Voluntary Clean Water Guidance for Agriculture Chapters

A phased approach is being used to develop these guidelines. During the first phase an overview of the guidance was produced along with its initial chapter which examines tillage and residue management practices. Additional chapters not completed though anticipated for inclusion in the overall guidance are listed below. These chapters will be completed in the following several years. Producers who are interested water quality guidance related to practices not yet addressed can contact Ecology's Agriculture and **Water Quality Planner Ron Cummings at ron.cummings@ecy.wa.gov or (360) 407-6600.**

Chapter 1 Cropping Methods: Tillage & Residue Management-Completed (December 2022)

Chapter 2 Cropping Methods: Crop System-***In development***

Chapter 3 Nutrient Management-***In development***

Chapter 4 Pesticide Management-***In development***

Chapter 5 Sediment Control: Soil Stabilization & Sediment Capture (Vegetative)-***In development***

Chapter 6 Sediment Control: Soil Stabilization & Sediment Capture (Structural)-Completed (December 2022)

Chapter 7 Water Management: Irrigation Systems & Management-***In development***

Chapter 8 Water Management: Field Drainage & Drain Tile Management-***In development***

Chapter 9 Water Management-Stormwater Control & Diversion-***In development***

Chapter 10 Livestock Management-Pasture & Rangeland Grazing-Completed (December 2022)

Chapter 11 Livestock Management-Animal Confinement, Manure Handling & Storage-***In development***

Chapter 12 Riparian Areas & Surface Water Protection-Completed (December 2022)

Chapter 13 Suites of Recommended Practices-***In development***

This report is available on the Department of Ecology's website at https://apps.ecology.wa.gov/publications/SummaryPages/2010008.html

Chapter 1

Cropping Methods: Tillage & Residue Management

Voluntary Clean Water Guidance for Agriculture

Prepared by:
Washington State Department of Ecology
Water Quality Program

December 2022
Publication Number 20-10-008a

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Acronyms

Acronym	Definition
BMPs	Best Management Practices
CD	Conservation District
CT	Conservation tillage
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FOTGs	Field Office Technical Guides
MT	Mulch tillage
NPS	Nonpoint Source Pollution
NRCS	Natural Resources Conservation Service
NT	No tillage
PNDSA	Pacific Northwest Direct Seed Association
RUSLE2	Revised Universal Soil Loss Equation, Version 2
SOC	Soil organic carbon
STIR	Soil tillage intensity rating
T-Factor	Soil loss tolerance factor
TMDL	Total Maximum Daily Load
WEPS	Wind Erosion Prediction System
WSDA	Washington State Department of Agriculture
WSU	Washington State University

Table of Units

Abbreviation	Meaning
Kg/M^3	Kilogram per cubic meter
Mg/ha	Mega-gram (10^6 grams) per hectare. (A mega-gram is equivalent to a metric ton.)
Mg/ha-yr	Mega-gram (10^6 grams) per hectare per year
mm/yr	Millimeter per year

Recommendations for Tillage and Residue Management

The Voluntary Clean Water Guidance introduction[1] provides overall goals and objectives, as well as information on how the guidance will be used. Readers are encouraged to read the Introduction before this chapter.

Introduction

This chapter describes tillage and residue management practices that support healthy farms and help producers meet clean water standards. It is intended as a technical resource for the agricultural community and to complement existing guidance on agricultural conservation practices, such as the Natural Resources Conservation Service's (NRCS) Field Office Technical Guides (FOTGs). It does not replace the FOTGs or the farm planning process and does not establish new regulatory requirements. However, this guidance should be considered when identifying tillage practices intended to protect water quality and support meeting Washington State water quality standards. Ecology will use this guidance to help make funding decisions for grant programs, to inform watershed cleanup plans, and to provide technical assistance, education, and outreach.

Importantly, this guidance does not prescribe a single approach or set of practices for all farms. Ecology recognizes that recommended tillage and residue management practices may not be applicable or desirable for all production operations. Ecology also recognizes that for most

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[1] https://apps.ecology.wa.gov/publications/documents/2010008.pdf

operations multiple conservation practices will be implemented as part of the farm planning process to meet conservation goals. Separate chapters of this guidance evaluate other practices including cover cropping, filter strips, buffers, and other practices through the lens of water quality and identify those that best support meeting water quality standards. Chapter 13 when completed will describe several common agriculture operations, and the suites of practices that Ecology recommends to protect water quality.

Definitions as Used in this Document

Tillage is the manipulation of soil with the purpose of preparing a seedbed, managing post-harvest crop organic material (residue), incorporating amendments such as fertilizers, weed control, and removing compaction. Tillage can be divided into conventional and conservation-based systems.

Conservation tillage includes a spectrum of practices such as no-till, strip-till, direct seed, ridge till and mulch till that minimize surface soil disturbance while retaining surface crop residue to control erosion. It is often defined by the retention of at least 30% residue cover of the soil surface at the time of planting. The Natural Resources Conservation Service (NRCS) uses the soil tillage intensity rating (STIR) value to provide a relative indication of tillage-based soil disturbance. To calculate the STIR value NRCS utilizes the speed, depth, surface disturbance percent and tillage type parameters to calculate a tillage intensity rating for the system used in growing a crop or rotation. STIR ratings show the differences in the degree of soil disturbance among tillage practices. Lower numbers indicate less overall soil disturbance. NRCS has two conservation tillage practice standards:

- **Residue and Tillage Management, No-Till (329)-STIR <20; and**
- **Residue and Tillage Management, Reduced Till (345)-STIR <80.**

Conventional tillage includes more intensive tillage methods such as the use of a moldboard plow and is characterized by full field soil inversion with STIR values typically greater than 80 and the majority of crop-related residue buried in the process.

In Washington State no-till, strip-till, direct seed, reduced tillage (ridge till and mulch till), and conventional tillage are all commonly used. These systems can be considered on a scale of tillage intensity and percent of soil disturbed, with no-till having the lowest tillage intensity and lowest soil disturbance and conventional tillage having the highest tillage intensity and highest soil disturbance. In no-till systems, producers plant directly into crop residue that has not been tilled. Planting is completed using a no-till hoe or disk drill. In strip-till, the soil is tilled and crop residue is removed from narrow strips where the crop is to be planted. The residue-covered area between the strips is left undisturbed. In direct seed, there is no full width tillage and fertilizing and planting is generally accomplished in two to three passes of tillage implements across fields. In ridge till, planting is completed in a seedbed prepared on ridges, with furrows protected by crop residue in between the ridges. In mulch till, tillage is completed with chisels, field cultivators, sweeps, or blades. Table 1 presents a relative comparison of these tillage approaches in terms of intensity and residue generation.

Table 1 Comparison of common tillage practices

Practice	Number of Passes *	STIR Value**	Tillage Intensity	Level of Residual Residue Maintained***
No-Till	1-2	<20	Low	High
Strip-Till	1-2	<20	Moderate-low	Moderate-High
Direct Seed	2-3	≤30	Moderate-low	Moderate
Ridge Till	3-5	<80	Moderate	Low-Moderate
Mulch Till	3-5	<80	Moderate	Low-Moderate
Conventional Tillage	5-10	>80	High	Low

* Generally associated with the tillage practice.

**STIR is an NRCS metric indicating the level of soil disturbance. Values for no-till, strip-till, ridge till and mulch till were taken from NRCS FOTG standards 329 and 345.

**Crop residue coverage is dependent on the crop type and can be highly variable. These are relative amounts of residue maintained after planting independent of previous crop.

Use of Conservation-Based Tillage Practices to Protect Water Quality

From a water quality perspective the primary aim of conservation-based tillage and residue management is to reduce erosion by minimizing soil disturbance and maximizing the retention of crop residue on the soil surface. Collectively, tillage and residue management practices are considered source control practices because they can significantly reduce wind and water-generated erosion from occurring. In addition, surface crop residue, along with subsurface root structures, provides fundamental organic material to maintain and build soil organic matter.

The impacts of soil erosion to aquatic resources can be significant. Sediment, and attached nutrients and toxicants, adversely impact the physical habitat and the chemical and biological attributes of receiving waters. Tillage and residue management practices that minimize erosion address the following pollutants: sediment, nutrients, pathogens, and pesticides (toxicants).

Erosion is influenced by multiple factors including rainfall intensity and duration, soil texture, field topography, tillage methods, and soil vegetative cover. Many of these factors cannot be controlled. However, producers can significantly decrease erosion from their fields through conservation tillage methods and residue management.

When tillage and residue management practices are being used to protect water quality, producers should try to:

- Minimize soil loss from fields; and
- Maximize the retention and enhancement of soil organic matter.

As further discussed in the Chapter 1 Appendix Part A, conservation tillage and residue management practices provide benefits to soil health in addition to their pollution control benefits.

Minimizing soil disturbances helps preserve beneficial soil structure. Increased soil organic matter results in greater soil aggregation and soil porosity, which results in higher water infiltration rates reducing runoff and reducing the risk of erosion. The stabilization and enhancement of soil organic matter also provides additional chemical, physical, and biological benefits from both crop productivity and erosion control perspectives. Other benefits include increased nutrient availability and utilization, enhanced resistance to pH change, and enhanced microbial diversity, aiding the suppression of disease and pests.

Recommendations

The purpose of this guidance is to help producers understand what tillage and residue management practices are most effective at protecting water quality.

Tillage and residue management practices will have a place in producers' efforts to protect water quality in many places, especially dryland or low irrigation agriculture and high-residue crops. Tillage and residue management are likely less applicable for operations that produce root crops and other low-residue crops (e.g., row vegetables), or for some operations that are situated in areas of wet, slow draining soil, or flood prone areas. For these types of crops and areas, other practices may be more applicable to protect water quality.

Primary Recommendations for Tillage and Residue Management

Ecology's guidance for using tillage and residue management to address water quality concerns is based on two general crop groupings: high and low levels of post-harvest residue production. For higher residue crops, a minimum residue coverage target (or alternatively a maximum STIR) is recommended to protect water quality. For low residue crops, producers should try to minimize tillage while maximizing the production of residue within the overall rotation.

Additionally, supplementing residue with cover crops or using alternative practices that can trap sediment may be necessary to protect water quality. It is recognized that not all crops generate the level of residue recommended to provide water quality protection.

For both groups, it is impossible to completely prevent all erosion and surface water runoff solely using tillage and residue management practices. Ecology anticipates that, where selected by producers for implementation, tillage and residue management practices will be implemented along with other practices appropriate to the operation to fully address operation-specific water quality concerns (i.e., nutrients, pathogens, pesticides, sediment, and temperature).

Higher Residue & Perennial Crops

Representative crops include: short grains and cereals (e.g., winter and spring wheat, barley, and corn) and forage crops (e.g., hay, alfalfa).

For high residue and perennial crops, to protect water quality, a conservation-based tillage system should achieve:

- A **residue coverage of 60% or more**. The residue coverage expectation is based on the minimum residue coverage observed from harvest through the next planting; or
- **A STIR of 30 or less** based on NRCS guidance and calculation tools. (In some areas of the state higher residue crops, because of site specific factors (e.g. soils, annual rainfall, etc.), cannot achieve the recommended residue levels. In those cases, producers should utilize conservation tillage systems that meet the STIR recommendation).

(The underlying analysis used to determine these guidance metrics is provided in Chapter 1 Appendix Part A.)

Residue coverage of 60% can provide an effective erosion protection of approximately 90% as compared to conventional tillage. In general, while a wider variety of tillage options are available to producers who grow higher residue crops, this residue level is best achieved through no-till or direct seed tillage systems. Both systems minimize tillage and provide a higher retention of surface residues, while protecting surface soils, thereby fostering the building of soil organic matter. Depending on site specific factors this recommendation can also be achieved with other conservation-based tillage systems (e.g., mulch till).

Lower Residue Crops

Representative crops include: potatoes, onions, peas, beans and lentils.

The tillage practices commonly used for vegetable row crops tend to require higher soil disturbance. The combination of high soil disturbance and low residue, characteristic of the production of these crops, impacts soil organic matter retention and soil structure increasing the susceptibility to erosion.

The use of conservation tillage systems may not be applicable for some vegetable row crops (or other) operations either because of the growing requirements of the type of crop (e.g., root crops) or the climate and site setting (e.g., wet or slow draining areas). While conservation tillage practices such as strip-tillage are viable for some vegetable row crop production, and have been used effectively for onion production in Washington, they are not commonly used and may not be applicable for other crops. Other low residue crops may have a wider range of tillage options available including no-till and direct seed systems.

Because conservation tillage may not be possible or the best option for some low residue crops, producers of these crops might choose to use different practices (e.g., filter strips, cover cropping) to address water quality concerns. For producers of low residue crops who choose to use conservation tillage practices, to protect water quality, a conservation-based tillage system should:

- **Achieve a STIR of 30 or less** based on NRCS guidance and calculation tools if a 30 STIR is achievable for the type of crop grown (There are many vegetable row crops, e.g., root crops, where achieving a STIR level below 30 is not possible given the planting and harvest methods required for those crops); or

- **Minimize tillage to the maximum extent possible and supplement residue cover to achieve 60 percent soil coverage.** Producers can increase soil cover at critical times by planting in-row cover, planting post-harvest cover crops, double cropping, and/or through crop rotation planning; and
- **Use supporting sediment trapping BMPs** to protect water quality from erosion in cases where it cannot be controlled in the field. For example, sediment trapping BMPs, which will be addressed in Chapter 5.

Additional Guidance and Technical Assistance Support

These secondary recommendations are provided to help ensure that the primary recommended BMPs are effective in protecting water quality.

Residue Management:

- Residue should be spread evenly and stubble and root structures retained (as appropriate to the crop type).
- Management of residue should not include burning.
- If post-harvest residue is harvested for other purposes, removal should not exceed levels required to maintain 60 percent residue cover after planting.
- Crop rotation planning should factor in the levels of post-harvest residue produced and maintained.
- Avoid fall tillage except to plant a double or fall crop or when establishing a cover crop.

Soil Organic Matter and Soil Structure - Retention and Promotion:

- Maximize living plant cover to sustain Mycorrhizal fungi and other beneficial soil organisms.

Technical Assistance and Farm Planning

Producers are encouraged to consult with the regional NRCS or local conservation district (CD) office for technical assistance specific to a farm’s operation. NRCS and conservation districts can provide assistance regarding conservation tillage options as well as cropping alternatives for a particular operation given its setting and site-specific factors. They can also assist in calculating STIR values and estimating the generation and retention of residue throughout the rotation. Financial assistance may also be available to help transition to conservation-based tillage and residue management practices that can meet this guidance’s recommendations. Producers are also encouraged to contact Ecology with questions regarding this guidance.

Information on how to find your local CD is available from the State Conservation Commission.[2]

You can find your local NRCS field office here.[3]

Related NRCS Practices

Residue and Tillage Management, No-Till (329)

Residue and Tillage Management, Reduced Till (345)

Commonly Associated Practices

Effective water quality protection and compliance with water quality standards requires a combination or system of practices to fully address all concerns. Common practices that complement tillage and residue management include those that trap sediment that leaves the field, filter pollutants, and protect sensitive areas. These practices are listed below.

Sediment Control Practices - Vegetative (alternative field cover practice option)

- Cover crop

Sediment Control – Vegetative (additional practices to trap or contain sediment from erosion)

- Field border
- Filter strip
- Grassed waterway
- Vegetative barrier
- Vegetated treatment area
- Field windbreak

Crop Systems (additional practices to reduce transport within the field)

- Contour farming
- Alley cropping
- Conservation crop rotation
- Strip cropping
- Contour buffer strips

Sediment Control – Structural (additional practices to trap or contain erosion)

- Sediment basins

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[2] https://scc.wa.gov/conservation-district-map/

[3] https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/washington

- Water and sediment control basin

Irrigation Systems & Management (prevent erosion)

- Irrigation systems and management

Riparian Areas & Surface Water Protection (address temperature)

- Riparian area protection

Chapter 1 Appendix Part A: Effectiveness Synthesis (Tillage and Residue Management)

This section examines how various tillage practices differ in terms of their overall effect on erosion and soil health. The intent is to provide information on which practices are more protective from a water quality perspective, and to describe how Ecology arrived at the tillage and residue management practices recommended in this guidance.

Conventional tillage practices result in high soil disturbance with little retention of surface crop residues decreasing water infiltration and increasing surface runoff, elevating erosion rates. The loss of soil through erosion can have significant impacts to aquatic resources in receiving waters. Sediment fills the interstices of stream gravels, which is critical habitat on an ecosystem level, from primary production to fish spawning (Tarzwell, 1953). Habitat, along with the organisms it supports, once lost is difficult to restore. Sediment also serves as a vector for nutrient and pesticide transport, further compounding off-site environmental impacts.

Tillage and residue management practices that minimize erosion can address the following pollutants:

Table 2 Common pollutants addressed by recommended practices

Pollutant	Addressed by Recommended Practices
Sediment	✓
Nutrients	✓
Pathogens	✓
Temperature	
Pesticides (Toxicants)	✓

This analysis will focus on how varying levels of residue cover, a surrogate for tillage practices, affects erosion rates and the retention of soil organic matter.

Erosion

Erosion is defined as the displacement or loss of soil from a field to an off-site location through wind or water forces. Erosion rates are dependent on soil characteristics, exposure (vegetative cover), slope, and the magnitude, intensity, and duration of precipitation and wind. Of these factors, the exposure of soil is a major determinant in the relative rates of erosion for a given crop and location. For this reason, tillage intensity and the resulting level of residue cover are critical factors in evaluating the soil vulnerability to erosion, especially during the harvest-to-planting period. Residue shields the soil surface from direct impact of precipitation that can result in particle detachment and the initiation of sheet erosion. Residue coverage also increases the surface complexity and surface flow pathways, which reduce surface runoff concentration, facilitating its infiltration.

The Natural Resources Conservation Service's (NRCS) Revised Universal Soil Loss Equation (RUSLE2) model is commonly applied to estimate water-generated sheet and rill erosion while wind-generated erosion is estimated with the Wind Erosion Prediction System (WEPS). These estimations can assist in understanding the soil loss tolerance factor (T) which serves as a goal for conservation planning. The T factor is a reference condition of the maximum average annual rate of erosion in agricultural lands, applied by the NRCS. It tends to range between 1-5 tons/acre-year (2.2-11.2 Mg/ha-yr) andis not set based on off-site environmental impacts ratherit is set based on the maximum rate of annual soil loss that will permit crop productivity to be sustained economically and indefinitely for a given soil. This soil loss can occur from either wind- or water-generated forces, but in the evaluation of T, the sources are considered separately. Assuming a soil bulk density of 1,200 kg/m3, a soil loss of 2.2-11.2 Mg/ha-yr (1-5 t/ac-yr) equates to a soil depth of 0.2 to 0.9 mm per year.

Within croplands, the replacement of soil lost to erosion comes primarily from crop-related organic decomposition (and amendments). Based on a global assessment of erosion and soil production rates, median rates of soil production are estimated at 0.017 mm/yr, an order of magnitude lower than the lower range of T (Montgomery, 2007).

Median erosion rates associated with conventional-type agricultural practices are estimated at

1.5 mm/yr, two orders of magnitude greater than soil production estimates. In comparison, median erosion rates associated with conservation-based practices - while 95% lower at 0.08 mm/yr, in comparison to conventional practices - are still about five times greater than the estimated rate of soil production. These differences underscore the importance of minimizing erosion.

Not only does erosion typically exceed replacement, but it disproportionately removes soil from the uppermost productive (organic) portion of the soil horizon. As will be discussed, soil organic matter levels are difficult to maintain and slow to build even under high residue conservation-based cropping systems.

Residue Coverage and the Rate of Water-Generated Erosion

There tend to be two study approaches used when examining the relationship between tillage and associated residue management practices and their combined effect on water-generated erosion. The most common approach applies simulated rainfall, controlling for its intensity and duration, soil type, area, length, and slope while varying tillage type and (or) residue coverage levels. The other variation is to examine actual runoff from fields under natural rainfall conditions while quantifying relevant variables. The first approach allows for a tighter parameter control and generates more significant types of relationships; whereas the latter approach, due to varying levels of rainfall intensity and duration, tends to have increased variability.

For instance, under natural conditions, a few rainfall events of high intensity could generate the majority of annual erosion. There are benefits and drawbacks in applying either study approaches. Given these varying approaches and widely disparate study settings, when examined collectively, the common comparative metric is the percent reduction in erosion from a baseline bare soil condition (representing conventional tillage practices) to that derived by varying tillage and (or) the residue level (represented as percent cover or dry weight biomass). The relative percent reduction in erosion serves as the dependent variable, whereas independent variables are percent residue cover and residue dry weight yield.

Figures 2 and 3 present a compilation of data from several studies that examined the relationship between soil residue cover, on a percent and dry weight biomass basis, and its effect on controlling runoff generated erosion. A three-point moving average was applied to these data to characterize their relationships graphically. (More information on these cited studies are included at the end of this section.)

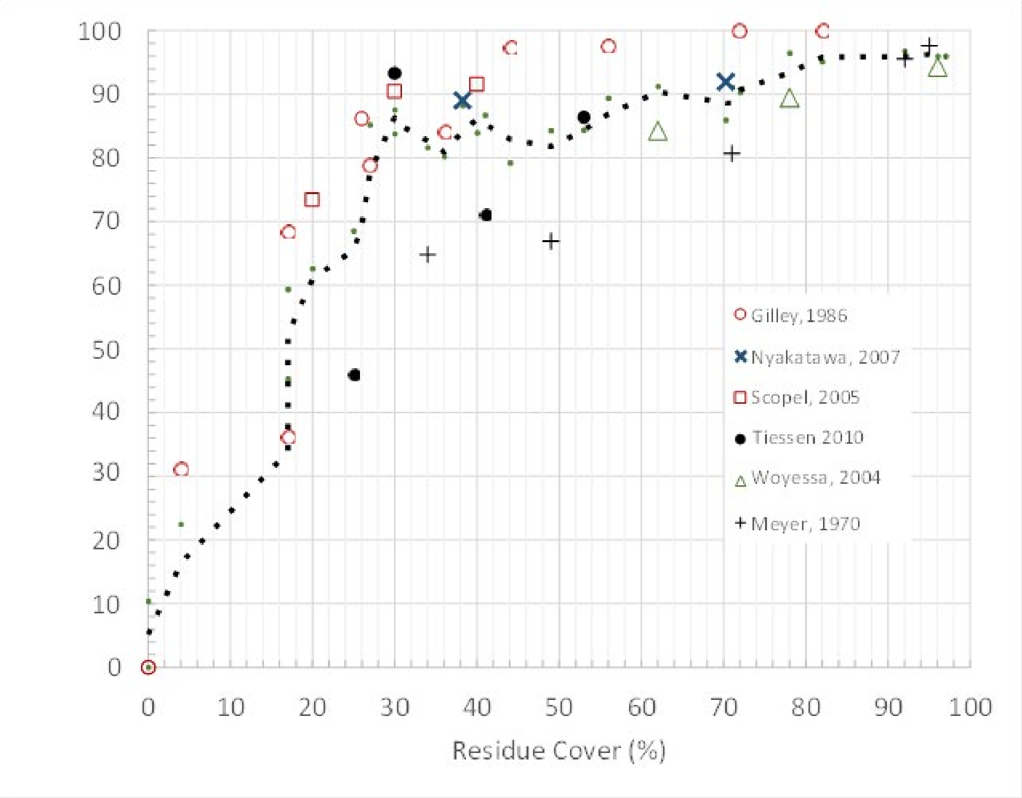

Figure 1 Relationship between surface residue cover and its effect on the relative level of erosion control

In both Figures 1 and 2, there is a positive relationship between the level of residue (expressed as either percent cover or biomass) and the level of erosion control. Greater residue cover results in greater erosion control. As previously discussed, conservation tillage is typically defined by a 30% minimum post-harvest-to-planting, surface residue cover level. From Figure 1, a 30% surface residue cover results in a relative erosion control level of about 80%. Above 30%, increasing levels of residue bring smaller increases in erosion control (a flattening slope of diminishing returns). Coverage levels below 30% bring a steep decline in erosion control.

Because these relationships are based on a relative level of erosion control, context is important. Potentially, even with an 80% control level, if the actual bare soil erosion yield was, for instance, 14 tons per acre per year (t/ac-yr) (a level not uncommon to the Palouse dryland wheat region in Washington), the estimated sediment loss would still be in the upper end of typical levels of T, the soil loss tolerance factor. An overall reduction level of 93% is required to achieve the typical low end of T at 1 t/ac-yr, which likely could be achieved only through low soil tillage disturbance with high crop associated residue production (i.e., no-till).

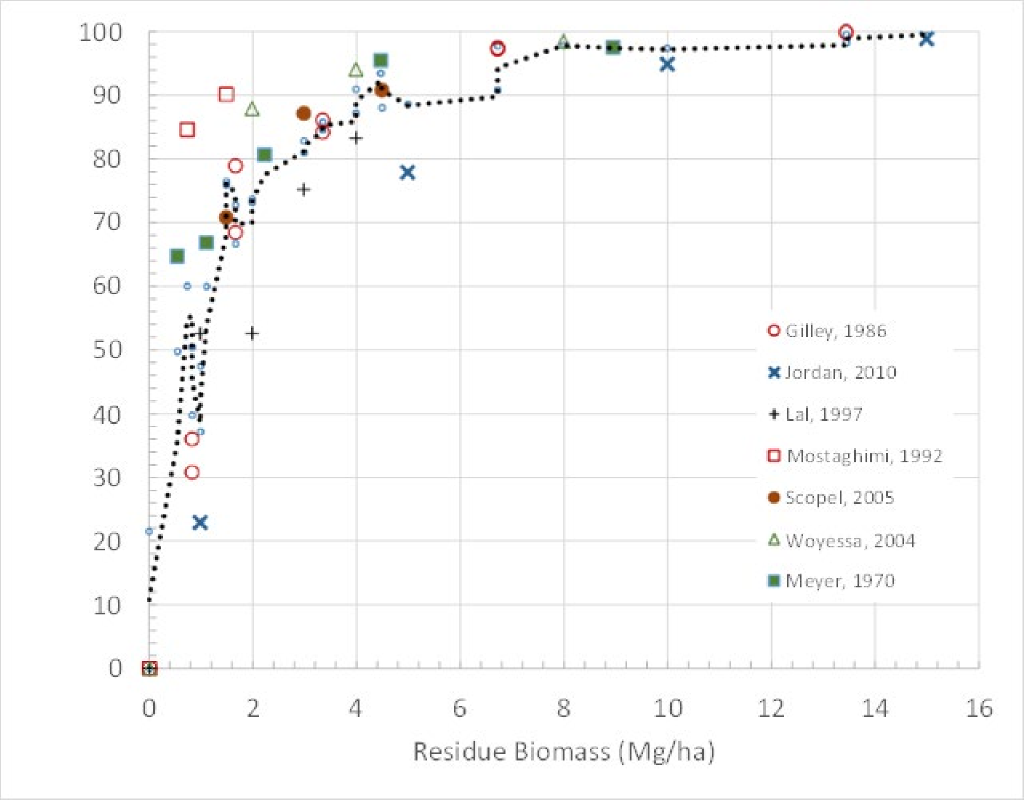

Figure 2 The relationship between surface residue biomass and its effect on the relative level of erosion control

Soil Organic Matter

Soil organic matter is a complex of heavily decomposed plant and micro-organism tissue most prominent within the upper few centimeters of the soil horizon, typically representing 1-6% of the composition of the upper soil layer. It provides a steady supply of nutrients to crops and serves as an important indicator of many beneficial soil quality outcomes, all of which are dependent on maintaining a diverse soil microbial ecosystem. Tillage practices can significantly affect soil organic matter.

Residue management directed toward maintaining soil organic matter improves both soil structure and crop vitality. Within croplands, both surface and subsurface residues (roots) serve as primary sources of energy and nutrients that facilitate microbial cellular growth and stabilize soil organic matter content. Indicators of improved structure are reduced compaction and increased moisture retention and infiltration. Additionally, soil organic matter serves as a source of nutrients, enhances cation exchange capacity, and provides a more diversified microbial soil population, which reduces the dominance of pathogenic forms.

The microbial population, its diversity and relative size, is expressed based on the level of residue availability, its placement within the soil matrix, and its state of decomposition.

Therefore, a key factor for facilitating a diverse soil microbial population is maintaining a steady supply of surface organic residues while maintaining living plant root systems. Residue quality, typically described in terms of carbon to nitrogen levels, is an additional controlling factor (accounting for site specific soil characteristics and climatic conditions).

Higher surface soil disturbance adversely effects soil organic matter formation in several ways. It affects the diversity of soil microbial assemblages through direct habitat and physical impacts, particularly for longer-lived forms of mycorrhizal fungi. (Mycorrhizal fungi have a critical role in soil macro-aggregate formation, the foundation of soil structure (Hoorman, 2009). The maintenance of soil structure is a critical component to stabilizing soil organic matter. Higher disturbance leads to higher levels of residue burial, increasing both decomposition rates and carbon loss. Slower rates of organic decomposition lead to more diverse and stable microbial populations and the maintenance (and potentially the increase) of soil organic matter levels.

Effects of Tillage on Soil Organic Matter

Tillage disrupts the complex interaction between fungi, bacteria, worms, and crop (surface plant) root systems. Lower tillage-related soil disturbance allows for these complex relationships to develop, enhancing overall soil health.

Tillage Disturbance

There is no natural system process equivalent to the residue burial/decomposition process of conventional tillage/residue management practices. In natural systems, plant residues are deposited to the land surface where decomposition then takes place. Surface-based residue retention, in comparison to burial, has a slower rate of decomposition. Though not fully understood, the rate of decomposition has bearing on the level of soil organic matter retained. (This outcome is likely a result of residue placement and soil disturbance levels.) This has the combined effect of depressing large swings (boom and bust) in bacterial populations while facilitating a greater diversity of other heterotrophic organisms, since each exploits particular niches in the decomposition/soil organic matter generation and retention processes. This is an important factor as to why certain low disturbance tillage practices, such as no-till, tend to have more diversified micro-organism (mycorrhizal fungi) and macro-organism (i.e., earthworm) populations. Of equal importance is that surface retention of residues is associated with lower tillage disturbance practices.

Residue Loading Required to Maintain Soil Organic Matter

There are a variety of factors that influence the level of soil organic matter generated from crop residues including:

- Climatic factors, particularly as they relate to soil temperature and moisture;
- The particular crop’s carbon to nitrogen ratio;

- The quality of the soil for its mineral fractions of silt, clay, and sand (texture);
- Tillage practices and cropping strategies (i.e., maintaining active root structures through cover crops); and
- The existing or reference levels of soil organic matter, the basis of comparison for measuring the effect of changes in management.

While recognizing the importance of these variables, the relationship between the level of residue loading to the land surface and its effect on the average annual increase in soil organic carbon was examined (Figure 3). (Surface residue loading, as biomass, is a more relevant variable for examining soil organic carbon, as opposed to percent cover, a more relevant metric for examining erosion.)

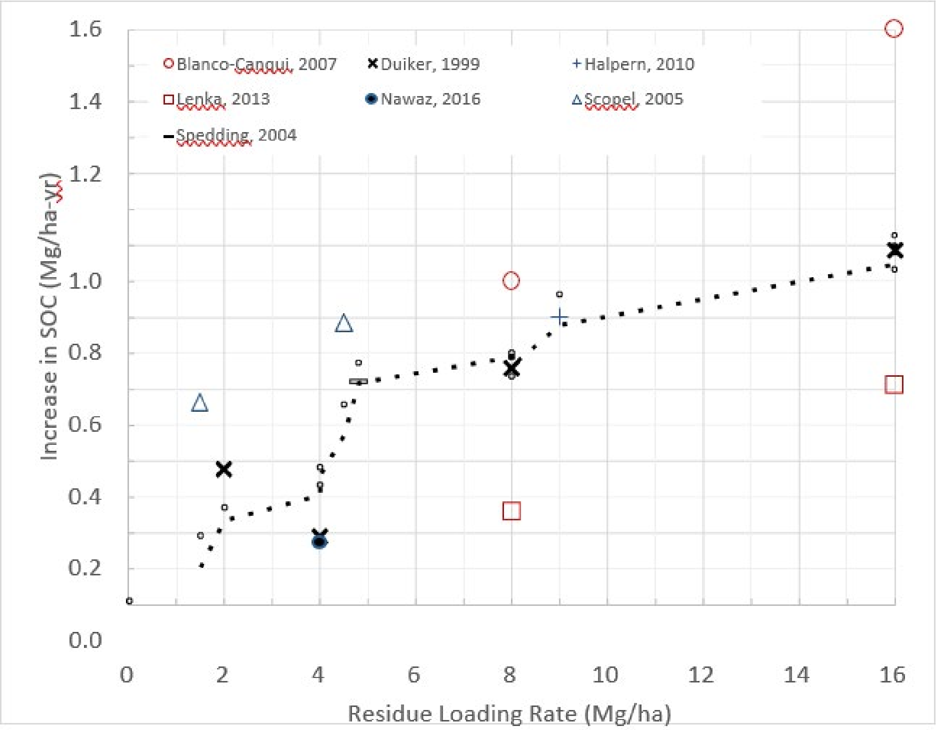

Figure 3 The residue loading rate in relation to the increase in soil organic carbon (SOC) under no-till.

A three-point moving average was applied to these data to characterize their overall relationship. To control for the influence of tillage practices, only data collected under no-till practices was considered.

Referring to Figure 3, while recognizing the high level of data variability, it's evident that only a low level of increase in soil organic carbon (SOC) occurs in relation to residue loading.

The overall median increase in soil organic carbon generated from crop residue is around 0.09 Mg C/ha-yr for each Mg/ha of residue applied. Assuming a typical residue carbon level of around 45% indicates a carbon loss of around 80%, further underscoring that the level of carbon loss is significant and that margins for its storage in soil are low, even under no-till practices.

Among the studies used to generate Figure 3, several also examined the relationship between soil organic carbon and residue loading for conventional-type tillage (Figure 4). The results for no-till and conventional tillage are both included with each individual study depicted by a common symbol. No-till data points have unfilled symbols while those for conventional tillage are filled. A three-point moving average was used to depict each relationship.

For no-till, as expected, increased residue loading results in an increase in soil organic carbon (similar to Figure 3) with an overall median increase of around 0.08 Mg C/ha-yr per Mg/ha of residue applied. However, even with no-till, there is a flattening of this overall relationship. As residue loading increases, there is proportionately less carbon transferred to soil likely due to increased carbon dioxide gas emissions. Carbon transfer efficiency appears to decline with increasing residue loading, likely due to increased biological respiration requirements.

For conventional tillage, the overall median increase is about half that found for no-till at 0.04 Mg C/ha-yr retained in soil per Mg/ha residue applied. However, the overall trend is relatively flat throughout the range in residue loading considered, hovering around 0.2 Mg/ha-yr, which indicates that increased residue loading has little effect on soil organic carbon levels.

Considering these data, the median level of residue carbon retention in soil for no-till and conventional tillage are 16% and 8%, respectively (Figure 5). (Relationships are depicted with logarithmic trend-lines.) Through the range in residue loading considered, carbon retention for no-till reaches a minimum at around 10% (90% carbon loss). In comparison, carbon retention under conventional tillage reaches this minimum at a 70% lower residue loading level.

Presumably, the lower carbon retention associated with conventional tillage is due to increased decomposition rates from residue burial, along with the loss of soil structure. The end result being, for what is already an inefficient process for carbon transfer efficiency, even under optimum conditions and practices, is minimized or negated under conventional tillage.

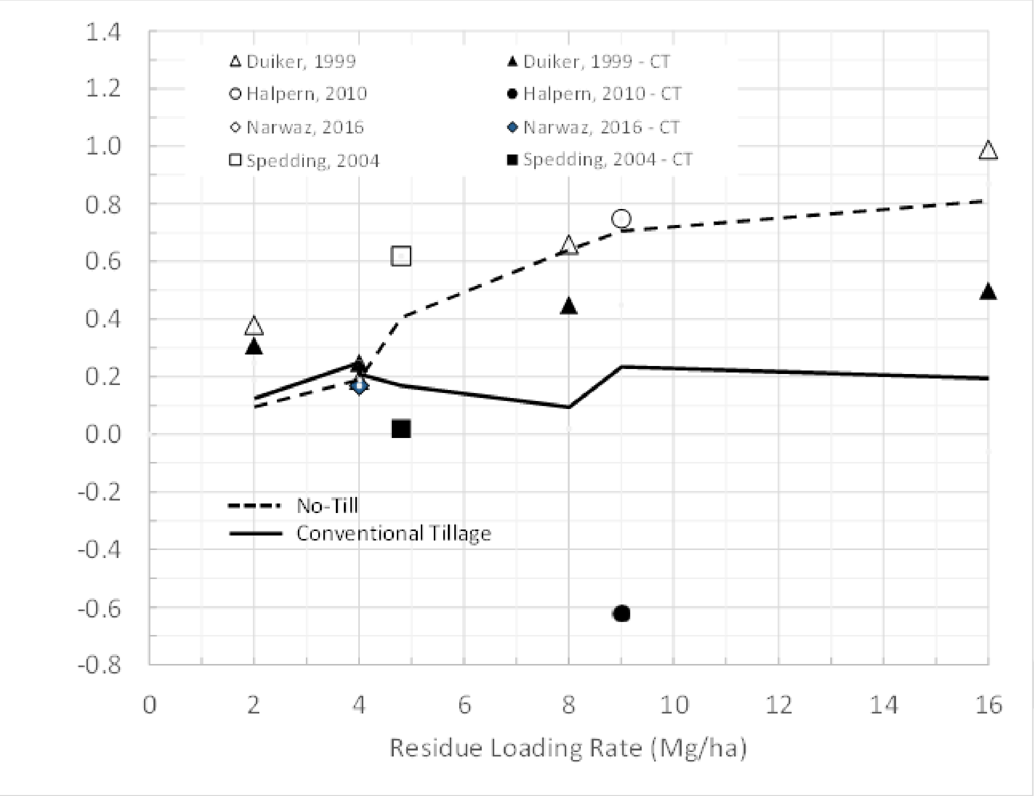

Figure 4 Comparison of the residue loading rate and the increase in soil organic carbon for no-till and conventional tillage.

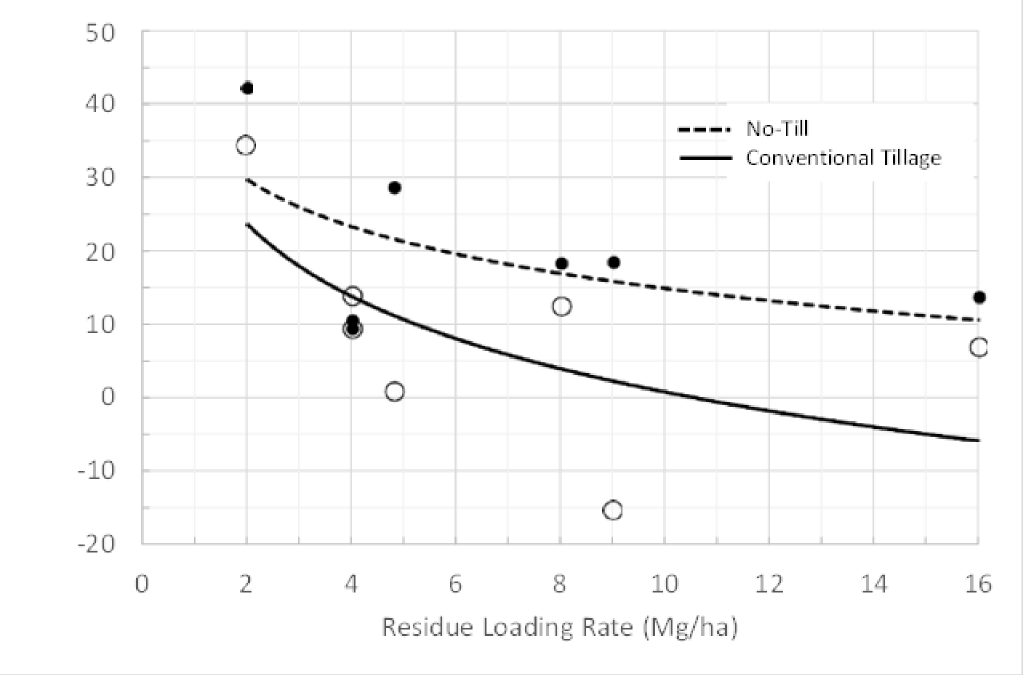

Figure 5 Comparison of the retention of residue carbon in soil for no-till and conventional tillage.

Overview of Cited Studies

Residue Cover Reduces Erosion

As noted previously, numerous studies have found that crop-based residue cover provides effective erosion control. Figure 6 includes data from several of these studies and presents the relationship between the percent reductions in erosion, for varying levels of residue cover, in relation to the soil loss observed had no residue been present. The bare soil condition is synonymous with conventional-types of tillage that often result in complete soil inversion with the majority of post-harvest residue buried. (A synopsis of the relevant metrics from these studies and others included in Figures 1 through 5 are included at this end of the section.)

Within figure 6, two lines display the overall trends of the data: the black-dashed line represents the best-fit relationship of the majority of the cited data, whereas the orange-dashed line represents the best fit relationship for wheat residue and erosion reduction for the dryland regions of the Pacific Northwest (McCool, 1995). When the full suite of data are considered, along with the associated best fit trend lines, it’s apparent that the level of residue coverage of soil has a fairly predictable effect on the relative level of erosion control.

The level of erosion control is based on a relative comparison, which is why these data provide a close relationship despite being collected from often quite different locations, soils, and crop settings. The reference condition is the level of erosion that occurs at the specific study location for a bare soil condition in relation to reductions occurring as a consequence of increased residue cover. While the amount of soil loss found for the bare soil condition varies among these studies, the relative level of its control, as a consequence of increased residue cover, share a similar response.

Overview of Cited Studies

The majority of these studies used a grain-based residue, though varying in type. Crop residue types included: sorghum, soybean, wheat, rye, maize (corn), canola, and barley. The data are also comprised of a combination of simulated, modeled, and actual scenarios. Of the studies that employed simulated rainfall, the events varied from 48 millimeters per hour (mm/hr) to 64 mm/hr (about 2 to 2.5 inches per hour), therefore tend to depict high intensity scenarios. The average slope used in these studies varied between 2 and 15%.

An assessment of soil erosion based on natural rainfall events that compared no-till maize, analyzed at three different residue cover levels, to a conventional disc-plowed maize with minimal cover resulted in a 60% reduction in erosion even at the lowest 20% surface residue level (Scopel, 2005).

Tiessen (2010) used a paired catchment approach to examine differences in generated soil loss between conventional and conservation tillage for a grain-based crop rotation in Manitoba, Canada under natural precipitation and runoff conditions. The study examined, in part, whether residue cover continued to maintain soil protection for a setting where surface runoff is generated by both rainfall and snowmelt. Over the four year study period, soil loss was most prominent for two of the years during periods of snowmelt: one for a rainfall dominated year and another year a combination of the two. In general, residue proved less effective during years of rainfall dominated runoff than snowmelt. However, though slightly lower than the majority of the other data cited, the conservation-tilled approach, even with a relatively low residue cover level of 25%, resulted in a 50% reduction in erosion when compared to the conventional tillage approach.

Nyakatawa (2007) applied the Natural Resources Conservation Service’s RUSLE2 model to estimate soil loss for a conventional and no-till cotton crop with a winter fallow, winter rye cover crop sequence. Data were collected from experimental plots concerning the tillage practices employed, crop sequencing, and meteorological conditions during the four-year study period, serving as model input. Residue levels remained significantly higher for no-till grown cotton during both fallow (>91%) or cover crop periods (>75%) leading to an estimated sediment export reduction of about 90% considering either scenario.

Among the simulated rainfall studies, Meyer (1970) examined the effectiveness of straw mulch on erosion reduction under extreme conditions: slopes of 15% with simulated rainfall events of 6.4 cm/hr (2.5 inches per hour). As a result, these data tend to have a slightly lower level of erosion control for equivalent residue levels in comparison to the other study’s findings. However, even given these extreme settings, these data do not substantially deviate from the overall trend through the full data set considered. For instance, a 34% residue cover still resulted in about a 65% level of control despite the extreme setting. In comparison, the other studies found about an 80% relative erosion control level at similar surface residue levels. In addition to examining soil loss, assessment metrics included in this study were average flow velocities and net infiltration. As is commonly found with these types of studies, decreased erosion was associated with increasing residue cover levels through the protection of soil from the impact of rain drops. In addition, the residue matrix increased flow (runoff) path complexity, decreased the effective land slope and runoff velocity resulting in particle deposition within the residue while allowing for increased water infiltration.

Woyessa (2004) examined the relationship between varying types of tillage and residue levels and its combined effect on soil loss. The tillage types included no-till, mulch till, and conventional tillage with wheat being the residue cover type. The simulated rainfall was delivered at a high intensity rate of 60 mm/hr (2.4 in/hr).

The study approach removed existing residue from the plots for all three types of tillage practices examined and replaced them with similar residue cover levels of 0%, 62%, 76%, and 92%.

On average, considering the results of the tillage practices examined, a residue cover of 70% was recommended to ensure higher rates of infiltration and lower runoff resulting in about a 90% control of soil loss.

Gilley (1986) also employed a simulated rainfall plot-based analysis approach to examine the relationship between varying levels of residue cover and erosion control. The residue used was sorghum and soybean. The effect of each residue type on erosion control was examined separately. The simulated rainfall event used was 48 mm/hr (1.9 in/hr). A similar soil tillage method was applied to each plot with five levels of residue cover applied to them varying between 4% and 82%. Similar to the other studies was the finding that reduced soil loss rates were associated with increased infiltration and that consistent reductions in soil loss resulted from increased levels of residue cover. No net runoff and, therefore, soil loss occurred to residue cover at and above 72% for either residue type.

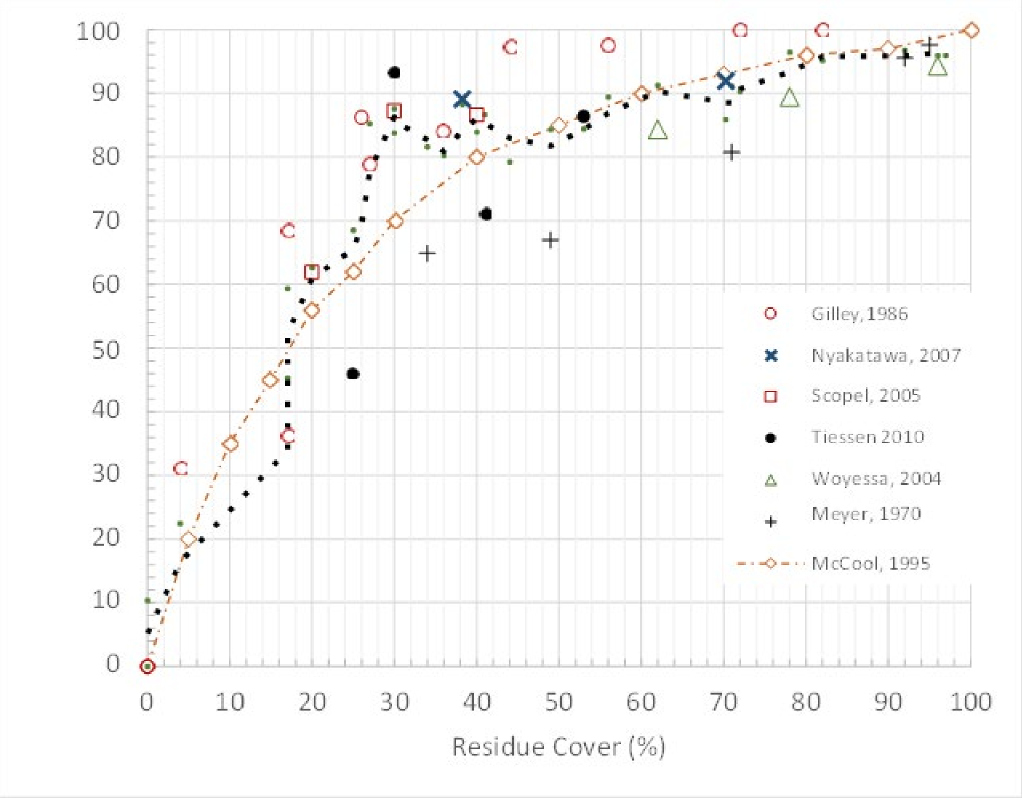

Figure 6 Relationship between surface residue cover and its effect on the relative level of erosion control

Meta-data for Figures 1-5

Table 3 Meta data for Figure 1 (Residue coverage vs relative erosion rate)

Citation	**Study Location**	**Rainfall**	**Tillage Type***	**Residue Type Cover %**	**Soil / Texture**	**Slope**
Gilley, 1986	Lincoln, NE	Simulated, 48 mm/hr + 24hr later	CT	Sorghum, Soybean 0, 11, 22, 31, 50, 77 0, 4, 17, 26, 44, 72	Typic Argiurdolls ===	6.4%
Meyer, 1970	W. Lafayette, IN	Simulated 63.5mm/hr, 1 hr + 2 x 30min 24hr later	Harrow	Wheat 0, 34, 49, 71, 92, 95%	Typic Hapludalf ===	15%
Nyakatawa, 2007	Belle Mina, AL	Simulated (RUSLE2)	NT, CT	Cotton (winter rye cover) 38, 70	Decatur silt loam ===	1.5%
Scopel, 2005	Jalisco, MX	Actual	NT, CT	Maize 0, 20, 30, 40	Dystric Cambisol 61% sand, 15% clay, 25% loam (silt)	3 - 7%
Tiessen, 2010	Manitoba, CA	Actual	CT, NT	Canola, barley, wheat 25, 30, 41, 53	Dark Grey Chernozems ===	===
Woyessa, 2004	SA	Simulated, 60mm/hr	NT, MT, CT	Wheat 0, 62, 76, 92	Bainsvlei Amalia 88% sand, 3.6% silt, 8.4% clay	===

*CT=conventional tillage; NT=no-till; MT=mulch till

Table 4 Meta data for Figure 2 (Reside coverage as biomass vs relative erosion rate)

Citation	Study Location	Rainfall	Tillage Type*	Residue Type Amount Applied	Soil Type / Texture	Slope
Gilley, 1986	Lincoln, NE	Simulated, 48mm/hr + 24 hr later	CT	Sorghum, Soybean 0,0.84, 1.68, 3.36, 6.73, 13.45 Mg/ha	Typic Argiurdolls ===	6.4%
Jordan, 2010	Cadiz, ES	Simulated 65mm/hr for 30min	NT	Wheat 0,1,5,10,15 Mg/ha	Fluvisol (loam) ===	===
Lal, 1997	NG	Actual	NT, CT	Rice straw 0, 1,2,3,4 Mg/ha	Ibadan Series ===	8%
Meyer, 1970	W. Lafayette, IN	Simulated 63.5mm/hr, 1 hr + 2 x 30min 24hr later	Harrow	Wheat 0, 0.56, 1.12, 2.24, 4.48, 8.96 Mg/ha	Typic Hapludalf ===	15%
Mostaghimi, 1992	Blacksburg, VA	Simulated, 100mm @ 50 mm/hr	NT, CT	Rye 0, .75, 1.5 Mg/ha	Grose-close Series 23.2% clay, 58.9% silt, 17.9% sand	8-15%
Woyessa, 2004	SA	Simulated, 60mm/hr	NT, MT, CT	Wheat 0, 2, 4, 8 Mg/ha	Bainsvlei Amalia 88% sand, 3.6% silt, 8.4% clay	===

*CT=conventional tillage; NT=no-till; MT=mulch till

Table 5 Meta data for Figures 3-5 (Soil organic carbon)

Citation	Study Location	Study Period	Tillage Type*	Residue Type Amount Applied	Soil / Texture / Sample	Slope
Blanco-Canqui, 2007	Columbus, OH	10-yr	NT	Wheat (surface) 0,8,16 Mg/ha	Crosby silt loam === 0-5cm	1%
Duiker, 1999	Columbus, OH	7-yr	NT, CT, RT	Wheat 0, 2, 4, 8, 16 Mg/ha-yr	Crosby silt loam === 0-5cm	===
Halpern, 2010	Quebec, CA	16-yr	NT, RT, CT	Corn (surface + stubble) 9 Mg/ha	Sandy loam 82% sand, 8.9% silt, 9.6% clay 0-5cm	===
Lenka, 2013	Columbus, OH	15-yr	NT	Wheat (straw) 0, 8, 16 Mg/ha	Silt loam Alfisol === 0-10cm	===
Nawaz, 2016	Columbus, OH	26-yr	NT, CT	Wheat 0, 4 Mg/ha	Crosby silt loam === 0-15cm	===
Scopel, 2005	Jalisco, MX	5-yr	NT, CT	Maize 0, 1.5, 4.5 Mg/ha	Dystric Cambisol 15% clay, 25% loam, 61% sand 0-10cm	3-7%
Spedding, 2004	Quebec, CA	9-yr	NT, RT, CT	Corn 2.3, 7.1 Mg/ha	Courval sandy loam === 0-10cm	===

*CT=conventional tillage; NT=no-till; MT=mulch till

Establishing Recommendations

These tillage guidance recommendations considered the relationship between the level of residue maintained on fields and its effect on erosion control. Because it is impossible to completely prevent all erosion and surface water runoff solely using tillage and residue management practices our goal is twofold: (1) identify tillage and residue management practices that are effective at protecting water quality and; (2) establish the recommendations at a level that ensures any remaining erosion can be further controlled by supporting practices such as sediment trapping, pollution filtering, and riparian area protection.

There is a positive relationship between the level of residue and the level of erosion control. Greater residue coverage results in greater erosion control. However, this relationship is not linear. At about 30% surface residue cover there is an inflection point. Coverage levels below

30% bring a steep decline in erosion control while levels above 30% provide smaller increases in erosion control. Commonly, a 30% surface residue cover present at the time of planting is used to differentiate between conventional and conservation-based tillage practices. While this point does provide a clear dividing line, depending on a variety of factors, even at a residue coverage of 30% an estimated net sediment loss from fields can still be significant, providing no margin of safety to water quality protection. For this reason, it is recommended that a minimum of 60% residue cover is present at the time of planting.

Recommending a minimum of 60% residue coverage provides a more conservative lower end limit. It achieves an effective erosion control of approximately 90%, or more, while limiting soil organic carbon loss. While residue coverage above 60% provides for increased erosion control, few crops can generate enough residue to meet those levels. In addition, the types of tillage systems that can be utilized also becomes a limiting factor. The 60% residue goal achieves effective erosion control while allowing for a variety of conservation-based tillage options, encouraging greater adoption by more farmers.

Importantly, it is anticipated that additional supporting BMPs will be required to be fully protective of water quality. It is expected that Ecology will revisit these tillage recommendations if it is found that the suite of practices, as a whole, are found to not provide the level of water quality protection required and that additional pollutant control measures are needed.

For low residue crops a slightly different approach is necessary. The recommendations still center on minimizing tillage to the maximum extent possible. However, Ecology recognizes the need to take additional steps because the recommended residue levels are not achievable for those operations. With the added risk of erosion that is present, the guidance also recommends maximizing the production of residue within the overall rotation, supplementing residue with cover crops, and using practices that can trap sediment.

References

Blanco-Canqui, H., R. Lal. 2007. Soil structure and organic carbon relationships following 10-years of wheat straw management in no-till. Soil Tillage Research. 95:240-254.

Duiker, S. W., R. Lal. 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil and Tillage Research. 52:73-81.

Gilley, J.E., S.C. Finkner, G.E. Varvel. 1986. Runoff and erosion as affected by sorghum and soybean residue. Trans. Am. Soc. Agric. Eng. 29:1605-1610.

Halpern M. T., J. K. Whalen, C. Madramootoo. 2010. Long-term tillage and residue management influences soil carbon and nitrogen dynamics. Soil Biology and Biochemistry. 74:1211-1217.

Hoorman, J., J. Carlos de Moraes Sa, R. Reeder. 2009. The biology of soil compaction. Fact Sheet, Agriculture and Natural Resources. The Ohio State University Extension. SAG-10-09 / AEX-543-09.

Jordon, A., L. Zavala, J. Gil. 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena 81:77-85.

Lal, R. 1997. Mulching effects on runoff, soil erosion, and crop response on Alfisols in western Nigeria. Journal of Sustainable Agriculture. 11:135-154.

Lenka, N., R. Lal. 2013. Soil aggregation and greenhouse gas flux after 15-years of wheat straw and fertilizer management in a no-till system. Soil Tillage Research. 126:78-89.

McCool, D. K., J. E. Hammel, R. I. Papendick. 1995. Surface residue management – Chapter 4 in Crop residue managment to reduce erosion and improve soil quality, northwest. United States Department of Agriculture. Agricultural Research Service, Conservation Research Report Number 40. May, 1995.

Meyer, L. D., W. H. Wischmeier, G. R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Amer. Proc. 34:928-931.

Montgomery, David. 2007. Soil erosion and agricultural sustainability. PNAS. 104/33.

Mostaghimi, S., T. Younos, U. Tim. 1992. Crop residue effects on nitrogen yield in water and sediment runoff from two tillage systems. Agriculture, Ecosystems and Environment. 39:187-196.

Nawaz, A., R. Lal, R. Shrestha, M. Farooq. 2016. Mulching affects soil properties and greenhouse gas emissions under long-term no-till and plough-till systems in Alfisol of central Ohio. Land Degradation and Development. 681:673-681.

Nyakatawa, E., V. Jakkula, K. Reddy, J. Lemunyou, B. Norris. 2007. Soil erosion estimation in conservation tillage systems with poultry litter application using RUSLE 2.0 model. Soil and Tillage Research. 94:410-419.

Scopel, E., A. Findeling, G. Chavez. 2005. Impact of direct sowing mulch-based cropping systems on soil carbon, soil erosion, and maize yield. Agronomy for Sustainable Development. 25:425-432.

Spedding, T., C. Hamel, G. Mehuys, C. Madramootoo. 2004. Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. Soil Biology and Biochemistry. 36:499-512.

Tarzwell, C., A. Gaufin. 1953. Some important biological effects of pollution often disregarded in stream surveys. United States Department of Health, Education, and Welfare; Public Health Service, Environmental Health Center. EHC-20.

Tiessen, K., J. Elliott, J. Yarotski, D. Lobb, D. Flaten, N. Glozier. 2010. Conventional and conservation tillage: influence on seasonal runoff, sediment, and nutrient losses in the Canadian prairies. Journal of Environmental Quality. 39:964-980.

Woyessa, Y. E., A. T. P. Bennie. 2004. Factors affecting runoff and soil loss under simulated rainfall on a sandy Bainsvlei Amalia soil. South African Journal of Plant and Soil. 21/4:203-208.

Additional References

Al-Kaisi, M. 2014. Managing crop residue removal and soil organic matter. Corn Stover Harvest, Iowa State University, Extension and Outreach. PM 3052B.

Bista, P., S. Machado, R. Chimire, G. Yorgey, D. Wysocki. (ND). Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest.

Clapp, C. E., R. R. Allmaras, M. F. Layese. 2000. Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Research. 55:127-142.

Deere & Company. 2007. Tillage - A practical guide to the latest methods; conservation planning crop residue management and solutions to soil problems. Fundamentals of Machine Operation. Deere & Company, John Deere Publishing. Fourth Edition.

Dejong-Huges, J., J. Vetch. 2007. On-farm comparison of conservation tillage systems for corn following soybeans. University of Minnesota Extension. BU-08483.

DeJong-Huges, J. (ND). Soil management and health, upper mid-west tillage guide. University of Minnesota Extension.

Gregory, J. M. 1982. Soil cover prediction with various amounts and types of residue. Trans. ASAE 25:1333-1337.

Hooker B. A., T. F. Morris, R. Peters, Z. G. Cardon. 2005. Long-term effects of tillage and corn stalk return on soil carbon dynamics. Soil Science Society of America. 69:188-196.

Horner, G. M., W. A. Starr, J. K. Patterson. 1957. The Pacific Northwest wheat region in Soil – The 1957 Yearbook of Agriculture. United States Department of Agriculture. 85th Congress, 1st Session, House Document No. 30.

IPCC, 2014: Climate Change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kok, Hans. 2007. STEEP (Solutions to Environmental and Economic Problems) impact assessment. USDA Research Grant EB2035A.

Lal, R. 1984. Mulch requirements for erosion control with the no-till system in the tropics: a review. In: Challenges in African hydrology and water resources, Proceedings of the Harare Symposium. International Association of Hydrological Sciences: IAHS-AISH Publication 144. Washington D.C., USA. 475-484.

Lal, R., J. Kimble, R. Follett, C. Cole. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press.

Lal R. 1998. Soil quality changes under continuous cropping for seventeen seasons of an Alfisol in western Nigeria. Land Degradation and Development. 9:259-274.

McCarthy, J., D. Pfost. (ND). Conservation tillage and residue management to reduce soil erosion. University of Missouri Extension.

McCool D., F. Young, R. Papendick. 1989. Crop and tillage effects on residue cover. Paper 89-2155. ASAE.

McCool, D., H. Kok, R. McClellan. 1990. Cover versus mass relationships for small grain residues. Paper 90-2040. ASAE.

McCool, D., D. Stott, J. Laflen, D. Schertz. 1995. Residue incorporation by tillage – interaction of mass and cover. J. Soil Water Conserv. 50:563-567.

McGuire, A. 2016. Using green manures in potato cropping systems. Washington State University Extension. FS218E.

Mitchell, J., L. Jackson, G. Miyao. 2004. Minimum tillage vegetable crop production in California. University of California, Division of Agriculture and Natural Resources. Publication 8132.

Mitchell, J., G. Pettygrove, S. Upadhyaya, A. Shrestha, R. Fry, R. Roy, P. Hogan, R. Vargas, K. Hembree. 2009. Classification of conservation tillage practices in California irrigated row crop systems. University of California, Division of Agriculture and Natural Resources. Publication 8364.

Nowatzki, J., G. Endres, J. DeJong-Huges. 2017. Strip till for field crop production. University of Minnesota Extension. AE1370.

Oregon State College (OSC). 1955. Trashy fallow for conservation. Extension Circular 588.

Papendick, R., W. Moldenhauer. 1995. Crop residue management to reduce erosion and improve soil quality. United States Department of Agriculture, Agricultural Research Service. Conservation Research Report Number 40.

Rannivoson, L., K. Naudin, A. Ripoche, F. Affholder, L. Rabeharisoa, M. Corbells. 2017. Agro-ecological functions of crop residues under conservation agriculture – a review. Agronomy for Sustainable Development. 37/26.

Rasmussen, P., R. Allmaras, C. Rohde, N. Roager. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil. Sci. Soc. Am. J. 62:1393-1397.

Reicosky, D., W. Kemper, G. Langdale, C. Douglas, P. Rasumssen. 1995. Soil organic matter changes resulting from tillage and biomass production. Journal of Soil and Water Conservation. 50:253-261.

Stumborg, M., L. Townley-Smith, E. Coxworth, S. East. 1996. Sustainability and economic issues for cereal crop residue export. Canadian Journal of Plant Science. 76:669-673.

United States Department of Agriculture (USDA), Oregon Soil Conservation Service. 1973. Technical Notes: Effectiveness of increasing mulch rates in reducing soil movement on steep slopes and mulch volume weight and texture as conditioning in estimating mulch needs.

Technical Note No. 23.

United States Department of Agriculture (USDA): Soil Conservation Service, Forest Service, Economics, Statistics and Cooperatives Service. 1978. Palouse cooperative river basin study.

United States Department of Agriculture (USDA), Soil Conservation Service. 1980. Soil Survey of Whitman County, Washington.

United States Department of Agriculture (USDA), Soil Conservation Service. 1984. Soil Survey of Grant County, Washington.

United States Department of Agriculture (USDA). 2013. Summary report: 2010 national resources inventory. Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa.

United States Department of Agriculture (USDA). 2015. Summary report: 2012 National resources inventory. Natural Resources Conservation Service, Washington DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames.

United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2016. Conservation Practice Standard - Residue and tillage management, no till. Code 329.

United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2016. Conservation Practice Standard – Mulch till. Code 345.

United States Department of Agriculture (USDA), National Agricultural Statistics Office: Northwest Regional Office. 2017. 2017 Washington annual statistical bulletin.

Chapter 1 Appendix Part B:
Implementation Considerations
(Tillage and Residue Management)

Introduction

This section describes a variety of factors related to the implementation of conservation tillage practices in Washington State. It is focused on factors that apply at the parcel (or farm) level and meant to encourage producers to move towards adopting conservation tillage. General information is provided below on costs and benefits along with a discussion of the barriers and incentives for practice adoption. The *Implementation Information Synthesis* section that follows provides additional and more specific information organized by tillage type in a series of tables.

This information is provided to support producers in adopting best management practices. Information was gathered through literature review and interviews with conservation districts, university extensions, and other tillage experts across the state.

The conversion from conventional to conservation tillage can carry higher initial capital costs depending on the farm operation. However, in general, conservation based tillage practices are less expensive over time and can improve soil quality providing collateral benefits and cost savings in addition to their water quality protection benefits

Adoption of Conservation Tillage Systems in Washington State

Washington's agricultural production is complex and diverse, producing over 300 different commodities (WSDA, 2013). Washington State's unique and varied physical and climatic conditions determines both the type of crops produced in different parts of the state, and how crops are managed to increase yields, reduce costs, and limit soil erosion. There are significant differences in rainfall, soil type, and ground water levels between Western and Eastern Washington.

These factors directly impact what type of crops are produced and which tillage systems are implemented. Adoption of direct seed for dryland grain in Eastern Washington has been increasing for several decades.

Benefits and Costs Associated with Switching to Conservation Tillage

Once conservation tillage systems are implemented on a farm, soil quality has been shown to increase over time due to reduced erosion, increased moisture and organic matter, improved soil aggregate stability and reduced soil compaction. Fertilizer application rates and associated costs in applying conservation tillage systems may also decrease over time compared to conventional tillage. These benefits can improve yields and increase the sustainability and resilience of the farming operation. The reduced number of passes associated with conservation tillage reduces fuel and labor costs and saves time. A pass refers to the number of times implements are dragged across fields to achieve a specific task such as seeding or weed control. Fewer passes also reduces carbon emissions, reduces dependence on fuel, and can improve machine lifespan. Over time, conservation tillage can be less expensive to operate and has on-farm benefits in addition to its water quality benefits.

Improved soil structure and crop residue associated with conservation tillage reduces evaporation and increases water availability for crops, thereby conserving water. Irrigated and non- irrigated agriculture have different outcomes and savings associated with high residue conservation tillage systems. In irrigated agriculture with residue cover, the soil surface is often wet and has high evaporation potential, so the impact of residue cover on evaporation is greater. In dryland agriculture, where the soil surface is often dry and has lower evaporation potential, residue cover may have less of an impact on evaporation (McGuire, 2014).

Switching to direct seed or other forms of conservation tillage from conventional tillage can entail an initial capital investment. For direct seed, a drill is estimated to cost up to $200,000 (Painter, 2010). In Washington, 94% of farms produce less than $250,000 per year, so many farms would benefit from access to financial assistance to help offset the initial capital costs associated with switching from conventional tillage (WSDA, 2013).

Larger farms may experience a greater return on investment compared to smaller farms (e.g., increased savings from reduced fuel and labor costs associated with fewer passes across the field). Sixty-three percent of farms in Washington are less than 50 acres (WSDA, 2013). To reduce the costs associated with the switch to conservation tillage several counties provide access to direct seed equipment; rental equipment also may be available. In addition, cost sharing programs are available to help producers with the capital costs associated with transition to conservation tillage equipment.

Barriers and Incentives to Conservation Tillage Adoption

Conservation tillage is part of the evolution of best farming practices. The confluence of education, technical expertise, machine rental programs, pilot projects, and seeing neighbors' success adopting conservation tillage encourages the transition towards more ecologically sound practices that can also save famers' time and money. Maintenance of these programs is key to continued support of the transition to conservation tillage.

Conservation tillage practices may not be suitable to all operations or crop types. It is important to recognize where conservation tillage practices make sense and where they might not. The practices that are most appropriate to protecting water quality for any given operation are highly dependent on farm-specific conditions and circumstances, and producer's priorities, crops, and production methods. For example, some tillage systems may not be suitable in wet climates with slow-draining soil or for certain low residue crops. In these situations, other types of best management practices, such as filter strips, contour farming, or cover crops may be better suited for water quality protection and should be used instead. To continue to promote the voluntary adoption of best management practices, it is important to make clear which practices in each practice category work best to protect water quality, while recognizing that there is not a one-size-fits all solution.

While initial capital costs can be a barrier to adopting conservation tillage, several other factors may affect a farmer's ability to make the switch. Farmers may have concerns about potential yield losses and risk associated with learning how to operate new machinery and implement new management practices. Learning how to successfully use conservation tillage equipment to best fit a farmer's operation takes time and practice; some farmers may choose to hire experts to do the direct seed planting for their farm. Some conservation districts and the Pacific Northwest Direct Seed Association have worked to set up networking and mentorship programs that can help producers learn how to successfully make the transition.

Farmers switching to conservation tillage, particularly no-till, have a greater reliance on chemical based management measures to control weeds. Cover crops can be planted to help control weeds and increase soil nutrients. Crop rotation is also used to control weeds, pests, and diseases while increasing soil fertility.

Many farmers in Washington lease land, and may be less inclined than landowners to make the needed capital investments to implement conservation tillage. In addition, some landowners may not want to implement reduced tillage because it might necessitate changes in crop production.

Some farming operations may be accustomed to higher intensity tillage practices for weed and pest control. For example, organic farming may use tillage to control weeds because fewer herbicide options are available resulting in higher labor costs.

Crop rotation is often a component of reduced tillage weeds, pest, and disease management. A landowner may be unwilling to allow alternative crops to be grown. Crop rotations can potentially reduce chemical applications by disrupting pest and disease cycles (Ecotrust, 2016). The reduced erosion benefits associated with no-till should be considered in light of potentially increased utilization of herbicides and pesticides.

Access to programs that provide technical assistance, education, and equipment rentals are an important approach to increasing voluntary adoption of conservation tillage practices. Local Conservation Districts (CD) throughout Washington are valuable resources in helping farmers adopt conservation tillage, especially direct seed. CDs can advise through the farm planning process and provide guidance regarding how to make the transition to conservation tillage given the unique conditions of the farm. Furthermore, several Washington CDs have used Ecology grants and loans to set up direct seed machinery rental programs, with direct seed drills affordably priced for rent per acre or day. These programs significantly reduce direct seed equipment costs for farmers and provide the opportunity for one-on-one technical assistance. Additionally, Ecology funding programs have been used to establish low interest loan programs for the purchase of conservation tillage equipment. Ecology grants and NRCS cost share programs also provide incentivizes to producers to pilot direct seed systems on their property (e.g., equipment rental cost reimbursement and cost of custom application fee reimbursement). More information on Ecology's grant and loan programs is provided at: https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan/Water-Quality-grants-and-loans.

Implementation of programs to help absorb some of the risk of switching to conservation tillage systems provide opportunities to increase voluntary adoption.

Pilot programs that demonstrate return on investment and increased crop yields are also compelling factors in a farmer's decision to move towards conservation tillage systems.

Education and outreach is an important element in preventing pollution sources and protecting water quality. Since the guidance is comprehensive in covering many conservation practices, it provides extensive and detailed information that can be distilled to educational and outreach efforts as is fit for varying educational goals. These goals could include building awareness around water quality concerns, educating producers on conservation practices and best management practices, and motivating behavior change towards water quality protection.

Direct Seed Resource

The Pacific Northwest Direct Seed Association (PNDSA) is a non-profit that provides peer-to-peer learning, research coordination, and advocacy around the adoption of environmentally and economically viable direct seed cropping systems. PNDSA works to unit growers in the Pacific Northwest around the direct seed cropping system, with the goal of advancing sustainable farming. PNDSA helps farmers learn more about adoption of direct seed through newsletters, research, annual conference, and by connecting growers.

Case Examples

Success Story: Spokane Conservation District

The Spokane Conservation District operates a Direct Seed Loan Program that helps producers in the area switch to direct seed and no-tillage operations through low-interest loans for agricultural equipment purchases. These purchases aid in the direct placement of seed and/or fertilizers in one or two passes (e.g., no-till and direct seed drills, fertilizer placement implements, sprayers, tractors) or aid in the removal or management of residue (e.g., heavy harrows, mowers, swathers, balers, combines). Contracts in the program range from five to ten years.

Success Story: San Juan Islands Conservation District Direct Seed Pilot

San Juan Island Conservation District (CD) is providing on-site technical assistance for direct seed implementation in pasture land throughout the county in spring and fall of 2019. The San Juan CD is working directly with 10 farmers on the San Juan Islands to plant pasture seed on up to two acres of land per site and allows farmers to loan a 6 foot hydraulic based, pull type no-till drill. Participants pay a fee of $250 a year, which includes machinery rental, technical expertise from CD staff, and the seed.

This pilot program provides the opportunity for farmers to gain valuable experience implementing direct seed in a low-cost, low-risk environment. While the final outcomes of the program have yet to be reported, producers have experienced a reduction in costs associated with fuel and labor due to fewer passes associated with direct seed systems. Producers in San Juan County are interested in transitioning to direct seed because it requires less seed, time, fuel, conserves water, and deposits fertilizer in a targeted fashion. Also, direct seed equipment is relatively inexpensive to operate. Direct outreach, marketing, and building on prior successes were important to establishing this pilot program.

References

Ecotrust. 2016. Differentiated cost of production in the northwest: an analysis of six food categories – wheat and small grains.

Huggins, D., J. Reganold.2008. No-till: the quiet revolution. Scientific American. 299: 70- 77.

Painter, K. 2010. Direct seed mentoring project: an economic comparison of direct seed and conventional growers in the Washington/Idaho Palouse. Pacific Northwest Direct Seed Association Newsletter. V:10, N:3.

McGuire, A. 2014. High residue farming under irrigation: what and why. Washington State University Extension.

Washington State Department of Agriculture (WSDA). 2013. Washington Agriculture Snapshot. https://agr.wa.gov/washington-agriculture

Conservation Tillage-Practices

No-Till

Table 6 Implementation No-Till

Considerations	Details
Capital Cost	A no-till hoe drill is estimated to cost $87,000 to $107,000 depending on size. A no-till disk drill is estimated to cost between $40,000 and $85,000 depending on size (Painter, K. 2011).
Operational and maintenance requirements and costs	The reduced number of passes and acres tilled typically result in reduced operational and maintenance costs compared to conventional tillage. There are also reduced costs associated with decreased erosion.
Technical requirements	The soil is left undisturbed from harvest to planting (Bista, P.,, 2017). Planting is completed using a no-till hoe or disk drill, and there is no full-width tillage for seedbed preparation.
Lifespan	Improved machine lifespan due to fewer passes.
Land area requirements	There are no specific land area requirements for no-till (NRCS, 2017).
Number of passes associated with practice and associated fuel and labor costs	One to two passes; there are fuel and labor costs associated with the reduced number of passes.
Fertilizer application rates and associated costs	Fertilizer application rates and costs may initially be higher than conventional tillage, but over time no-till systems use less nitrogen fertilizer than conventional tillage systems. Increasing organic matter at the surface of no-till systems immobilizes nutrients, including nitrogen. To address this, in the first four to six years of no-till extra nitrogen fertilizer may be needed to achieve nutritional requirementsof some crops. This can be up to 20% more fertilizer than conventional tillage (Huggins, D., 2008).
Pesticide and herbicideapplication rates and associated costs (resistance)	Pesticide and herbicide application rates and costs are generally higher than conventional tillage. Different pest, weed, and crop diseases can arise as a farm transitions from conventional tillage to no-till. The elevated moisture levels associated with no-till may promote soil-borne fungal diseases (Huggins, D., , 2008). Crop rotations can potentially reduce chemical applications by disrupting pest and disease cycles (Ecotrust, 2016).

Considerations	Details
Factors that influence acceptance and resistance	Acceptance to adopting no-till may be due to fuel, labor, and equipment savings after the upfront investment in new equipment. Also, no-till adoption may improve soil quality through reduced Greater dependence on pesticides may contaminate water, air, and soil and may affect nontarget species (Huggins, D., 2008).
Other implementation factors	Significant differences in climate, rainfall, and soil type between Western and Eastern Washington directly impact what type of crops are produced and what types of tillage systems can be implemented.
Resources	Environmental Quality Incentives Program (EQIP) funding is availablefor producers in 12 Washington counties to implement conservationpractices, including no-till/direct seed. Various Conservation Districtshave no-till technical assistance programs.

References

Bista, P., S. Machado, R. Ghimire, G. Yorgey, D. Wysocki. 2017. Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest. 99-124.

Ecotrust. 2016. Differentiated cost of production in the northwest: an analysis of six food categories – wheat and small grains

Huggins, D., J. Reganold, 2008. No-till: the quiet revolution. Scientific American. 299: 70-77.

Natural Resources Conservation Service (NRCS), Washington. 2017. Residue and Tillage Management, No Till. Code 329. 329-CPS-1

Painter, K. 2011. Cost of owning and operating farm machinery in the Pacific Northwest. Pacific Northwest Extension, University of Idaho PNW 346.

Creech, E. 2017. United States Department of Agriculture. Saving Money, Time, and Soil: The Economics of No-Till Farming. https://www.usda.gov/media/blog/2017/11/30/saving- money-time-and-soil-economics-no-till-farming

Strip Till

Table 7 Implementation Strip-Till

Considerations	Details
Capital Cost	Equipment, such as a leading coulter, tillage shank, and pair of covering disks, may need to be purchased. Other components of a strip-till system can include row cleaners, auto-reset and fertilizer application tubes, and soil conditioners (McGuire, A., 2014).

Considerations	Details
Operational and maintenance requirements and costs	The reduced number of passes and acres tilled typically result in reduced operational and maintenance costs compared to conventional tillage, along with reduced soil erosion and soil compaction (Luna, J., M. Staben, 2003).
Technical requirements	In strip-till systems, 6- to 12-inch wide tilled strips between 8- to 16-inches deep are created. Residue covered area between the tilled strips is undisturbed. Traditional planters are used to plant into the tilled strips (Luna, J., M. Staben, 2003).
Lifespan	Machinery depreciation is reduced in strip-till compared to conventional tillage.
Land area requirements	Strip-till is most common with crops grown on 30-inch row spacing. Strip-till can be adapted to row spacing as narrow as 20 inches, but ismore difficult to implement in narrower spacing because of the reduced area for residues, according to the Washington State University Extension.
Number of passes associated with practice and associated fuel and labor costs	Fall strip-till requires a two-pass system while the spring strip-till canbe a one- or two-pass system. The reduced number of passes and acres tilled typically result in reduced fuel and labor costs compared to conventional tillage.
Fertilizer application rates and associated costs	Some strip-till machines allow for application of two different fertilizers at adjustable depths, while other machines only provide the option for one depth. Fertilizer application rates and costs may initially be higher than conventional tillage, but over time strip-till systems use less nitrogen fertilizer than conventional tillage systems.
Pesticide and herbicide application rates and associated costs (resistance)	Strip-till increases the level of weed control management and associated costs compared to conventional tillage (the tilled and untilled areas may be favorable to different weed species). Pre-plant herbicides may be used to kill weeds and surviving cover crops (Luna,J., M. Staben, 2003).

Considerations	Details
Factors that influence acceptance and resistance	Strip-till creates both clean-till and high residue conditions, which may be advantageous to farm production. Other benefits of strip-till include: • Warmer soils at planting • Potential for faster crop germination and growth • Reduced soil compaction and evaporation • Increased water infiltration • Reduced time and labor needed for tillage Resistance to strip-till may be due to concerns such as increased weed management, increased pest control management, and upfront capital costs. Strip-till management challenges include: • Water erosion if strips are oriented parallel to slope • In dry spring seasons, strip-till may require earlier irrigation • Strip-till eliminates cultivation as a weed control method (McGuire, A., 2014).
Resources	Environmental Quality Incentives Program (EQIP) funding is available for producers in 12 Washington counties to implement conservation practices, including no-till/direct seed. Various Conservation Districts have no-till technical assistance programs.

References

Luna, J., M. Staben. 2003. Using strip-tillage in vegetable production systems in Western Oregon. Oregon State Extension Series. EM 8824.

McGuire, A. 2014. High residue farming under irrigation: strip-till. Washington State University Extension. EM036E.

Direct Seed

Table 8 Implementation Direct Seed

Considerations	Details
Capital Cost	Direct seed tillage generally has a higher capital cost than conventional tillage, with a new direct seed drill costing up to $200,000 (Painter, K., 2010).

Considerations	Details
Operational and maintenance requirements and costs	Reduced costs associated with erosion (including crop loss fromerosion). Reduced maintenance costs due to fewer passes over the field. Analysis of the Spokane Conservation District Direct Seed Mentoring Program by the University of Idaho showed that direct seeding versusconventional tillage (on a spring grain crop) reduced repairs (parts and labor) by 20% and reduced labor costs by 50% (Spokane Conservation District).
Technical requirements	• Loose residues should be uniformly distributed on the soilsurface. • If used, combines or similar machines should be equipped with spreaders capable of distributing residue over at least80% of the working width of the header. • Planters or drills should be equipped to plant directly throughuntilled residue or in a tilled seedbed prepared in a narrow strip along each row by planter attachments such as rotary tillers, sweeps, multiple coulters, or row cleaning devices (NRCS, 2000).
Lifespan	Improved machine lifespan due to fewer passes.
Land area requirements	Disturbance caused by seedbed preparation, planting, and fertilizer placement should be between one third and two thirds of the row width (NRCS, 2000).
Number of passes associated with practice and associated fuel and labor costs	One-pass fertilization and seed system or a two-pass system with fertilizing and seeding as separate operations (Bista, P., et al., 2017).According to the Pacific Northwest Direct Seed Association, direct seeding in one-two passes as compared to five-six passes in conventional tillage saves an average of 3.5 gallons of diesel an acre,totaling 8,750 gallons on a 2,500-acre farm each year. Analysis of the Spokane Conservation District Direct Seed Mentoring Program by the University of Idaho showed that direct seeding versusconventional tillage (on a spring grain crop) can reduce labor costs by50% and save 42% on fuel and lubrication costs.
Fertilizer application rates and associated costs	Fertilizer application rates and costs may initially be higher than conventional tillage, but over time direct seed systems may use less fertilizer than conventional tillage systems.

Considerations	Details
Pesticide and herbicide application rates and associated costs (resistance)	Pesticide and herbicide application rates and costs may be higher than conventional tillage.
Factors that influence acceptance and resistance	Acceptance to adopting direct seed may be due to fuel, labor, andequipment savings. Resistance to adopting direct seed may be due to concerns about potential yield losses and that the initial cost of investing in new equipment can be significant.
Other implementation factors	Additional implementation factors include improved soil health due to increased moisture available in the soil, reduced erosion and improved water quality, and reduced emissions and improved air quality due to fewer passes across the field. According to the Pacific Northwest Direct Seed Association, direct seeding in one-two passesrather than five-six passes in conventional tillage can reduce emissions from farm equipment by 0.5 to 0.66 tons per acre of carbon per year on a 2,500 acre farm. Greater dependence on pesticides, may affect water, air, and soil quality and adversely impact non-target species.
Resources	Environmental Quality Incentives Program (EQIP) funding is available for producers in 12 Washington counties to implement conservation practices, including no-till/direct seed. Various Conservation Districts have no-till technical assistance programs.

References

Bista, P., S. Machado, R. Ghimire, G. Yorgey, D. Wysocki. 2017. Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest. 99-124.

Natural Resource Conservation Service (NRCS), Idaho. 2000. Conservation Practice Standard – Residue Management, Direct Seed. Code 777.

Pacific Northwest Direct Seed Association (PNDSA). Why direct seed. http://www.directseed.org/about/why-direct-seed/

Painter, K. 2010. Direct seed mentoring project: an economic comparison of direct seed and conventional growers in the Washington/Idaho Palouse. Pacific Northwest Direct Seed Association Newsletter. V:10, N:3. https://www.webpages.uidaho.edu/~kpainter/PNDSAarticle.pdf

Spokane Conservation District. Direct Seed Loan Program. http://sccd.org/programs/direct-seed-loans

Ridge Till

Table 9 Implementation Ridge Till

Considerations	Details
Capital Cost	Planting equipment must be designed to operate between ridged surfaces. Equipment, such as sweeps, disk openers, coulters, and rowcleaners, may need to be purchased (Bista, P., et al., 2017).
Operational and maintenance requirements and costs	Planting is completed in a seedbed prepared on ridges; residue is lefton the surface between ridges. Machines used for harvesting are equipped with spreaders capable of distributing residue over at least80% of the working width of the header. The reduced number of passes associated with ridge till may result in reduced operational and maintenance costs compared to conventional tillage.
Technical requirements	• Following crop harvest and any residue removal operation,residues are maintained until planting. • After planting, the tops of the ridges are maintained at leastthree inches higher than the furrow between the ridges. Ridge till may be implemented continuously throughout thecrop sequence or may be part of a residue management system that includes other tillage practices.
Lifespan	A field cultivator and a coulter are estimated to have a lifespan of 2,000 hours, according to research by the Pacific Northwest Extension in 2011.
Land area requirements	According to the Sustainable Agriculture Research and Education (SARE), ridge till is well suited for flat fields with slow-drying or heavysoils, on contoured rows on slopes up to 6%, and/or for furrow- irrigated fields. Ridge till is successful with wide row spacing. Round or flat-top ridges require a broad base for stability.
Number of passes associated with practice and associated fuel and labor costs	Two passes may be needed to manage weeds. The reduced number of passes may result in reduced fuel and labor costs compared to conventional tillage.

Considerations	Details
Fertilizer application rates and associated costs	Fertilizer application rates and costs may initially be higher than conventional tillage, but over time ridge till systems use less nitrogenfertilizer than conventional tillage systems.
Pesticide and herbicide application rates and associated costs (resistance)	Pesticide and herbicide application rates and costs may be higher than conventional tillage.
Factors that influence acceptance and resistance	A benefit of ridge till is the potential for earlier planting due to the raised ridges that result in increased warming and drainingin the spring. The residue between the ridges reduces erosion and evaporation while increasing moisture. Resistance to ridge till may be due to the inconvenience of driving across ridges during harvest, inconvenience in forming and maintaining ridges, and the upfront capital costs of specialized equipment (Simmons, F.W., et al.)
Other implementation factors	Some farmers may use other types of conservation tillage systems atthe end of ridge-till rows (turning equipment on ridged surfaces can be challenging).
Resources	Environmental Quality Incentives Program (EQIP) funding is available for producers in 12 Washington counties to implement conservation practices, including no-till/direct seed. Various Conservation Districts have no-till technical assistance programs.

References

Bista, P., S. Machado, R. Ghimire, G. Yorgey, D. Wysocki. 2017. Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest. 99-124.

National Resource Conservation Service. 2001. Conservation Practice Standard and Specifications– Residue Management, Ridge till. Code 329C.

Painter, K. 2011. Cost of owning and operating farm machinery in the Pacific Northwest. Pacific Northwest Extension. V:10, N:3.

Simmons, F.W., E. Nafziger. (ND) Soil management and tillage. Illinois Agronomy Handbook, Chapter 10: Soil Management and Tillage. 133-142.

Sustainable Agriculture Research and Education (SARE). 2012. Ridge-till planter. https://www.sare.org/Learning-Center/Books/Steel-in-the-Field/Text-Version/Row-Crop-Tools/Ridge-till-planter

Mulch Till

Table 10 Implementation Mulch Till

Considerations	Details
Capital Cost	Equipment, such as disks, chisel, field cultivator, sweeps, blades, and harrows, may need to be purchased (Bista, P., et al., 2017). Planting equipment must be designed to operate in high residue situations. A mulch tiller is estimated to cost between $38,000 to $40,000 on average depending on size. Field cultivators are estimated to cost between $24,000 to $64,000 on average, depending on size and accessories, according to research by the Pacific Northwest Extensionin 2011.
Operational and maintenance requirements and costs	Operation and maintenance requirements include evaluating crop residue cover levels and crop orientation. Additional seedbed preparation may also be needed (NRCS, 2012). Mulch till may requiremore passes over a field than other conservation tillage systems, so operational maintenance and costs may be more similar to conventional tillage.
Technical requirements	• Uniformly spread the residue on the soil. • Select tillage implements that will maximize residue retentionon the soil surface. • Planting implements should be equipped with coulters anddisk openers designed to cut through surface residue. • Row cleaners may be attached to the planters to move residue out of the row area (USDA, 1999).
Lifespan	A field cultivator and chisel plow are estimated to have a lifespan of 2,000 hours, according to research by the Pacific Northwest Extension in 2011.
Land area requirements	The entire soil surface is tilled (although enough residue remains on the soil to reduce erosion). Mulch till can be adopted in various soil types, including poorly drained soils.
Number of passes associated with practice and associated fuel and labor costs	One to three passes. Mulch till may require more passes over a field than other conservation tillage systems, so fuel and labor costs may be similar to conventional tillage.

Considerations	Details
Fertilizer application rates and associated costs	Fertilizer application rates and costs may initially be higher than conventional tillage, but over time mulch till systems use less nitrogen fertilizer than conventional tillage systems.
Pesticide and herbicide application rates and associated costs (resistance)	Pesticide and herbicide application rates and costs may be lower thanother conservation tillage systems.
Factors that influence acceptance and resistance	Benefits of mulch till include increased soil organic matter, increased water conservation, and improved weed-control compared to other conservation tillage systems. Mulch till may also provide food and cover for wildlife. Also, since mulch till is similar operationally to conventional tillage, farmers may be more likely to find the transitioneasier.
Resources	Environmental Quality Incentives Program (EQIP) funding is available for producers in 12 Washington counties to implement conservation practices, including no-till/direct seed. Various Conservation Districts have no-till technical assistance programs.

References

Bista, P., S. Machado, R. Ghimire, G. Yorgey, D. Wysocki. 2017. Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest. 99-124.

National Resource Conservation Service (NRCS). 2012. Practice Introduction – Mulch till. Code 345.

Painter, K. 2011. Cost of owning and operating farm machinery in the Pacific Northwest. Pacific Northwest Extension. V:10, N:3.

United States Department Agriculture (USDA). 1999. Core4 Conservation Practices Training Guide. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025540.pdf

Conventional Tillage

Table 11 Implementation Conventional Tillage

Considerations	Details
Capital Cost	Conventional tillage generally has a lower capital cost than no-till,with a new, top-of-the-line conventional tillage drill costing up to $80,000 (Painter, K., 2010).
Operational and maintenance requirements and costs	Operational and maintenance requirements and costs can be estimated using the 2018 Iowa Farm Custom Rate Survey. Overtime,conventional tillage generally has higher operational and maintenance costs than no-till.

Considerations	Details
Technical requirements	Conventional tillage requires four or more intensive tillage operationsa year for seedbed preparation, weed control during fallow, and fertilization prior to planting. There may be up to eight tillage operations during a 14-month fallow period, not including sowing (Bista, P., 2017).
Lifespan	Compared to no-till, conventional tillage has decreased machine lifespan due to more passes, increasing wear
Land area requirements	No specific land area requirements.
Number of passes associated with practice and associated fuel and labor costs	Since conventional tillage generally requires more passes than no-till,conventional tillage results in higher fuel and labor costs.
Fertilizer application rates and associated costs	Over time, conventional tillage systems use more nitrogen fertilizer than conservation tillage systems (Huggins, D., 2008).
Pesticide and herbicide application rates and associated costs (resistance)	Pesticide and herbicide application rates and costs are generally lower than conservation tillage systems (Huggins, D., 2008).
Factors that influence acceptance and resistance	A growing number of Washington farmers are transitioning from conventional tillage to reduced/no-till systems to achieve increased net returns, improved soil health, and environmental benefits.
Other implementation factors	Organic farmers may rely on tillage to manage weeds and incorporate cover crops into soil (EcoTrust, 2016).
Resources	Environmental Quality Incentives Program (EQIP) funding is available for producers in 12 Washington counties to implement conservation practices, including no-till/direct seed. Various Conservation Districts have no-till technical assistance programs.

References

Bista, P., S. Machado, R. Ghimire, G. Yorgey, D. Wysocki. 2017. Conservation tillage systems. Chapter 3 in Advances in Dryland Farming in the Inland Pacific Northwest. 99-124.

Ecotrust. 2016. Differentiated cost of production in the northwest: an analysis of six food categories – wheat and small grains.

Huggins, D., J. Reganold, 2008. No-till: the quiet revolution. Scientific American. 299: 70-77.

Painter, K. 2010. Direct seed mentoring project: an economic comparison of direct seed and conventional growers in the Washington/Idaho Palouse. Pacific Northwest Direct Seed Association Newsletter. V:10, N:3.

Plastina, A., A. Johanns. 2018. 2018 Iowa farm custom rate survey. Iowa State University, Extension and Outreach. FM 1698