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Factors Affecting Agricultural Sustainability in the Pacific Northwest, USA: An Overview

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ABSTRACT

Tillage-based crop management systems have been a major factor in the degradation of soil quality in the Northwestern Wheat and Range Region of the Pacific Northwest, USA. Subsoil has become exposed by water erosion and tillage translocation, and tillage-based management has caused oxidation of soil organic matter, and adversely impacted soil fauna. Soil acidification increased rapidly after the introduction of commercial fertilizer. Conventional tillage-based crop management is clearly agronomically unsustainable. Reduced tillage and retention of crop residues on the soil surface reduce erosion as well as the rate of soil degradation. True agricultural sustainability will be achieved only when the numerous agronomic and engineering challenges to no-till seeding practices are overcome and the practices are widely adopted in the region.

INTRODUCTION

Achieving agricultural sustainability in the Northwestern Wheat and Range Region (NWRR) (Figure 1) (Austin, 1981) will be challenging to producers, researchers, and policy makers and will require fundamental changes in current farming systems. Conventional tillage-based agricultural systems dominate the region and have seriously degraded the soil resource base and caused adverse environmental impacts including air and water pollution (Saxton et al., 2000). The long-term productivity of the region's soil resources are currently threatened by wind and water erosion (Saxton et al., 2000), tillage-induced translocation of soil from ridge-tops and upper side slopes to lower landscape positions (McCool et al., 1998), declining soil organic matter levels (Rasmussen et al., 1989), increasing soil acidification (Mahler et al., 1985), and reduced soil biological activity and diversity (Elliott and Lynch, 1994). Effects of soil degradation have been masked by increased overall crop yields through technological advancements in crop breeding, and nutrient and pest management. However, conventional tillage-based crop management systems are not compatible with long-term sustainability. The purpose of this paper is to provide an overview of major factors affecting agricultural sustainability in the NWRR, the impact of past and present agricultural practices, and to enumerate challenges that must be overcome to achieve long-term sustainability.

BACKGROUND

Cropland soils in the NWRR, USA (eastern Washington, northern Idaho, north central Oregon, and southern Idaho) (Figure 1) are predominantly developed from loess deposits. The loess is layered over massive basalt flows, and accumulated from seasonal dust storms over the past 2 million years (Busacca, 1989). The most recent loess layer of 60 to 150 cm depth was deposited during the last 18,000 years (Busacca and McDonald, 1994). The soil profiles that developed in this layer were first tilled by early settlers in the late 1860's (Kaiser, 1961). Twenty years later, much of the land suitable for non-irrigated cropping was under cultivation (Kaiser, 1961).

A steep precipitation gradient exists from the rain shadow east of the Cascade Mountains in Washington and Oregon where as little as 150 mm yr^{-1} of precipitation occurs (Daubenmire, 1988), to the eastern part of the cropped area that extends to the mountains in Washington, Idaho and Oregon and which may receive as much as 635 mm $yr^{-1}$of precipitation (McCool and Busacca, 1999). A gradient of soil texture also occurs with loam and coarse silty-loam soils generally found in the western portion of the region and finer-textured silt loams in the east (Busacca and McDonald, 1994). The drier areas of the western portion are suitable for cropping only where irrigation water is available. Wind erosion can be severe on these relatively flat landscapes after low residue crops such as potatoes. In areas slightly east where precipitation is sufficient for crop production with natural rainfall, winter wheat-summer fallow cropping

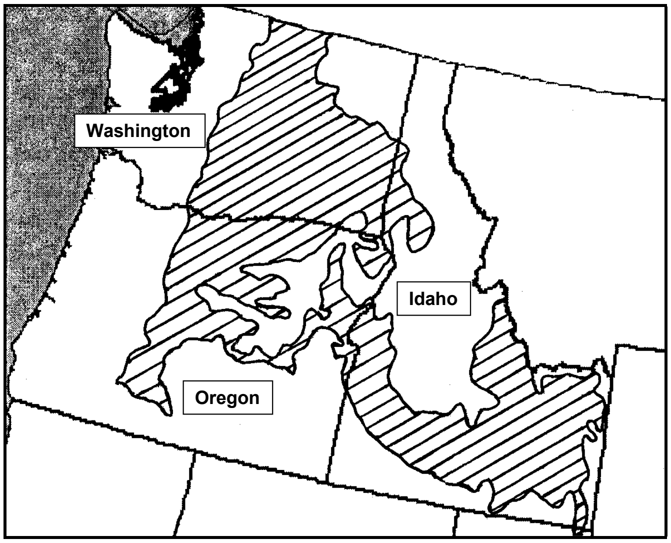

Figure 1. Northwestern Wheat and Range Region of the Pacific Northwest, USA.

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Figure 2. Exposed subsoil decreases productivity on ridge-tops and knobs in eastern Washington.

systems predominate. Here, coarse-textured soils are susceptible to creep and saltation wind erosion, while finer-textured, poorly aggregated, soils are prone to suspendable dust emission.

In the eastern portion of the region, the soils are primarily silt loams, topography is steeper than in the western portion of the region and may have a unique dune-like form (Figure 2), and water erosion is a major concern in areas where annual precipitation is greater than 300 mm. The seasonal precipitation pattern is Mediterranean. Winters are cold and wet and summers are warm to hot and dry. About 60% of the annual precipitation occurs from November through March, and only 5% in July and August (Kaiser, 1967).

The Snake River Plains and Eastern Idaho Plateaus in southern Idaho are included in the NWRR (Figure 1). This area is similar to the drier to intermediate precipitation zones east of the Cascade Mountains in Washington and Oregon in terms of soil, precipitation, native vegetation, and current land use. Precipitation is not sufficient to support annual cropping; summer fallow is included in most rotations.

The vast loess deposits of the Pacific Northwest are often considered to be an inexhaustible supply of productive soil. This assumption is incorrect, even though the loess in some areas can be as much as 75m deep (Ringe, 1970). The loess parent material is generally less conducive to crop production than higher organic matter surface soils. Developed soil profiles may contain argillic horizons with low permeability or root impeding characteristics (Busacca, et al., 1985). Ancient buried soils (paleosols) are frequently found. These can restrict roots or can reduce water available to crops by impeding permeability and causing increased runoff (Busacca et al., 1985). Soils in many of the wheat producing areas of Oregon are shallow-to-bed rock, and thus have a low allowable soil loss. Ridge-tops and tops of isolated knobs in the eastern part of the region are areas where topsoil is quite shallow and productivity is correspondingly low (Busacca et al., 1985).

Soil Erosion

Wind and water erosion are currently major factors affecting agricultural sustainability in the region. The primary wind erosion and dust emission areas are those with low rainfall and sandy or poorly aggregated soils, occupying the central portion of the NWRR in Washington and Oregon, and portions of the NWRR in southern Idaho (Figure 1). About 2.75 million ha of cropland are susceptible to wind erosion. Wind erosion in the area is usually the result of high velocity events of short duration. While gusty winds can be expected at nearly any time of the year, cropland is mainly susceptible to wind erosion in the fall and spring because of limited soil cover and dry soil conditions. Wind erosion prediction models such as the wind erosion equation (WEQ) (Woodruff and Siddoway, 1965), that use mean monthly wind speed as primary input do not perform well under these conditions. Surface cover and roughness are primary means of preventing wind erosion. Retaining adequate surface cover to protect from wind erosion is extremely difficult in areas receiving the minimum amount of precipitation needed for non-irrigated cropping, particularly during times of drought. Direct seeding offers the greatest potential for retaining sufficient surface residues to protect against wind erosion while conserving soil water critical for crop production.

Water erosion is greatest from November through March, when about 60% of the precipitation occurs and the soil is subjected to numerous cycles of freezing and thawing, frequently accompanied with rainfall and snowmelt. Soil freezing increases water content at the freezing front and can result in an impermeable frost layer, thus decreasing permeability and infiltration. When thawing at such high water content, the soil is very weak and erodible (Kok and McCool, 1990). Land slopes are steep and may be quite long. Despite rainfall of low intensity and kinetic energy, even small amounts of rainfall or snowmelt can cause disproportionately large soil losses under these conditions. Management practices such as winter wheat after summer fallow with conventional tillage, that result in very small amounts of crop residue and plant cover prior to the winter erosion season, exacerbate the hazard of soil erosion. Past federal farm subsidy programs attempted to reduce production by restricting the number of acres planted. This resulted in the adoption of summer fallow in high precipitation zones, not because the extra water was needed, but because summer fallow increased yields per acre seeded and, during the fallow year, met the requirements for land taken out of production.

Since the area was broken from virgin prairie or timber less than 120 years ago, much of the cropland has been degraded by wind, water, or tillage erosion. The USDA estimated in 1978 that erosion in the Palouse River Basin in eastern Washington and northern Idaho had removed all of the original topsoil from 10% of the cropland, and one-fourth to three-fourths of the topsoil from another 60% (USDA, 1978). Erosion losses were recognized as critical in the 1920's, and the Pacific Northwest Soil Erosion Experiment Station (PNSEES) was established near Pullman, WA in 1930. Original experiments included runoff plots, terraces, crop rotation studies, and small watersheds. Current emphasis at the Palouse Conservation Field Station (PCFS) of the USDA-Agricultural Research Service, that evolved from the PNSEES, is on wind erosion and dust emission prediction and controls, water erosion prediction

Figure 3. Tillage operations have removed approximately one meter of soil from the down slope boundary of this hill top wind break.

and reduction, soil quality improvement, and direct seeding as a tool to achieve sustainability.

Tillage Translocation

Traditional use of the moldboard plow on steep slopes has made tillage translocation of soil a problem on an ever-increasing portion of the landscape in steeper areas. While sometimes mentioned, tillage translocation receives little serious attention, but may be the cause of much of the exposed subsoil and calcareous layers in the NWRR. The amount of translocated soil is difficult to determine beyond measuring the quantities deposited above fencerows up slope from areas that have never been tilled, and the depth removed down slope from fixed features such as windbreaks that have been in place for a known period (Figure 3). A recent study in the region demonstrated the relationships between years of cultivation, number of plow passes, and measured deposition (McCool et al., 1998). These data support the hypothesis that tillage translocation is currently exposing more subsoil than water erosion on ridge-tops and the upper portion of steep slopes (Figure 2).

Soil Acidification

Conversion of natural ecosystems to agricultural production often accelerates soil acidification, primarily as a consequence of base depletion from crop removal, increased organic matter decomposition, and the application of ammonium-based nitrogen fertilizers (Mahler et al., 1985). Soils formed under native prairie in eastern Washington and northern Idaho were near neutral pH (7.0) when the land was first cultivated in the latter part of the 19th century. Mahler et al. (1985) reported that soil pH had declined from near neutral to values less than 6.0 in over 65% of the agricultural soils by the early 1980's. This rapid acidification rate was attributed to the increased use of commercial N fertilizers that occurred after 1960. Furthermore, Mahler et al. (1985) reported that the rate of soil acidification appeared to be increasing over time. Recently, Bezdicek et al. (1998) reported soil pH values as low as 4.6 near Touchet, WA and 4.9 near Palouse, WA, indicating that soil acidification has continued to increase across the region. At these pH levels, grain yields of all major crops (wheat (*Triticum aestivum* L.)), barley (*Horeum vulgare* L.), lentils (Lens Mill. (Fabaceae)), and peas (*Pisum sativum* L.)) are adversely affected (Mahler and McDole, 1987). Predicting the effects of soil acidification on future crop production and developing of management alternatives requires an understanding of how different acidifying factors contribute to the overall rate of soil acidification, but these processes are currently not well understood. Long-term direct seeding of crops tends to further decrease soil pH in the seed zone as compared to conventional tillage (Bezdicek et al., 1998). The rapid acidification of soils in the region takes on additional significance because there are currently no readily available sources of lime in the region.

Declining Soil Organic Matter

Tillage-based farming systems exploit soil organic matter and quickly exhaust biologically oxidizable forms (Huggins et al., 1998). Long-term research at Pendleton, OR indicates that organic matter levels of tillage-based agricultural systems have declined by 40 to 50% over the course of 100 years of cultivation. Recent concerns over rising levels of atmospheric carbon dioxide (CO_2) and global change have drawn attention to management influences on soil organic matter and carbon (C) sequestration (Lal et al., 1995). Greater soil C sequestration would benefit soil, air, and water quality and is a fundamental objective to develop a sustainable cropping system. Cropping systems that increase C inputs and reduce or eliminate intensive tillage will improve C sequestration. Increasing C inputs could result from eliminating residue burning and intensifying crop rotations to reduce or eliminate fallow periods and/or from including more winter annual or perennial crops in rotation. Developing continuous no-till cropping systems is a promising approach to increasing C inputs into the farming system by reducing tillage-induced biological oxidation. Many studies have shown that soil organic matter can be increased with continuous no-till (Paustian et al., 1997).

Soil Microbial Activity

Soil biology is vital to the functioning of soil, and thus can influence the sustainability of an agroecosystem. Tillage alters the physical and chemical characteristics of the soil and this will profoundly affect the growth, functioning, and survival of the soil biota. Intensive cultivation and disturbance generally have a negative affect on microbial populations and processes (Elliott and Lynch, 1994). Microbial community analyses are useful in distinguishing changes occurring with differing cropping systems and tillage (Drijber et al., 2000; Ibekwe and Kennedy, 1999). The biological components of soil can serve as an early indication of the effect of a management practice on soil quality (Kennedy and Papendick, 1995).

Conventional tillage practices may result in microbial community shifts by increasing resource heterogeneity and altering microbial diversity (Wander et al., 1995; Kennedy and Smith, 1995). Since conventional tillage practices disrupt soil aggregates, more organic matter is exposed to microbial interactions (Beare et al., 1994). Increasing tillage stimulates the mineralization of organic matter that will improve the soil nutrient supply, but reduces organic matter accumulation (Wander et al., 1994). Exposed soil and organic matter allows for pulses of increased microbial activity, which releases CO_2 at an accelerated rate due to the oxidation of C in the residue to CO_2 (Reicosky, et al., 1995). Increased respiration rates associated with more intensive tillage practices leave less C available for microbial growth (Follett and Schimel, 1989). Surface managed residues leads to improved soil aggregation and greater organic matter content (Elliott and Papendick, 1986). Conventionally tilled, no-till, and grassland systems have different physical environments that alter growth and structure of the microbial population (Kennedy and Smith, 1995). Grasslands, or other perennial crops, generally have higher levels of microbial biomass, compared to land under cultivation (Carter, 1991). In long-term plots, Jordan et al. (1995) found that enzyme activity, microbial biomass C, and phospholipids were significantly greater in no-till and uncultivated prairie soils compared to that in cultivated soils. Microbial investigations may enhance our understanding of the changes that are occurring with the adoption of minimum or no-tillage systems.

Achieving Sustainability

Sustaining soil productivity has been described as the balance between degradation processes and conservation and reclamation practices (Hornick and Parr, 1987). If soil degradation processes become and remain dominant, then a cropping system cannot be sustained over time. This is the current situation in most of the non-irrigated cropping region of the NWRR.

Sustainability can be achieved only if soil erosion rates are reduced well below current levels. Wind erosion is a selective process, sending fine nutrient-rich fractions aloft for deposition many kilometers downwind and leaving behind coarser sand particles of lower fertility. Water erosion causes excessive local damage on certain parts of the landscape but leaves other areas unscathed. Interrill water erosion removes the finer soil fractions, whereas rill erosion is much less selective. Rill erosion, however, does not remove soil uniformly across the landscape, but at higher rates where runoff moves toward concave areas, and in swales.

Even though erosion prediction schemes such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) estimate mean annual soil loss, the erosion rate varies widely throughout a crop rotation that is under conventional management. The bulk of the erosion on non-irrigated cropland in the NWRR occurs from fall-seeded small grain. Erosion is generally much less from spring-seeded crops. Thus, if average annual soil loss over a multi-year rotation is 10 t ha^{-1}, soil loss might be 20 to 30 t ha^{-1} from rills alone from a fall-seeded crop, but only 2 to 3 t ha^{-1} of inter-rill erosion from spring-seeded crops. High soil loss in one year of five may cause greater localized damage over the course of a few rotation cycles than would be indicated by a mean soil loss of 11.2 t ha^{-1}.

Tillage translocation can be minimized either by ceasing the use of inversion tillage, or by turning the furrow slice uphill. Areas heavily damaged by tillage translocation can not be reclaimed by these techniques. No-till seeding techniques can gradually reverse this damage, but on some locations exposure of nonproductive soil horizons will make crop production uneconomical. Returning this land to permanent vegetation may be the best option.

While the use of the moldboard plow or chisel can increase water infiltration and prevent erosion during a single season, this benefit can be cancelled later by erosion under reduced residue cover resulting from the aggressive primary tillage. Recent data indicate rapid oxidation of soil organic matter following use of the moldboard plow (Reicosky et al., 1995). The losses of C were greater than the amount added to the soil by the previous crop, and greater than the loss of C due to erosion at a tolerance rate of 11.2 t ha^{-1}. Reducing the number of highly disruptive tillage operations such as moldboard plowing will decrease the rate of oxidation of soil organic matter in the soil (Paustion et al., 1997). The greater amount of surface residue resulting from reducing tillage will increase infiltration and decrease evaporation.

Results of studies in the NWRR confirm the value of surface cover to control wind and water erosion (Horning et al., 1998; McCool et al., 1997; Pannkuk et al., 1998). For water erosion under tillage-based crop production, crop management elements such as residue, canopy cover, and surface roughness are more effective in reducing erosion than in reducing runoff, mostly due to the formation of impermeable frost layers that hamper infiltration. Soil macro-porosity is necessary to maintain infiltration under these frozen conditions. Macro-porosity may be maintained in the soil using a slot mulch technique with narrow trenches filled with crop residue (Saxton et al., 1981), or by the natural channels formed by roots or worms in continuous no-till fields.

Developing viable conservation tillage practices, including continuous no-tillage, is a key element in achieving sustainable non-irrigated agriculture in this region. Continuous no-tillage management could control erosion, increase water infiltration and conservation, decrease air and water pollution, and restore soil productivity. Many challenges remain to be overcome before this technology is widely adopted by growers who are reluctant to abandon current systems and technologies that have successfully increased production. Challenges to continuous no-tillage include developing equipment and techniques to reliably plant into heavy residues, designing suitable crop rotations, and addressing possible system constraints such as localized soil acidification. Gaining greater understanding of changes that occur in soil processes and crop performance under no-tillage, and developing equipment and management practices that compliment the no-tillage environment are major research needs.

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