead>
<tr>
<th>Previous crop</th>
<th>Tillage</th>
<th>Residue cover (%)</th>
<th>Runoff (in)</th>
<th>Soil erosion (T/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>Conventional</td>
<td>10</td>
<td>2.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Cereals</td>
<td>Reduced</td>
<td>35</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Cereals</td>
<td>No-till</td>
<td>96</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Spring pea</td>
<td>Reduced</td>
<td>30</td>
<td>1.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Spring pea</td>
<td>No-till</td>
<td>51</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>(Rough-tilled stubble)</td>
<td>52</td>
<td>0.6</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

*60 to 90% of soil loss occurred on frozen soil

1 Data recorded by D. K. McCool, USDA-ARS, Pullman, WA.
STEEP Tillage-Rotation Plots — Another runoff/erosion monitoring site has been the STEEP tillage-rotation research plots near Moscow. Runoff and soil loss were monitored on winter wheat under no-till, minimum tillage and conventional tillage after spring pea during the winter months from December through March (Dowding et al., 1984). The research area faces south and has an average slope of 20 percent. Plots are 28 feet by 50 feet.

Runoff from winter wheat after spring pea, 1979-1984 (Average December-March precip: 9.2 inches)

<table>
<thead>
<tr>
<th>Tillage System</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>No-Till</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>

Percent of December-March precipitation as runoff

Fig. 10. Surface runoff under winter wheat after spring pea, December-March, 1979-84, STEEP Tillage-Rotation Plots, Moscow, ID (Dowding et al., 1984).

Soil erosion from winter wheat after spring pea

<table>
<thead>
<tr>
<th>Tillage System</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-Till</td>
<td></td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent of soil erosion under conventional tillage

Fig. 11. Soil erosion under winter wheat after spring pea, December-March, 1979-84, STEEP Tillage-Rotation Research Plots, Moscow, ID (Dowding et al., 1984).

The conventional tillage treatment consisted of a moldboard plow, disc and harrow sequence followed by seeding with a double disk drill. The minimum tillage treatment used the University of Idaho "Chisel Planter" (Peterson et al., 1979), which is a modified chisel plow that tills, bands fertilizer and places the seed in one operation. A John Deere Power-Till drill was used for the no-till treatment until 1983. Since then, a plot-size Yielder drill has been used for the no-till system.

Winter surface runoff from winter wheat after spring pea from 1979 through 1984 is summarized in Fig. 10. Precipitation during the December through March monitoring periods averaged 9.2 inches. Under conventional tillage, an average of 21 percent (nearly 2 inches) of the winter precipitation was measured as runoff, compared to 7 percent for minimum tillage and 6 percent for no-till.

Surface residues under conservation tillage systems were even more effective in reducing soil erosion. Fig. 11 illustrates the winter soil erosion under minimum tillage and no-till as a percent of soil erosion under conventional tillage. Soil loss under minimum tillage was 7 percent of that under conventional tillage. No-till reduced soil loss to 10 percent of that under conventional tillage. This is a 90 to 93 percent reduction in soil erosion through the use of these conservation tillage practices. Soil loss under conventional tillage ranged from 0.5 to 7 tons per acre with an average of 3.5 tons per acre. These soil loss rates are lower than typical field loss rates because of the short plot length (50 feet). This research illustrates that even the small amount of residue from a spring pea crop can significantly reduce runoff and soil erosion when most of it remains on the surface with minimum tillage and no-till.

Runoff on frozen soil was a major factor in the soil erosion losses. During the five years of monitoring, more than 90 percent of the total soil loss each winter season occurred during one runoff event on frozen soils. This typically occurred with the first warm rainfall which came when soils were frozen to a depth of 1.5 inches or more and surface soils were beginning to thaw. This was either with or without snow cover.
Literature Cited


The Crop Management Series on no-till and minimum tillage farming includes two other publications. You may order the following from your Extension County Office.

PNW 283 Fertilizer Band Location for Cereal Root Access 50 cents
PNW 297 Uniform Combine Residue Distribution for Successful No-Till and Minimum Tillage Systems 50 cents

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