Chapter 3

Conservation Tillage Systems

Prakriti Bista, Oregon State University
Stephen Machado, Oregon State University
Rajan Ghimire, New Mexico State University (formerly of Oregon State University)
Georgine Yorgey, Washington State University
Donald Wysocki, Oregon State University

Abstract

Conservation tillage may improve the sustainability of winter wheat-based crop rotations in the dryland areas of the inland Pacific Northwest (PNW). Intensive tillage systems often bury most surface crop residues, pulverize soil, and reduce surface roughness. The tilled systems also have the potential to accelerate soil fertility loss and soil erosion, reducing the long-term sustainability of dryland agriculture. This chapter reviews the sustainability challenges posed by conventional tillage, including soil erosion, soil organic matter (SOM) depletion, soil fertility loss, and soil acidification. It also synthesizes recent studies in the region and evaluates agronomic and environmental benefits of direct seeding, undercutter tillage fallow, and other forms of reduced tillage. Conservation tillage systems are contributing to enhanced sustainability of dryland agriculture in the region by reducing erosion, and improving soil health and ecosystem services.

Key Points

- Conventional tillage-based cropping systems deplete SOM, enhance soil erosion, and threaten sustainable crop production.

Research results are coded by agroecological class, defined in the glossary, as follows:

● Annual Crop ▲ Annual Crop-Fallow Transition ■ Grain-Fallow

- Conservation tillage systems have been increasingly adopted by growers in the inland PNW to conserve soil fertility and SOM, reduce soil erosion, and improve sustainability of dryland cropping systems in the region.
- Adoption of conservation tillage systems is dependent on considerations such as agroecological class, crop rotations, equipment, residue management, soil fertility management, support systems, and economics.

Introduction

Sustainable agricultural systems produce sufficient yields of farm products at profitable levels while conserving natural resources over the long-term (Wysocki 1990). For a system to be sustainable, it must be biologically productive, economically viable, environmentally sound, and socially beneficial. Soil erosion and SOM depletion are among the biggest sustainability challenges for conventional tillage dryland agriculture that is predominant in the **inland PNW**. The adoption of **conservation tillage** practices can address these issues and therefore contribute to sustainable farming systems in the region.

The Natural Resource Conservation Service (NRCS) and the Conservation Technology Information Center (CTIC) define conservation systems as crop management systems that leave at least 30% of crop residue on the soil surface after planting, to reduce soil erosion by water. In areas where wind erosion is a concern, any system that maintains at least the equivalent of 1,000 pounds per acre of crop residue from small grains on the surface throughout the critical erosion period is known as conservation tillage (CTIC 2016). In the inland PNW, the primary rationale for adopting conservation systems was to mitigate soil erosion by water and wind (Papendick 2004). This chapter provides an overview of tillage systems drawing on sources including the conservation tillage handbook and reports from Solution to Environmental and Economic Problems (STEEP) and the Columbia Plateau Project (PM10), reviews past and present literature related to conservation systems, and provides grower considerations for enhancing the sustainability of dryland agriculture in the inland PNW region.

Conventional System

Conventional tillage practices require four or more intensive tillage operations a year for seedbed preparation, weed control during **fallow**, and fertilization prior to planting. Conventional tillage has many variations and depends on cropping intensity and rotation, but a typical system in the region for managing summer fallow as described by Schillinger (2001) is (1) sweep tillage in August following winter wheat harvest (for weed control), (2) chiseling in November with straight point shanks (to prevent runoff from frozen ground), (3) glyphosate herbicide application in late winter (to control late fall and winter germinating weeds), (4) primary tillage in March with a cultivator equipped with sweeps and tine harrows, (5) a shank anhydrous ammonia application in April, and (6) rodweeding in May, June, and July. In total, a typical conventional system can have up to eight tillage operations during a 14-month fallow period, not including sowing. The repeated tillage often buries up to 90% of crop residue, pulverizes soil clods, and reduces surface roughness (Feng et al. 2011; Schillinger and Papendick 2008).

Because the dryland area of the inland PNW has diverse tillage, challenges and solutions also vary across the region. This section provides a brief overview of the major cropping systems of the inland PNW. Additional details on crop rotations can be found in Chapter 5: Rotational Diversification and Intensification.

Winter Wheat-Summer Fallow

Under a winter wheat-summer fallow rotation, only one crop is produced in two years. About 2.52 million acres of crop land are part of the Grain-Fallow **agroecological class** (AEC) (Huggins et al. 2015) that receives less than 12 inches of precipitation annually (Huggins et al. 2015; Schillinger et al. 2006a). In this system, winter wheat planted in fall or late summer is harvested the following summer (July). After crop harvest, the land is left fallow until the following September/October, a fallow period of about 14 months. The main purpose of the fallow is to store winter precipitation to enable the successful establishment of winter wheat planted in the fall. Fallow also helps to control weeds, reduce the risk of crop failure, and lessen the effects of drought.

Three-Year Winter Wheat-Based Rotation

In the Annual Crop-Fallow Transition AEC, covering 1.85 million acres of cropped land, crops are grown in two out of every three years. Rotations generally incorporate winter wheat, a spring cereal or legume, and fallow. This AEC covers areas receiving 12–18 inches of precipitation annually. More intensive cropping reduces the potential for soil erosion compared to the Grain-Fallow AEC. The enhanced diversity of the three-year rotation, especially when a non-cereal crop is included, also reduces weed and disease pressure (Ogg et al. 1999; Schillinger et al. 2006b; Smiley et al. 2013). The spring crops usually grown in rotation with winter wheat are spring barley, spring wheat, pea, lentil, chickpea, canola, and condiment mustard. ▲

Annual Cropping

In the Annual Crop AEC, about 1.44 million acres are annually cropped. This AEC generally receives more than 18 inches of precipitation per year. In addition to the spring crops, rotations often include winter triticale, winter canola, winter barley, and winter peas, with no fallow. Between 2007 and 2013, diversification and cropping intensity were found to be higher in the Annual AEC than in the Grain-Fallow AEC (Huggins et al. 2015). The Annual AEC presents more opportunities to vary crops making this AEC less vulnerable to weather or potential climate change than Grain-Fallow AEC (Huggins et al. 2015). ●

Conservation Systems

Conservation tillage practices are useful for erosion control, **soil health**, crop productivity, farm efficiency, and profitability. The three types of conservation tillage systems and one other tillage system defined by CTIC are described below.

Ridge Tillage

Ridge tillage eliminates full-width tillage. The soil is left undisturbed from harvest to planting except for strips up to one-third of the row width. Planting is completed on the ridge and usually involves removal of the top of the ridge. Equipment for such tillage often includes sweeps, disk openers, coulters, or row cleaners. Ridges are rebuilt during row cultivation and residue is left on the surface between ridges. Weed control is accomplished with crop protection products.

Mulch Tillage

Mulch tillage is designated as full-width tillage that disturbs the entire soil surface, and it is done prior to and/or during planting. Equipment used for this type of tillage includes chisel, disks, field cultivator, sweeps, or blades and harrows.

No-Till/Chemical Fallow

No-till/chemical fallow leaves the soil undisturbed from harvesting to planting. In the inland PNW, no-till is commonly described as **direct seeding**. Direct seeding eliminates full-width tillage for seedbed preparation. However, there are some variations within this system (Veseth 1999). Planting, seeding, or drilling is done using hoe drills. Weeds are controlled with crop protection products.

Low-disturbance direct seeding

Low-disturbance direct seeding involves the use of narrow knives, single discs, or double discs (standard or offset with one leading edge) that typically disturb less than 40% of the row width and retain nearly all residues on the surface.

High-disturbance direct seeding

Under high-disturbance direct seeding, hoe or sweep openers may disturb up to about 65% of the row width, but still retain much of the crop residue on the soil surface. With some flatter sweep blades, the surface soil and residue disturbance can be minimal even though much of the surface layer is undercut with the opener. Obviously, the furrow size, soil disturbance, and residue retention will vary with opener designs, speed, soil moisture, and other factors.

One-pass and two-pass direct seed systems

Growers can choose between one-pass direct fertilize and seed systems, and two-pass systems with direct fertilizing and direct seeding in separate operations. In both cases, there are no other tillage operations for seedbed preparation before seeding. The choice depends on the precipitation zone and seasonal distribution, length of planting windows, equipment availability, cost, crop choices, available labor, and other considerations.

The high-disturbance direct seed implement with wider hoe or sweep openers may not fit the classic no-till definition, but rather fall in the "mulch till" category because of full-width tillage between harvest and planting.

Reduced Tillage

Reduced tillage is designated as full-width tillage that disturbs the entire soil surface, leaving 15% to 30% of residue cover after planting.

Other conservation tillage practices in the inland PNW include minimum tillage, delayed minimum tillage, undercutter fallow, chisel, discs, and sweep tillage systems.

The undercutter method of fallow management uses wide V blade sweeps that slice beneath the soil surface and simultaneously deliver nitrogen during primary spring tillage followed by one or two non-inversion rodweeding operations during the summer to control weeds (Schillinger et al. 2010; Schillinger and Young 2014).

Both minimum tillage and delayed minimum tillage use undercutter V-sweep as a primary tillage. Herbicides may be used to control weeds following primary tillage, but secondary tillage such as rodweeding is used more commonly. Delayed minimum tillage is similar to minimum tillage except primary spring tillage with undercutter V-sweep is delayed until at least mid-May (Schillinger 2001).

Adoption of Conservation Systems in the Inland PNW

In general, there are considerable variations among conservation tillage practices. Certain conservation practices in the inland PNW are unique to the region. For example, farmers prefer hoe-type drills for cereal planting in narrow rows. As per the CTIC definition for no-till/direct seed, the threshold limit for soil disturbance is less than one-third the row width, which is difficult to achieve with the hoe drills used in this region. Hence, many acres of wheat or barley planted using direct seed are categorized as mulch tillage rather than no-till systems (Smiley et al. 2005). Other conservation tillage practices followed in the inland PNW besides direct seed are undercutter, chisel, discs, and sweep tillage systems. All forms of conservation practices, however, are aimed at protecting soil and water resources. Effects of different tillage implements on residue cover, SOM, and erosion in the inland PNW are summarized in Table 3-1.

As farmers in different AECs gain experience and confidence in conservation tillage systems and are motivated by fuel savings and government programs to promote such practices, the number of conservation farmers in the inland PNW is growing (Schillinger et al. 2010). Advances in no-till grain drill technology have allowed precise seed and fertilizer placement in one pass, saving growers the cost of multiple tillage operations needed under conventional systems. No-till acreage in Oregon for winter wheat has increased from less than 1% in 1996 to 16% (102,000 acres) in 2004, whereas no-till spring wheat acreage increased to 19% (434,000 acres) in 2004 from less than 2% in 1996. Similarly, in Washington no-till planting increased for both winter and spring wheat. Acreage under no-till winter wheat increased from 3% in 1990 to 11% (182,900 acres) in 2004, and no-till spring wheat acreage increased from 2% in 1990 to 18% in 2000 and remained steady throughout 2004 (Smiley et al. 2005). The increase in direct-seeded acres was attributed partly to the Pacific Northwest Direct Seed Association (***http://www.directseed.org/***), a grower-based organization formed in 2000 to promote conservation tillage and no-till farming in the region (Kok et al. 2009). A survey conducted in Columbia County, Washington, showed that 94% of winter crop land and 40% of spring crop land were direct seeded in 2007–2008 (***http://www.nacaa.com/presentations/presentation_list.php?app_id=407***). A recent representative survey of wheat growers from 33 different counties in Washington, Idaho, and Oregon showed that nearly 70% of the growers were using no-till or another form of conservation tillage in 2012–2013 (Figure 3-1).

Sustainability Challenges and Benefits of Conservation Systems

Dryland farming in this region faces three major sustainability challenges: erosion, loss of SOM, and soil acidification. This section describes each,

Table 3-1. Summary on the effects of crop rotations, tillage equipment, and tillage depths on residue cover, soil organic matter (SOM), and soil erosion.

Tillage system†	Crop rotation	Equipment	Years under current management	Tillage depth (cm)	Residue cover/ Ground cover (%)	SOM (ton/ac/yr) Loss (–) Gain (+)	Soil erosion (lb/ac)
Machado 2011 study site: Pendleton, OR ■							
Conventional	WW-F	MB plow	>65	23	22	–0.14 to –0.26	NR*
Conventional	WW-Pea	MB plow	42	23	21–27	+ 0.014 (SP) +0.07	NR
Reduced	WW-F	Disc Sweep	>65	15	63–66	–0.14 to –0.26	NR
Reduced	WW-Pea	Disc Chisel	42	15	49	+0.07	NR
Direct seed	WW-Pea	No-till drill	23	–	97	+0.56	NR
Machado et al. 2015 study site: Moro, OR ■							
Conventional	WW-F	Chisel Sweep	6	15	<15	NR	NR
Direct Seed	WW-WW SW-SW SB-SB WW-ChF WW-WP WW-SB-ChF	None	6	–	25 to >65	NR	NR
Williams and Wuest 2011 study site: Pendleton, OR ■							
Reduced	WW-SP- WW-F	Disc Chisel	4	31	59	NR	19

Tillage system†	Crop rotation	Equipment	Years under current management	Tillage depth (cm)	Residue cover/ Ground cover (%)	SOM (ton/ac/yr) Loss (–) Gain (+)	Soil erosion (lb/ac)
Direct seed	WW-SP-WW-F	None	4	–	81	NR	9
Williams et al. 2009 study site: Wildhorse Creek Watershed, OR ▲							
Conventional	WW-F WW-ChF	MB plow	4	–	5	NR	375
Direct seed	WW-F-WW-CP	None	4	–	67	NR	9
Riar et al. 2010 study sites: Davenport, WA and Helix, OR ▲							
Conventional	WW-F	Tandem disk	2	12	33.4 (OR) 69.3 (WA)	NR	NR
Reduced	WW-F	Sweep undercutter	2	12	37-42 (OR) 77-82 (WA)		
Direct seed	WW-F	None	2		43-48 (OR) 88-93 (WA)		
Stockle et al. 2012 study sites: multiple in eastern Washington ● ▲ ■							
Conventional to Direct seed	WW-F WW-SB-F WW-SB-SW SW-SB-SP SC-SC-P	NR	–	NR	NR	+0.13 to +0.24 CO_2 ton/ac/yr	NR

Tillage system†	Crop rotation	Equipment	Years under current management	Tillage depth (cm)	Residue cover/ Ground cover (%)	SOM (ton/ac/yr) Loss (–) Gain (+)	Soil erosion (lb/ac)
Brown and Huggins 2012 study sites: multiple (non-irrigated inland PNW region) ●▲■							
Conventional to Direct seed	Multiple	–	10-12	–	NR	+0.8 to +0.13	NR
Umiker et al. 2009 study sites: Palouse and Nez Perce, ID							
Conventional	WW-SW-SP	MB plow Chisel	2	NR	NR	1.79% SOM at 0-10 cm	NR
Direct seed	WW-SW-SP	None	2	–	>30	2.05% SOM at 0-10 cm	NR
Kok et al. 2009 study sites: multiple, inland PNW ●▲■							
Conventional to Reduced/Direct seed	Multiple	–	30	–	–	–	Reduced erosion from 40,000 to 10,000 lb/ac/yr

*NR: Not Reported

†Tillage system: Conventional tillage included moldboard plowing or offset heavy disk or tandem disk followed by tillage with secondary tillage – straight point chisel, harrow, cultivators, rodweeder. Reduced-tillage included combination two or more – sweep, chisel, cultivator, harrow, undercutter, rodweeder – minimum soil disturbance and direct seed included no-till hoe drill, no-till drill. SP = spring plow, FP = fall plow.

‡Crops in rotations: F = fallow, CP = chick pea, SW = spring wheat, SB = spring barley, WP = winter pea, SP = spring pea, ChF= chemical fallow.

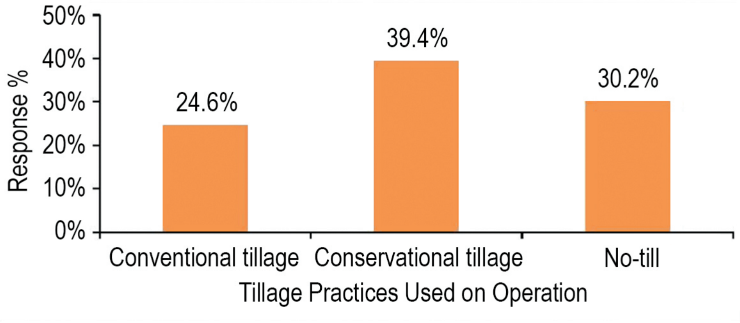

Figure 3-1: Distribution of tillage practices used by growers in inland PNW. Final response rate was 46.2% (900 surveys) with a sampling margin of error of +/- 3% at the 95% confidence interval. (Source: REACCH 2015)

explores the impacts of tillage on these issues, and provides insight on the effect of conservation systems on enhancing various aspects of sustainability including crop yield and farm economy.

Soil Erosion

Wind and water erosion are major factors affecting the sustainability of the cereal-producing regions of the inland PNW influencing both crop productivity and soil health. Historically, conventional farming practices had annual erosion rates of 10 to 30 ton/acre/year, resulting in topsoil loss equivalent to 0.75 ton of soil per bushel of wheat (Kok et al. 2009). ●▲■

Wind erosion and dust emissions mostly occur in low precipitation areas with sandy silt loam soils that are poorly **aggregated** and dominated by particulates <100 μm in diameter, which are vulnerable to wind erosion by direct suspension and have a great potential to emit particulate matter (PM10) (Feng et al. 2011). ■ Short duration, high-velocity winds affect nearly 6 million acres of crop land, posing an especially severe threat during fall and spring when soil is dry and soil cover is very limited (McCool et al. 2001; Papendick 2004). The dominance of winter wheat-fallow in this area often means that residue is produced in only one out of every two years, and, even in cropped years, water limitations constrain residue production (Papendick 2004). Excessive tillage during summer fallow pulverizes soil clods and buries residue (Young and Schillinger 2012).

Meanwhile, water erosion is a significant issue in wetter areas of the region, resulting in the loss of millions of tons of topsoil annually (Kok et al. 2009). Water erosion is caused by a combination of factors including winter precipitation with high potential for frozen soil runoff, steep and irregular topography (35% to 45% slope), and crop management systems that leave the soil with inadequate protection during the winter rainy season (Kok et al. 2009; Michalson 1999).

Planting winter wheat in early September in bare soil following intensive tillage causes up to two-thirds of annual soil erosion across the inland PNW (Papendick 2004).

Erosion is problematic for a number of reasons. Approximately one-third of eroded soil is deposited on surface water and can adversely affect water quality. Erosion of topsoil also results in the loss of nutrients resulting in declines in crop productivity and increased input costs (to replace lost nutrients) to sustain yield (Schillinger et al. 2010). In addition, loss of soil removes SOM and reduces water storage potential, negatively influencing root zone and seedbed environments, and the nutrient-supplying capacity of soil. Eastern Oregon fields with residue burning and no fertilizer application had higher soil erosion rates (1.47 ton/acre/year vs. 0.04 ton/acre/year) and lower SOM content compared to fields with standing stubble (Williams 2008). ■

While tillage is not the only factor that causes erosion, it is a major contributing factor. The tillage-intensive conventional systems create a dry, loose zone of fine soil particles which are susceptible to erosion by strong winds prevalent in the spring, late summer, and early autumn. Intensive inversion tillage increases total runoff to as high as 0.2 inches and soil erosion to 0.20 ton/acre compared to 0.03 inches and 0.005 ton/acre, respectively, in a no-till system at a similar slope position (Williams et al. 2009). ■ Remarkable improvements in erosion control have been achieved over the last 30 years mostly through the reduction in tillage (Kok et al. 2009). However, erosion remains an ongoing threat to the resources, environment, and agricultural economy of the region (Schillinger et al. 2010), emphasizing the need for conservation tillage practices.

Conservation tillage practices have been effective in minimizing soil erosion. The undercutter method of summer fallow management left sufficient surface residue to reduce soil loss from wind erosion by 65% and PM10 (an air quality indicator) by 70% compared to conventional (disk) tillage in winter wheat-fallow in a low precipitation zone of the Columbia Plateau (Sharrat and Feng 2009). Similarly, spring-sown cereal and chemical fallow or direct seed systems were reported to increase stored water, residue cover, soil aggregation, and soil strength, reducing the risk of wind erosion when compared to the conventional winter wheat-fallow rotation in east-central Washington (Feng et al. 2011). ■ Greater soil aggregation in a conservation tillage rather than in a conventional tillage system is shown in Figure 3-2.

Direct seed was also found highly effective in controlling runoff and soil erosion compared with inversion tillage systems in northeastern Oregon. The runoff and erosion totaled 0.2 inches and 0.19 ton/acre, respectively, under moldboard plowing, versus 0.03 inches and 0.005 ton/acre, under direct seed (Williams et al. 2009). ▲ In a four-year rotation of winter wheat-spring pea-winter wheat-fallow, direct seed had increased ground cover and **infiltration** rates, and decreased runoff and soil erosion when compared to tilled conservation practices such as mulch tillage, chisel plow, and undercutter (Williams and Wuest 2011). ■

Soil Organic Matter

Soil organic matter is essential for long-term sustainability of agricultural systems. It promotes soil aggregation, increases soil water and nutrient

Figure 3-2: Soil aggregation in conventional and reduced tillage. (Photo credit: Rajan Ghimire.)

holding capacity, serves as a sink for sequestration of atmospheric carbon, and facilitates **mitigation** of greenhouse gas emissions. Further discussion of the soil health impacts of SOM is presented in Chapter 2: Soil Health. Repeated tillage during field operations loosens the soils, makes it susceptible to erosion, and facilitates SOM loss through **mineralization** and oxidation.

Winter wheat-summer fallow systems in low precipitation zones of the inland PNW have lost more than 60% of SOM from topsoil (Brown and Huggins 2012; Ghimire et al. 2015; Machado 2011; Rasmussen and Smiley 1997). Similarly, a study on high precipitation regions of the Palouse has shown that conversion of native prairie to wheat cropping systems using intensive inversion tillage has caused substantial loss of organic matter pools including 56% of soil organic carbon, 79% of particulate organic carbon, 50% of microbial biomass carbon, and 28% of mineralizable carbon (Purakayastha et al. 2008). In addition to loss of SOM under intensive tillage, disease and weed incidence and weather variability negatively affected winter wheat production in the region (Camara et al. 2003; Sharma-Poudyal and Chen 2011; Smiley et al. 2009). ●▲■ The continued decline in SOM content and higher yield variability under intensive tillage threatens long-term agronomic and environmental sustainability of the winter wheat-fallow systems in the inland PNW.

Increasing SOM is a prerequisite for sustainable agricultural production. Conservation tillage systems are recognized for their ability to sequester carbon, minimize greenhouse gas emissions, and reduce the threat of climate change (Stöckle et al. 2012). Restoring SOM that has been lost due to years of intensive tillage in cold and dry regions of the inland PNW, however, is a great challenge because of low biomass production in dryland areas (Brown and Huggins 2012). Conservation tillage practices, along with intensifying cropping rotations, are recommended for increasing soil organic carbon sequestration in dryland areas where biomass production limits SOM accumulation (Machado et al. 2006). In a study evaluating the effects of different tillage and cropping systems on soil carbon sequestration, continuous cropping under direct seed was able to increase SOM in the top 10 cm of soil within a short period of six years compared to 73 years in a conventional winter wheat-fallow system in long-term experiments in Pendleton, Oregon (Machado et al. 2006). ■ Reduced tillage practices minimize SOM loss by eliminating or reducing tillage operations for field preparation, which benefits dryland cropping systems through soil water conservation (Lenssen et al. 2007) and protects biomass carbon from decomposition. In the low precipitation regions of eastern Washington, greater total SOM was observed with continuous direct seed spring cropping than with tillage fallow and direct seed chemical fallow (Gollany et al. 2013).■ The increased SOM in continuous direct seed spring cropping was mainly due to the accumulation of undecomposed crop residues that increased readily useable SOM for soil microbes (Gollany et al. 2013). Direct seed also increased near surface SOM content in the high precipitation region under spring wheat and pea compared to the conventional tillage system (Umiker et al. 2009).● Long-term use of direct seed systems has the potential to recover lost SOM compared with intensive tillage systems (Bista et al. 2016; Brown and Huggins 2012). ●▲■ Converting intensive tillage winter wheat-fallow to direct seed can reduce SOM loss by 17% to 47% depending on the residue and nutrient management practices (Bista et al. 2016). (Figure 3-3). ■

Soil pH and Soil Fertility

Acidification of soils is a major concern in the inland PNW. Soils with **pH** below 5 have been reported across all three AECs in the region (McFarland and Huggins 2015). Low soil pH affects many chemical and biological reactions in soil that influence nutrient availability and crop productivity. Agricultural management practices accelerate the rate of soil acidification mainly due to the continuous application of ammonium-based nitrogen fertilizers, continuous depletion of basic cations by crop removal, and accelerated rate of SOM decomposition (Mahler 2002). (See Chapter 2: Soil Health and Chapter 6: Soil Fertility Management for further detail.)

Conventional and conservation systems influence soil profile acidification differently. Stratified layers of acid soil at the depth of fertilizer placement has been observed in both direct seed fields in Palouse, Washington, and tilled long-term fertility trials in Pendleton, Oregon (Koenig et al. 2013). In a direct seed system, soil acidity develops more rapidly at the depth of fertilizer placement when compared to conventional tillage systems

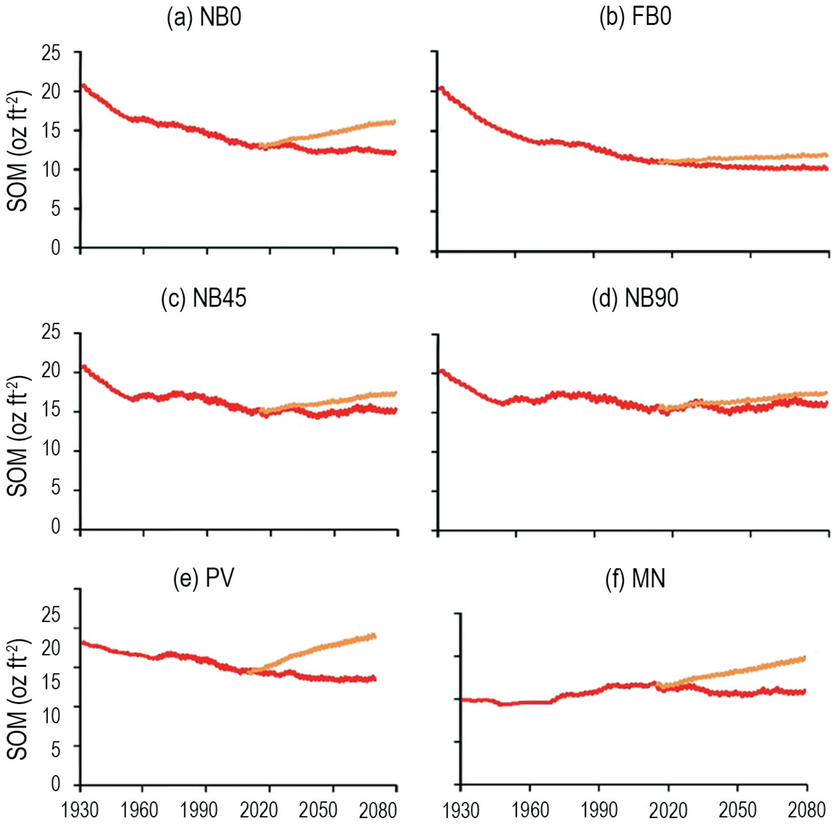

Figure 3-3: Prediction of soil organic matter (SOM) until 2080 under different crop residue and nitrogen (N) management treatments (a) to (f) with the baseline management (conventional tillage: red line) and alternative management (direct seed: orange line) in a moldboard plowed winter wheat-fallow system at Pendleton, Oregon, long-term experiments. (FB = fall stubble burn, NB = no burn, MN = manure application at primary tillage, PV = pea vine application at primary tillage. Accompanying numbers 0, 45, and 90 indicate amount of N applied from chemical fertilizer.) (Modified from Bista et al., 2016).

due to the absence of mechanical mixing (McCool et al. 2001). Therefore, there is some concern that direct seeding may exacerbate soil acidity.

Tillage management also influences nutrient availability and crop performance (Pan et al. 1997). Intensive tillage facilitates SOM decomposition and nutrient release. Over the long-term, this can deplete the nutrient bank in soil. (Fertility management strategies are discussed in Chapter 6: Soil Fertility Management.) For example, continuous use of conventional tillage in a winter wheat-fallow system for 84 years depleted nearly 30% of the soil N reservoir from the 0–60 cm soil profile in eastern Oregon (Ghimire et al. 2015). ■

Conservation tillage can also create challenges for managing fertility (Veseth 1999). Greater residue cover on the soil surface under a conservation tillage system sometimes immobilizes nutrients and makes them unavailable for the following crop. Reduced availability of nutrients, particularly nitrogen, is one of the many impacts of high concentrations of residue in conservation systems. (See Chapter 4: Crop Residue Management.)

Yield and Economics

The effects of direct seed, which is widely accepted for efficient erosion control and SOM sequestration, on crop yield and farm economy need to be further explored. Recent studies suggest that sufficiently high yield and greater farm profitability from conservation tillage compared to conventional tillage can be achieved. Similar wheat yield and grain quality as in a conventional system (disc/chisel) was obtained with a conservation tillage system (sweep tillage) in an intermediate precipitation region of Washington (Riar et al. 2016). However, the surface residue cover was greater with the conservation tillage system. ▲ Although sweep tillage systems had similar yields as conventional systems, they were more profitable because of reduced tillage operations and associated production costs. In Moro, Oregon (11-inch precipitation) comparable yields were observed under the conventional (chisel) winter wheat-fallow, direct seed winter wheat-chemical fallow, and winter wheat-spring barley-chemical fallow (Machado et al. 2015). ■ Given the conservation benefits from a direct seed system, such as greater residue cover and ecosystems services, direct seeding was recommended as an alternative system to conventional tillage. In eastern Washington, conservation tillage practices such as minimum tillage and delayed minimum tillage were found to be more profitable as they reduced fuel and farm labor expenses compared to conventional tillage winter wheat-fallow (Nail et al. 2007).

Similarly, a survey of 47 farmers in the inland PNW showed equivalent winter wheat grain yields and profitability in undercutter systems and conventional tillage fallow systems (Young and Schillinger 2016). In the low precipitation region of Washington, greater profitability from undercutter fallow systems than conventional dust mulch fallow systems were due to reduced costs of production (Zaikin et al. 2007). ■ Moreover, the undercutter system is eligible for conservation payments, but the traditional system is not. Such benefits further strengthen the profitability advantage of the undercutter system over the conventional system.

Additional Grower Considerations

Adoption of conservation farming systems vary based on factors such as climatic conditions, available equipment, crop rotations, soil type, topography, cash flow, information resources, federal farm programs, and other factors. When used in combination with other sustainable management practices, reduced tillage practices (e.g., direct seeding, undercutter tillage fallow, delayed planting, and minimum tillage) can help achieve favorable yields, attain farm profitability, and maintain environmental integrity. Details of alternative crop management practices such as legume incorporation are discussed in Chapter 5: Rotational Diversification and Intensification. The impacts of tillage on weed and disease control are described in Chapter 9: Integrated Weed Management and Chapter 10: Disease Management for Wheat and Barley. Differences among conventional and conservation tillage systems are given in Table 3-2.

Resources and Further Reading

Conservation Tillage Handbook

http://pnwsteep.wsu.edu/tillagehandbook/chapter1/index.htm

Columbia Plateau PM10 Project

http://pnw-winderosion.wsu.edu/

Regional Approaches to Climate Change – Pacific Northwest Agriculture

https://www.reacchpna.org/

Table 3-2. Differences between conservation and conventional tillage.

Parameters	Conservation tillage	Conventional tillage
Tillage operation	Minimum soil disturbance	Requires intensive tillage (more than four per year)
Crop residue	Leaves more than 30% (≈1,000 lb/ac) on surface	Crop residues are incorporated in soil
Soil organic matter (SOM)	Increase SOM sequestration in surface soil	Increase SOM loss from surface soil
Greenhouse gas emission	Reduce greenhouse gas emission such as CO_2	Increases greenhouse gas emissions
Erosion	Reduce soil loss from wind and water erosion	High risk of soil loss from wind and water erosion
Soil water storage	Increase infiltration and reduce evaporation	More soil water loss from evaporation and poor infiltration
Water body pollution	Minimum water body pollution with sediment load and field-applied chemicals	High risk of water body pollution
Aggregate stability	Increase soil aggregate stability	Lower soil aggregate stability
Labor and fuel	Low fuel use and labor cost	High fuel use and labor costs due to more trips over the field
Tillage equipment	Direct seed drills costlier than conventional drills	Machinery is widely available
Weed control	Reliance on herbicide during fallow	Tillage used to control weeds
Crop management	Information on new crop management strategies evolving	Relatively more information on crop management strategies
Germination	Potential slower germination	Well-tilled and clean seeding facilitates germination and plant establishment
Fertilizer	May initially require more nitrogen	Initial nitrogen requirement does not increase

Costs of Owning and Operating Farm Machinery in the Pacific Northwest. Pacific Northwest Extension Publication PNW346.

http://whatcom.wsu.edu/ag/documents/enterbudgets/CostOwnOperFarmMachPNW.pdf

References

Bista, P., S. Machado, R. Ghimire. S.J. Delgrosso, and M. Reyes-Fox. 2016. Simulating Organic Carbon in a Wheat-Fallow System Using Daycent Model. *Agronomy Journal* 108: 2554–2565.

Brown, T.T., and D.R. Huggins. 2012. Soil Carbon Sequestration in the Dryland Cropping Region of the Pacific Northwest. *Journal of Soil Water Conservation* 67: 406–415.

Camara, K.M., W.A. Payne, and P.E. Rasmussen. 2003. Long-Term Effects of Tillage, Nitrogen, and Rainfall on Winter Wheat Yields in the Pacific Northwest. *Agronomy Journal* 95: 828–835.

CTIC (Conservation Technology Information Center). 2016. West Lafayette, Indiana. ***http://www.ctic.org/resourcedisplay/322/***

Feng, G., B. Sharratt, and F. Young. 2011. Soil Properties Governing Soil Erosion Affected by Cropping Systems in the U.S. Pacific Northwest. *Soil and Tillage Research* 111: 168–174.

Ghimire, R., S. Machado, and K. Rhinhart. 2015. Long-Term Crop Residue and Nitrogen Management Effects on Soil Profile Carbon and Nitrogen in Wheat-Fallow Systems. *Agronomy Journal* 107: 2230–2240.

Gollany, H.T., A.M. Fortuna, M.K. Samuel, F.L. Young, W.L. Pan, and M. Pecharko. 2013. Soil Organic Carbon Accretion vs. Sequestration Using Physicochemical Fractionation and CQESTR Simulation. *Soil Science Society of America Journal* 77: 618–629.

Huggins, D.R., R. Rupp, P. Gessler, W. Pan, D. Brown, S. Machado, J. Abatzoglou, V. Walden, and S. Eigenbrode. 2012. Dynamic Agroecological Zones for the Inland Pacific Northwest, USA. ASA Annual Meeting, Oct. 21–24, Cincinnati, OH.

Huggins, D., Pan, W., Schillinger, W., Young, F., Machado, S. and K. Painter. 2015. Crop Diversity and Intensity in the Pacific Northwest Dryland Cropping Systems in Regional Approaches to Climate Change for Pacific Northwest Agriculture: Climate Science Northwest Farmers Can Use. REACCH Annual Report Year 4: 38-41. University of Idaho, Washington State University, and Oregon State University.

Koenig, R., K. Schroeder, A. Carter, M. Pumphrey, T. Paulitz, K. Campbell, and D. Huggins. 2013. Soil Acidity and Aluminum Toxicity in the Palouse Region of the Pacific Northwest. Washington State University Extension Publication FS050E. ***http://pubs.wpdev.cahnrs.wsu.edu/pubs/fs050e/?pub-pdf=true***

Kok, H., R.I. Papendick, and K.E. Saxton. 2009. STEEP: Impact of Long-Term Conservation Farming Research and Education in Pacific Northwest Wheatlands. *Journal of Soil and Water Conservation* 64: 253–264.

Lenssen, A.W., G.D. Johnson, and G.R. Carlson. 2007. Cropping Sequence and Tillage System Influences Annual Crop Production and Water Use in Semiarid Montana, USA. *Field Crop Research* 100: 32–43.

Machado, S. 2011. Soil Organic Carbon Dynamics in the Pendleton Long-Term Experiments: Implications for Biofuel Production in Pacific Northwest. *Agronomy Journal* 103: 253–260.

Machado, S.M., K. Rhinhart, and S.E. Petrie. 2006. Long-Term Cropping System Effects on Carbon Sequestration in Eastern Oregon. *Journal of Environmental Quality* 35: 1548–1553

Machado, S.M., L. Pritchett, and S.E. Petrie 2015. No-Tillage Cropping Systems Can Replace Traditional Summer Fallow in North-Central Oregon. *Agronomy Journal* 107: 1863–1887.

Mahler, R.L. 2002. Impacts and Management of Soil Acidity Under Direct-Seed Systems: Status and Effects on Crop Production. Proceedings of Northwest Direct-Seed Cropping Systems Conference, Jan. 16–18, Spokane, WA. ***http://pnwsteep.wsu.edu/directseed/conf2k2/dscmahler.htm***

McCool, D.K., D.R. Huggins, K.E. Saxton, and A.C. Kennedy. 2001. Factors Affecting Agricultural Sustainability in the Pacific Northwest, USA: An Overview. 10th Sustaining the Global Farm: International Soil Conservation Organization Meeting, West Lafayette, IN. 24–29 May 1999. National Soil Erosion Research Laboratory, West Lafayette, IN. p. 255–260.

McFarland, C., and D.R. Huggins. 2015. Acidification in the Inland Pacific Northwest. *Crop and Soils Magazine* March-April: 4–12.

Michalson, E.L. 1999. A History of Conservation Research in the Pacific Northwest. In Conservation Farming in the United States—The Methods and Accomplishments of the STEEP program, E.L. Michalson, R.I. Papendick, and J.E. Carlson, eds. CRC Press, Boca Raton 1–10.

Nail, E.L., D.L. Young, and W.F. Schillinger, 2007. Diesel and Glyphosate Price Changes Benefit the Economics of Conservation Tillage versus Traditional Tillage. *Soil and Tillage Research* 94: 321–327.

Ogg, A.G., R.W. Smiley, K.S. Pike, J.P. McCaffrey, D.C. Thill, and S.S. Quisenberry. 1999. Integrated Pest Management for Conservation Systems. In Conservation Farming in the United States: The Methods and Accomplishments of the STEEP program, E.L. Michalson, R.I. Papendick, and J.E. Carlson, eds. CRC Press, Boca Raton 97–127.

Pan, W.L., D.R. Huggins, G.L. Malzer, C.L. Douglas, Jr., and J.L. Smith. 1997. Field Heterogeneity in Soil-Plant Nitrogen Relationships: Implications for Site-Specific Management. In the Site-Specific Management for Agriculture Systems. ASA-CSSA-SSSA, Madison, Wisconsin.

Papendick, R.I. 2004. Cropping Systems Research to Control Wind Erosion and Dust Emissions on Dryland Farms. In Farming with the Wind II. Wind Erosion and Air Quality Control of the Columbia Plateau and Columbia Basin. University Publishing, WSU, Pullman, Washington.

Purakayastha, T.J., D.R. Huggins, and J.L. Smith. 2008. Carbon Sequestration in Native Prairie, Perennial Grass, No-Till, and Cultivated Palouse Silt Loam. *Soil Science Society of America Journal* 72: 534–540.

Rasmussen, P.E., and R.W. Smiley. 1997. Soil Carbon and Nitrogen Change in Long-Term Agricultural Experiments at Pendleton, Oregon. In Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America, E.A. Paul et al., eds. CRC Press, Boca Raton, FL.

REACCH (Regional Approaches to Climate Change). 2015. Variation in Tillage Practices among Inland Northwest Producers. Regional Approach to Climate Change – Pacific Northwest Agriculture report by J. Gray, S. Gantla, L. McNamee, L. Bernacchi, K. Borrelli, B. Mahler, M. Reyna, B. Foltz, S. Kane, and J.D. Wulfhorst.

Riar, D.D., D.A. Ball, J.P. Yenish, S.B. Wuest, and M.K. Corp. 2010. Comparison of Fallow Tillage Methods in the Intermediate Rainfall Inland Pacific Northwest. *Agronomy Journal* 102: 1664–1673.

Schillinger, W.F., and R.I. Papendick. 2008. Then and Now: 125 Years of Dryland Wheat Farming in the Inland Pacific Northwest. *Agronomy Journal* 100: 166–182.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2006a. Dryland Cropping in the Western United States. In Dryland Agriculture, 2nd ed., G.A. Peterson et al., eds. *Agronomy Monograph* 23. ASA, CSSA, and SSSA, Madison, WI.

Schillinger, W., T. Paulitz, R. Jirava, H. Schafer, and S.E. Schofstoll. 2006b. Reduction of Rhizoctonia Bare Patch in Wheat with Barley Rotations. Washington State University Publication XB1045E. ***http://www.pnw-winderosion.wsu.edu/Docs/Publications/06%20 pubs/RedRhizocXB.pdf***

Schillinger, W.F. 2001. Minimum and Delayed Conservation Tillage for Wheat-Fallow Farming. *Soil Science Society of America Journal* 65: 1203–1209.

Schillinger, W.F., and D.L. Young. 2014. Best Management Practices for Summer Fallow in the World's Driest Rainfed Wheat Region. *Soil Science Society of America Journal* 78: 1707–1715.

Schillinger, W.F., R.I. Papendick, and D.K. McCool. 2010. Soil and Water Challenges for Pacific Northwest Agriculture. In Soil and Water Conservation Advances in the United States, T.M. Zobeck and W.F. Schillinger, eds. Soil Science Society of America Special Publication 60, 47–79. Soil Science Society of America, Madison, WI.

Sharma-Poudyal, D., and X.M. Chen. 2011. Models for Predicting Potential Yield Loss of Wheat Caused by Stripe Rust in U.S. Pacific Northwest. *Disease Control and Pest Management* 101: 544–554.

Sharratt, B.S., and G. Feng. 2009. Windblown Dust Influenced by Conventional and Undercutter Tillage within the Columbia Plateau, USA. Earth Surface Processes and Landforms 34: 1323–1332.

Smiley, R., W.S. Machado, J.A. Gourlie, L.C. Pritchett, G.P. Yan, and E.E. Jacobsen. 2013. Influence of Semi-Arid Cropping Systems on Root Diseases and Inoculum Density of Soil Borne Pathogens. *Plant Disease* 97: 547–555.

Smiley, R.W., D. Backhouse, P. Lucas, and T.C. Paulitz. 2009. Diseases which Challenge Global Wheat Production—Root, Crown, and Culm Rots. In Wheat: Science and Trade. Blackwell Publishing, Ames, IA. 125–153.

Smiley, R.W., M.C. Siemens, T.M. Gohlke, and J.K. Poore. 2005. Small Grain Acreage and Management Trends for Eastern Oregon and Washington. Dryland Agricultural Research Annual Report (Special Report 1061): 30–50

Stöckle, C., S. Higgins, A. Kemanian, R. Nelson, D. Huggins, J. Marcos, and H. Collins. 2012. Carbon Storage and Nitrous Oxide Emissions of Cropping Systems in Eastern Washington: A Simulation Study. *Journal of Soil Water Conservation* 67: 365–377.

Umiker, K.J., J.L. Johnson-Maynard, T.D. Hatten, S.D. Eigenborode, and N.A. Bosque-Pérez. 2009. Soil Carbon, Nitrogen, pH, and Earthworm Density as Influenced by Cropping Practices in the Inland Pacific Northwest. *Soil and Tillage Research* 105: 184–191.

Veseth, R.J. 1999. PNW Direct Seeding Status and What's Driving it. PNW Conservation Tillage Handbook Series No. 25, Chapter 2.

Williams, J.D. 2008. Soil Loss from Long-Term Winter-Wheat/Summer Fallow Residue and Nutrient Management Experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon. In 2008 Dryland Agricultural Research Annual Report. Agricultural Experiment Station, Oregon State University.

Williams, J.D., and S.B. Wuest. 2011. Tillage and No-Tillage Conservation Effectiveness in the Intermediate Precipitation Zone of the Inland Pacific Northwest, United States. *Journal of Soil and Water Conservation* 66: 242–249.

Williams, H.D., H.T. Gollany, M.C. Siemens, S.B. Wuest, and D.S. Long. 2009. Comparison of Runoff, Soil Erosion, and Winter Wheat Yields from No-Till and Inversion Tillage Production Systems in Northeastern Oregon. *Journal of Soil and Water Conservation* 1: 43–52.

Wysocki, D. 1990. Conservation Farming and Sustainability. In Pacific Northwest Conservation Tillage Handbook Series No. 12, Chapter 1: Soil Erosion Impacts on Productivity.

Young, D.L., and W.F. Schillinger. 2012. Wheat Farmers Adopt the Undercutter Fallow Method to Reduce Wind Erosion and Sustain Profitability. *Soil and Tillage Research* 124: 240–244

Young, D.L., and W.F. Schillinger. 2016. Wheat Farmers Adopt the Undercutter Fallow Method to Reduce Wind Erosion and Sustain Profitability. Washington State University Extension Bulletin.

Zaikin, A.A., D.L. Young, and W.F. Schillinger. 2007. Economic Comparison of the Undercutter and Traditional Tillage Systems for Winter Wheat-Summer Fallow Farming. Washington State University Working Paper Series 2007–15. ***http://faculty.ses.wsu.edu/WorkingPapers/WP_2007-15_Undercutter.pdf***