

Promoting and Applying Conservation Practices on Dry and Irrigated Croplands

FARMING TO PROTECT SOIL ECOSYSTEM HEALTH

A major goal in efforts to control soil erosion by wind and improve air quality on the Columbia Plateau is the development and grower-adoption of best management practices that will maintain soil quality in a healthy and productive state to ensure long-term agricultural sustainability. Taking only hours to lose in a windstorm, the topsoil is exceptionally slow to rebuild through geologic and biologic processes that take centuries or more to complete. Blowing dust from agricultural fields is an indication of farming practices that not only leave inadequate surface cover but have destroyed the soil structure and aggregation that provide natural resistance to erosion.

The key criterion of a soil with good quality is its ecosystem consisting of a living biota that enables the soil to achieve its productivity and environmental functions at the highest and most efficient level possible. A.C. Kennedy, soil microbiologist with the USDA's Agricultural Research Service at Pullman, WA describes the soil biota as an interconnected web of life ranging from microorganisms (i.e., bacteria, fungi, and algae), micro and mesofauna (i.e., protozoa, nematodes, and mites), and macrofauna (i.e., arthropods, ants, and earthworms) all interacting with members of the whole soil community. The soil biota and its collective functional behavior is very sensitive to soil management and can have profound long-term effects on the agronomic, economic and environmental performance of croplands on the Columbia Plateau.

The case for no-till as a solution to wind erosion and air quality control has generated interest in how adopt-

ing this technology under different crop management systems will affect intrinsic soil properties that are vitally important to improving and maintaining long-term agricultural productivity and environmental health. With less soil disturbance, a new soil ecology may develop that functions differently than that in an intensively tilled system. For example, fungi appear to dominate in no-till compared with conventional tillage systems whereas the opposite occurs with bacteria (Hendrix et al., 1990; Guggenberger et al., 1999). However, neither group of organisms in isolation can be claimed as superior to the other with regard to a niche or functional role within the soil ecosystem.

EFFECTS OF TILLAGE AND RESIDUE MANAGEMENT ON SOIL QUALITY

Kennedy initiated research studies in 2000 to characterize soil quality parameters and to monitor changes over time in reduced tillage and no-till systems as affected by residue and crop management practices (Kennedy et al., 2000; Kennedy, 2001). This research was conducted jointly with ongoing wind erosion field research projects at locations with varying lengths of time in continuous no-till, and precipitation levels. Replicated soil samples obtained from the surface horizons in early spring, midsummer and/or fall from the different treatments were analyzed for physical, chemical and microbial properties that relate to changes in soil quality. In addition, chemical analysis was also conducted on wheat, oat and safflower residues to determine their relative decomposition potential.

Observations and results of this research are summarized:

1. A procedure known as Principal Component Analysis of fatty acid methyl ester (FAME) profiles differentiated no-till from tilled soils on the basis of microbial community structure. Fungal biomarkers were more prominent in no-till soils while biomarkers for both gram-positive and gram-negative (i.e., a staining technique used to differentiate between kinds of bacteria) bacteria were greater in tilled soils. Plant-biomarkers did not change with tillage. This indicates that changes in the soil microbial community were the result of reduced disturbance and not of plant residue.
2. Soil quality was assessed at three paired no-till and conventionally tilled sites having similar slope and aspect and representing two to 20 years of continuous no-till management. Organic matter content averaged higher in the no-till than conventionally tilled soils, especially in the top two inches. Due to a buffering effect of carbonates from a caliche layer present at the mid-slope position on two of the paired sites, the soil pH and dehydrogenase enzyme activity (an indicator of microbial activity) were higher in tilled soil where it was distributed more uniformly than in no-till soil. At one site soil bulk density was lower in no-till soil than in tilled soil indicating that a longer history of no-till may ameliorate compaction often observed in the early years of transition from tillage to no-till. When site and tillage type were compared in the FAME analysis the samples separated more by tillage than by site.

However, microbial communities in tilled soils at mid- and bottom-slope positions were very different from those in no-till soils, while those in the ridge-top position did not reveal large differences due to tillage. This indicates that landscape position may play an important role in microbial community structure. One possibility in this case is that the top slopes have been so degraded by past farming that their biological status has not been restored to earlier levels even after 20 years of no-till.

3. Changes in soil quality parameters during the transition to no-till were less dramatic and more variable in the low (6- to 12-inch average annual precipitation) than in the higher precipitation (>12 inches) zones.
4. Changes in soil organic matter and microbial activity are beginning to emerge after four years of transition to continuous no-till annual cropping from a conventional winter wheat-fallow system. The fallow system shows lower microbial activity because of less available carbon due to greater residue decomposition and loss of soil carbon through mineralization than in the no-till annual cropping system. Microbial community analysis showed an increase in the fungal component of the soil ecosystem with no-till compared with conventional tillage. However, differences in soil physical and chemical properties were less discernible than the biological changes after a four-year comparison of no-till and tilled treatments.
5. Fiber analysis showed higher lignin and lower hemicellulose contents in safflower residue compared with spring wheat and oat residues indicating that the partitioning of carbon in the biomass differs for these crops. Total carbon was similar for all residues but N was significantly higher in safflower residue than in wheat or oat. The lower C:N ratio for safflower residue suggests that it is more decomposable than wheat or oat residue, but this is not likely the case because results are largely due to its initially high content of lignin and hemicellulose.
6. In the experiment "No-Till Sowing into Irrigated Stubble instead of Burning and Plowing" described in Chapter 5, the continuous winter wheat-burn/plow treatment shows

lower microbial activity after three years compared with no burning and direct seeding. There was no significant change in soil carbon among treatments but it trended higher where the wheat stubble was left standing. Preliminary evidence indicates that irrigation may reduce the transition time from tillage to no-till, and that the lack of disturbance may be more important for improving soil quality than surface residue management (Kennedy and Schillinger, 2002).

TAKE-OUT OF CONSERVATION RESERVE PROGRAM (CRP) FARMLANDS

Best management practices for return to cropping of lands retired under the CRP are a concern with regard to preservation of soil quality benefits accrued during the years that it was in a perennial grass system. A study comparing changes in soil quality benefits for wheat grown after CRP take-out by direct-seed-spring plant, conventional tillage-spring take-out, and conventional tillage-fallow at eight dryland sites in eastern Washington state in 1995-96 showed that readily-mineralized carbon (RMC) and soil pH were lower after one year with the conventional tillage treatments compared with the original CRP grassland (Gewin et al., 1999). The authors suggest that tillage take-out is unlikely to sustain the accrued soil quality benefits on these lands that were designated as "highly erodible" and, thus, eligible for the CRP. The direct seed (no-till) soil properties of pH, dehydrogenase activity, and RMC were more similar to the CRP soils than the conventionally tilled treatments, thus retaining the benefits to the soil ecosystem established by the CRP grassland system.

EFFECTS OF SOIL DISTURBANCE ON AGGREGATION

Scientific study has long established that increased soil aggregation improves soil structure and stabilizes the surface soil against both wind and water erosion (Lindstrom et al., 1994). It is also well known that because of minimal disturbance and root proliferation some of the most stable aggregation occurs in grassland soils. A simple test conducted by A.C. Kennedy (USDA-Agricultural Research Service, Pullman, WA, personal communication, November, 2002) demonstrated differences in soil aggregation as a result of past management. She

obtained fresh samples of soil (3-inch depth) in June at the WSU Dryland Research Station, Lind, WA from: 1) a long-term, perennial grass lawn, 2) an annually-cropped dryland spring wheat plot that had been in continuous no-till for four years, and 3) an intensively-tilled fallow plot in a long-term winter wheat-fallow rotation.

A one-quart volume of each of the soils was sieved to retain aggregated particles larger than 1-mm mesh (0.040 inch). The amount that passed through was returned to the original container. Figure 7.1 shows that most of the lawn soil and a substantial fraction of the no-till soil were retained on the sieve but most of the tilled fallow soil passed through. This indicates that the lawn soil, as expected, was well-aggregated, the no-till soil was reasonably well-aggregated and the fallow soil was poorly aggregated and would be more subject to blowing than the other two soils. Thus, the effect of no-till in improving aggregation is similar to that of the permanent lawn/grass soil, thereby enhancing the soil's inherent ability to resist wind erosion, and should be recognized as an important long-term conservation benefit of this farming practice.

EFFECTS OF TILLAGE AND RESIDUE MANAGEMENT ON CARBON STORAGE IN SOIL

Conservation farming systems will help to control wind erosion and should also enhance carbon sequestration in soil through practices that increase cropping intensity and reduce tillage. A laboratory study was conducted on soils from the cropping system's plots established in the Ralston Field Study (see Chapter 4, Continuous No-Till Spring Cropping Systems Compared with Minimum Tillage Fallow: The Ralston Field Study) to assess the effects of cropping intensity and tillage on residue decomposition, mineralization of soil organic matter and carbon storage in soil after five years of treatment (Bell, et al., 2003).

The field treatments studied were: soft white winter wheat–minimum tillage fallow (SWWW–MTF), soft white spring wheat–chemical fallow (SWSW–CF), no-till hard red spring wheat (HRSW), and no-till hard red spring wheat–barley (HRSW–SB). The rate and extent of decomposition of ¹⁴C-labeled wheat straw added to soils from the treatment plots were determined by monitoring CO₂ and ¹⁴CO₂

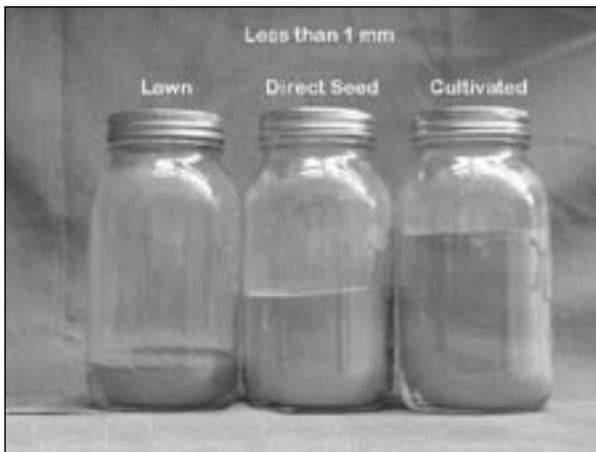


FIGURE 7.1. Quantity of Shano silt loam soil from an original one-quart volume that passed through a 1 mm (0.04 in) mesh sieve. The soils left to right were obtained in June 2002 from a 1) grass lawn (lawn), 2) dryland plot after four years of continuous no-till (direct seed), and 3) field of intensively tilled fallow (cultivated), all from the WSU Dryland Research Station at Lind, WA. The fine soil represents the mass that is readily subject to blowing if it was not protected with soil surface cover or soil surface random roughness. Accordingly, nearly 70% of the tilled fallow soil, 45% of the no-till, and 15% of the lawn soil would be fine enough to blow if exposed to strong winds. Photograph by A.C. Kennedy, USDA/ARS, Pullman, WA.

evolution during incubation. Non-labeled wheat straw was added to soils from the SWWW-MTF and continuous HRSW treatment plots at different times during incubation to compare effects of soil disturbance only, or disturbance plus additions of wheat straw to determine whether a “priming effect” might enhance the decomposition of soil organic matter.

The results showed that the soil carbon content was approximately 10% greater in the HRSW and SWSW-SB soils compared with those of SWWW-MTF and SWSW-CF due to more efficient carbon metabolism in the continuous no-till cereal cropping systems (Bell et al., 2003). Most of the increase in soil carbon was stored in the “particulate organic matter” fraction that is more sensitive to management than total soil carbon. Thus, this stored fraction could be subject to rapid loss, mainly as CO₂, from changes in soil management practices or the natural environment (increased temperatures). These workers conclude that the lower particulate organic matter content of soil in the SWSW-CF compared with continuous no-till cropping indicates that fallow reduces the potential soil carbon sequestration even in the absence of tillage. More CO₂ was evolved from the SWWW-

MTF rotation where the soil microbial biomass was half that of the HRSW-SB rotation indicating that fallow was inefficient in storing carbon from residue inputs (Bell et al., 2003).

Differences in CO₂ production between the continuous no-till cereal and fallow soils suggest a priming of soil organic matter caused by additions of crop residue that is controlled by the size of the soil microbial biomass and the composition of the soil microflora, primarily the fungi:bacteria ratio. Bell et al. (2003) concluded that residue additions are likely more important than soil disturbance in the priming process that may affect long-term carbon storage in intensive (annual vs fallow) cropping systems.

In another study of the same field plots, measured straw carbon inputs were 21 to 24% higher from the annual spring crop rotations than from the SWWW-MTF while the SWSW-CF produced 42% less straw than the SWWW-MTF treatment (Pan et al., 2001). An estimation from a linear regression of soil carbon sequestration efficiency showed that the increase in soil carbon from the spring of 1997 to the fall of 2000 was 16, 11, 2, and 1% for the HRSW-SB, annual HRSW, SWWW-MTF, and SWSW-CF, respectively. These field results agree closely with the laboratory results of the Bell et al. (2003) study on gains in soil carbon with no-till annual cropping, and together the studies provide strong evidence that the continuous no-till cropping systems are accumulating soil organic matter at a much faster rate than either of the conservation tillage fallow systems.

FARMING WITH THE AIR QUALITY STANDARDS AND THE NATURAL EVENTS POLICY

Virtually all of the concerns with wind erosion and air quality control involve episodic events. Dust storms powered by high winds are responsible for most of the top soil loss from the

Columbia Plateau farmlands. These same storms cause a majority of the exceedances of the air quality 24-hr average PM₁₀ standard at monitoring sites in the region. For many years conservationists and growers have designed and implemented strategies to minimize erosion at the farm level with the resources and technologies available. However, all have limits of effectiveness depending on the storm intensity and soil conditions, and even with the best of efforts many fail to prevent significant soil loss and PM exceedances.

The EPA’s Natural Events Policy (NEP) protects a monitored area from being charged with a violation of PM₁₀ National Ambient Air Quality Standards (NAAQS) caused by a natural event based on two criteria (Nichols, 1996, and see Chapter 1). First, in situations where a State has reason to believe that natural events have caused measured exceedances of NAAQS it is responsible for establishing a clear causal relationship between the measured exceedance and the natural event (e.g., high winds combined with dry soil conditions). Second, the State must establish that the atmospheric dust during the natural event originated from either or both 1) non-anthropogenic sources or 2) anthropogenic sources controlled by BACM (best available control measures, equivalent to best management practices). According to the NEP, BACM must be implemented for anthropogenic dust sources in order for PM₁₀ NAAQS exceedances to be designated as due to “uncontrollable natural events.”

CROP RESIDUE MANAGEMENT: AN EFFECTIVE APPROACH FOR ACHIEVING BMPS

The hazards with episodic events underscores the need for growers to implement best management practices as needed, to protect against loss of valuable topsoil, and to avoid designation as a contributing source area to PM nonattainment as a result of high winds. The Conservation Technology Information Center (CTIC), West Lafayette, IN promotes crop residue management (CRM) as the lynch pin for control of wind and water erosion in most farming systems. In its definition it is “a year-round system beginning with the selection of crops that produce sufficient quantities of residue and may include the use of cover crops after low residue-producing crops.”

CRM is an umbrella term that covers several forms of conservation tillage designed to minimize soil erosion from wind and water and includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. The concept of CRM fits well as the first line of defense for controlling wind erosion on the Columbia Plateau where many soils are believed to erode by direct suspension. Crop cover and adequate surface residues along with surface roughness are currently the most effective and practical means of controlling suspension-dominated wind erosion on croplands.

The CTIC conducts a survey of tillage systems in the US referred to as the National Crop Residue Management Survey. These data presented in acres by county, are available on the Internet (CTIC, 2002) and have been reported annually from 1989-1998 and biennially after that. The primary operations for planted and fallow acres are conservation tillage, reduced till (15 to 30% residue cover) and conventional till (less than 15% surface residue cover). The tillage type definitions according to CTIC at Web site <http://www.ctic.purdue.edu/Core4/CT/Definitions.html> are as follows.

Conservation tillage. This is defined as tillage and planting systems that cover at least 30% of the soil surface with crop residue after planting, a level considered sufficient for effective erosion control. This definition assumes randomly distributed residue and is the same for the control of wind or water erosion. Variations of conservation tillage include the following practices:

- **No-till.** This includes such variations as strip-till, direct seeding, slot planting, zero-till, row till and slot till but the primary feature in all is that the soil is only minimally disturbed from planting to harvest. Cultivation may be used for emergency weed control.

- **Ridge-till.** This system is used primarily with row-farming where planting is completed on ridges formed by cultivation, and residue is concentrated in the furrow between the ridges. The soil is left undisturbed from harvest to planting except for strips up to one-third of the row width atop the ridges. Weed control is accomplished with herbicides or cultivation. Ridges are rebuilt during row cultivation.

- **Mulch-till.** This consists of full-width tillage involving one or more operations that disturb all of the soil surface. The tillage is performed prior to and/or during planting with tools such as chisels, field cultivators, disks, sweeps or blades. Weed control is accomplished with herbicides or cultivation.

Other tillage types.

- **Reduced-till.** This system involves full-width tillage with one or more operations and is performed prior to and/or during planting. There is 15 to 30% residue cover after planting. Weed control is accomplished with herbicides or cultivation.

- **Conventional-till or intensive-till.** These consist of full-width tillage that disturbs all of the soil surface and is performed prior to and/or during planting. Less than 15% residue cover remains after planting. The system generally involves plowing or intensive (numerous) tillage trips. Weed control is accomplished with herbicides or cultivation.

Thirty-percent cover was used as a criterion for meeting conservation compliance on highly erodible lands as required by the 1985 Food Security and Agricultural Productivity Act (1985 Farm Bill) (US Congress, 1985) and the 1990 Food, Agriculture, Conservation and Trade Act (1990 Farm Bill) (US Congress, 1990).

USE OF CONSERVATION TILLAGE PRACTICES IN THE DRYLAND AND IRRIGATED AREAS

Figure 7.2 presents the CTIC survey results, individually and combined for seven Washington state counties on the Columbia Plateau and Columbia Basin that are most prone to wind erosion, showing the percentage of farmland¹ acreage in conservation management during a 13-year period 1990-2002. The categories are: 1) Conservation Reserve Program (CRP) with its perennial grass cover, 2) total planted acres under conservation tillage (CTP), and 3) fallow acreage under conservation tillage (CF). Permanent pasture is included as a category in the national CTIC survey but was not included in the results of Figure 7.2 because the acreages reported were usually negligibly small or zero. The “reduced-tillage” category (15 to 30% residue cover) is not used in our assessment because the lower amounts of surface residue are not optimum for effective wind erosion control.

Although not optimal as a conservation measure there is a continuum of effectiveness that extends into the reduced till system with 15 to 30% residue cover. At times this category may be the best defense possible against wind erosion and the only option available to growers under uncontrollable conditions of drought, pest infestations and other unforeseen hazards that limit grain and straw production (see discussion in next section *Farming to Conserve Soil and Protect Air Quality*).

The “conservation acreage” in our Washington state survey is that land which meets the goal of 30% residue after planting (i.e., 550 lb ac⁻¹) as specified by the CTIC for conservation tillage. The graphs are primarily to show if the surveys indicate any differences in application of conservation practices among the seven counties, and trends in use over time.

All seven counties have both dry-farmed and irrigated croplands and all have major concerns with wind erosion and contributing to fugitive dust emissions. However, most of the cropland in Adams, Benton, Douglas, Lincoln and Walla Walla counties is dry farmed, whereas a large percentage in Franklin and Grant counties is irrigated. In this analysis the main categories of conservation tillage are no-till and mulch-till with 30% or more surface residue cover after planting. Use of ridge-till is almost nonexistent, but a small acreage is indicated for irrigated crops in Adams County.

Figure 7.2 shows considerable variation in the percent of farmland acreage in conservation among counties. CRP quite consistently is the dominant conservation acreage in Adams, Benton, Douglas and Franklin Counties. Moreover, the percentage of CRP acreage has remained unchanged for most counties during the 13 years of the survey. There has however, been a small decrease in CRP acreage in Adams County and small increases in Benton and Walla Walla Counties toward the end of this period. Overall, the percentage of farmland in CRP during the 13 years of survey ranged from 10% or less in Benton, Grant and Lincoln Counties to 30% or more in Douglas County.

Walla Walla, Douglas and Lincoln Counties rank highest in the use of conservation management on farmlands although there is a downward trend in Douglas County extending to near the

¹ In this survey farmland is considered as all land that was/is used for crop production (retired and active). Conservation management includes all land in soil conserving uses or with conservation practices applied.

PROMOTING AND APPLYING CONSERVATION PRACTICES ON DRY AND IRRIGATED CROPLANDS

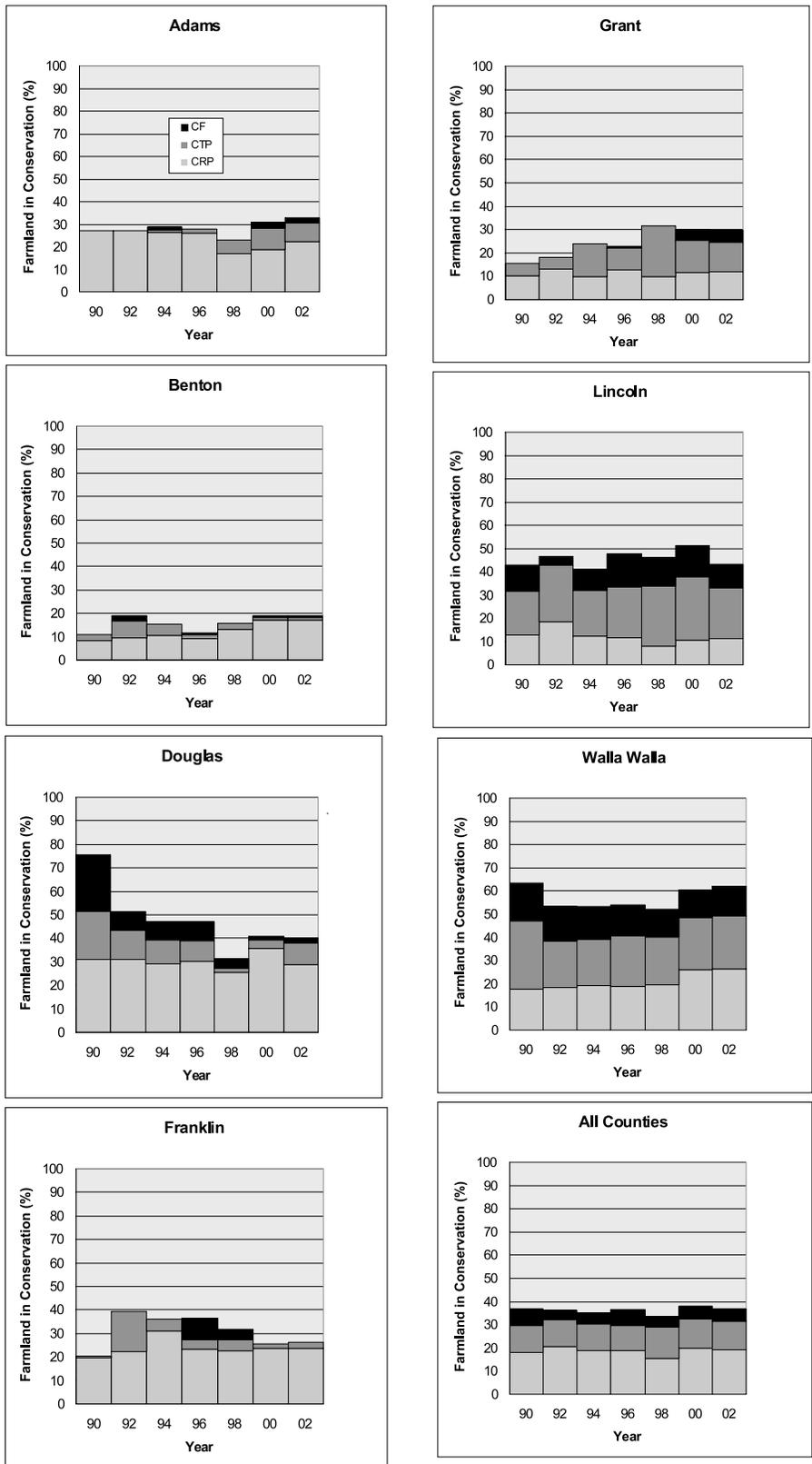


FIGURE 7.2. Percentage of farmland in conservation management in seven eastern Washington counties and their aggregate average (all counties) during alternate years 1990-2002. The breakout of percentages of farmland acres in conservation is: CF = conservation fallow with 30% or more residue cover, CTP = planted acres with 30% or more residue cover after planting, and CRP = Conservation Reserve Program (in perennial vegetation). Source: CTIC (2002).

end of the survey study. Of the seven counties, these three show the highest average percentages of fallow (usually the most erodible soil condition) and planted acres under conservation management. The rest indicate little or inconsistent use of conservation tillage for fallow. The percentage of planted acres in conservation management are highest in Lincoln and Walla Walla Counties with Lincoln averaging between 20 to 25% and Walla Walla about 20% in this category.

The average percentage of total acres in conservation (including CRP) during the survey was about 45% in Lincoln County to over 55% in Walla Walla County. Benton County at about 15% and Adams at 28% show the lowest percentage of acres in conservation management of the seven counties. Only Grant County showed a modest increase in percentage of farmland in conservation management during the survey period, likely due to an increase in planted cropland. There appears to have been a trend toward more conservation in Franklin County during the early to mid 1990s from earlier years but that did not carry through to the 2000s (Fig 7.2).

The “all counties” summary in Figure 7.2 shows the percentage of farmland in the seven Washington counties that are in some type of conservation management (i.e., BMPs) by summing and averaging the individual county data by year. The results indicate essentially no change in the use of crop residue management or CRP for the seven-county area over the 13-year survey period. According to the survey, the percentage of farmland acres meeting the minimum 30% surface residue requirement averaged a relatively constant 37% throughout the period with about 20% in CRP, 11% in planted crops and 6% in fallow.

Figure 7.2 shows that the percentage of planted and fallow acres in conservation management during the survey years fluctuated least in Lincoln and Walla Walla Counties and considerably more in the others, whereas the CRP acreage was more stable. The CRP acreages are obtained from county records and therefore should be quite accurate and not expected to vary considerably from year to year without some obvious explanation. However, the conservation tillage data with greater fluctuations are obtained primarily by subjective judgment of field

technicians independent of the base acres of land use, and therefore are subject to a greater margin of error and variation as evident from their values in Figure 7.2. These variations in themselves do not discredit the tillage data because it was obtained systematically on a large scale by skilled technicians. The data collection process makes the inconsistencies less significant and helps to ensure that the trends established are meaningful and can be accepted with a reasonable level of confidence.

The PM₁₀ monitoring data in Figure 1.8, Chapter 1 indicates that there has been a decline in PM₁₀ exceedances after 1994, and it is noteworthy that this has continued despite several below-normal precipitation years in the early 2000s. In addition to possibly less dust from farmlands, the decrease in exceedances has been attributed to efforts by Ecology, local air authorities, local government and the public in reducing PM₁₀ emissions from unpaved road dust, traction material, and wood stoves. For example, the Spokane County Air Pollution Control Authority focused on control of re-suspended traction material and wood stove emissions in their PM₁₀ Spokane Attainment Plan. This significantly reduced the number of PM₁₀ exceedances in the Spokane, WA area.

An analysis by Lauer et al. (2003) shows a cluster of windblown dust

exceedances at the Kennewick monitoring site following the drought cycle in the Horse Heaven Hills during the late 1980s and early 1990s, and another, but of lesser degree following the dry years during the mid to late 1990s and early 2000s (Fig. 7.3). The trend of decrease in NAAQS exceedances appear to bear little or no relationship to the conservation statistics in Figure 7.2, indicating that weather or other factors may dominate PM trends at the Washington state air quality monitoring sites.

A project is underway to develop the use of Landsat imagery for the assessment of changes in soil surface cover across the Columbia Plateau over periods of years (Frazier and Rupp, 2002). Changes in the use of conservation tillage will be determined by comparing data from satellite images from the same test areas at 10-year intervals or more. The data will be verified by aerial photography. This approach has the potential to provide accurate data on changes in land use with time and location across the entire Columbia Plateau and Columbia Basin.

It must be emphasized that the percentages of farmland in conservation management reported in Figure 7.2 do not consider other erosion control measures that growers might apply in addition to crop residue management. One is random surface soil roughness that

usually results from conservation tillage in fallow to achieve higher residue levels. For example, a significant contribution to the soil loss ratio (SLR) for the minimum tillage and delayed minimum tillage fallow (in addition to surface residues) was due to an increase in random roughness (Schillinger, 2001). Another effective conservation practice used by many growers is cross-wind sowing, i.e., sowing winter wheat after fallow at right angles to the predominant wind direction. Although not quantified, some experts believe that cross-wind sowing with deep-furrow drills would provide as much erosion control as conservation tillage.

FARMING TO CONSERVE SOIL AND PROTECT AIR QUALITY

Topsoil is a nonrenewable resource that is essential for sustaining an economic and productive agriculture for future generations. Its loss by wind erosion destroys this capability and depreciates the value of the region's croplands for agricultural use. Moreover, if not checked, farmland wind erosion along with other sources of particulate pollution can lead to nonattainment status of the source areas due to violation of federal air quality standards for protecting human health in downwind areas. Documented adverse health effects include increased respiratory symptoms and disease, decreased lung function, alterations in the body's defense system against foreign materials, carcinogenesis and premature death.

In addition to health concerns and physical discomfort, airborne particulate matter can also injure vegetation and damage machinery, paint and building materials. Suspended dust from erosion is also cited as a major cause of visibility impairment nationwide (see Figures 3B and 4B in Appendix B). A likely consequence of a nonattainment designation for a given area is imposition of additional, and more stricter and costly control measures to reduce particulate concentrations to within the range allowed by federal standards.

Much of the dryfarming on the Columbia Plateau with the highest soil erodibility and PM emission hazards lie in some of the driest area where the winter wheat-fallow system dominates and where, according to Figure 7.2, a significant percentage of the farmland acres may lack cover requirements for wind erosion control. These in particular include sizeable portions of Adams, Benton and Franklin Counties where

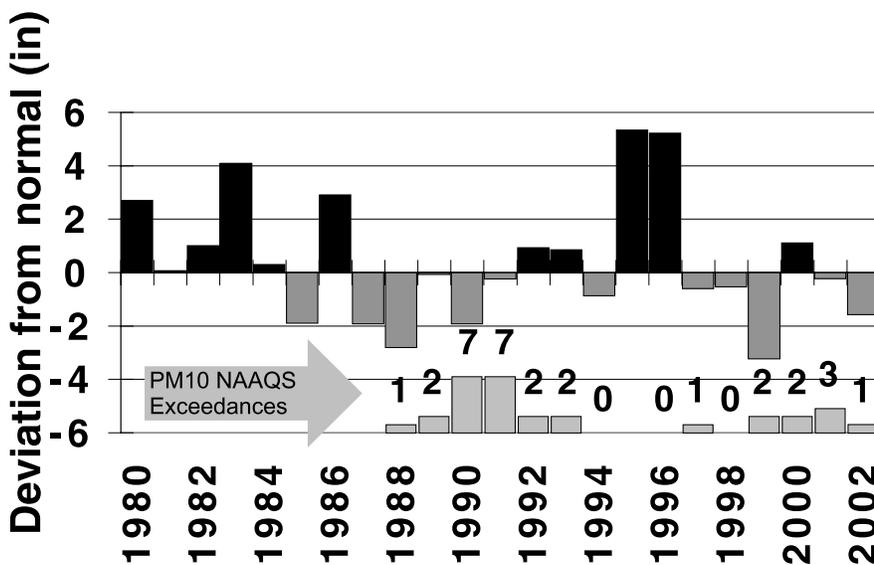


FIGURE 7.3. Deviation of precipitation from normal at the Hanford, WA meteorological weather station during 1980-2002, and number of times the PM₁₀ 24-hr average concentration was exceeded in a given year during 1989-2002 at Kennewick, WA. The precipitation data are from the Hanford Meteorological Station. Normal precipitation during 1970-2000 was 6.98 inches. The weather station and the PM₁₀ monitoring site are separated by a distance of 8 mi. Source: Lauer et al. (2003).

annual precipitation averages from 6.5 to about 10 inches (see Figs. 3.5 and 3.7 in Chapter 3 for erodibility and PM₁₀ emission hazards in these areas). Grant County also shows a significant acreage of land with high erodibility and PM₁₀ emission hazards, and a high percentage of farmland not meeting the conservation standard for soil cover. Franklin County has considerable acreage of dryland but like Grant County has a significant acreage under irrigation. The other counties represented in Figure 7.2, i.e., Douglas, western Lincoln, and western Walla Walla receive higher average annual precipitation that contributes to more crop residues and surface cover, thus, providing more soil protection than in the other counties.

Low residue production, especially during drought cycles, most likely explains why there is less conservation implemented in the driest areas than in others with higher precipitation (in Fig. 7.2 compare Adams, and Benton Counties with Douglas, Lincoln and Walla Walla Counties, also predominantly dry-farmed, but where precipitation is higher). Even with the best of conservation farming methods, growers in the lower precipitation areas may have insufficient residue cover or early fall growth to protect fallow land from high winds that lead to NAAQS exceedances downwind at certain times of the year. Similarly, where irrigation is practiced (e.g., Franklin and Grant counties) significant areas are susceptible to wind erosion and dust emissions during spring planting, and after harvest of low-residue crops.

Nevertheless, to comply with NEP and keep topsoil in place, maximum efforts should be made by individual growers to ensure that BMPs are utilized to the extent possible on all land during the critical (spring, fall) wind

erosion periods. In most situations crop residue and green cover are the key elements in providing soil protection against wind erosion and dust emissions. These measures can be supplemented with tillage/planting-induced random and oriented roughness and amendments to stabilize the soil surface.

CP₃ research has clearly identified minimum tillage and delayed minimum tillage fallow as effective BMPs for winter wheat-fallow systems. These practices should be adopted in all areas, but especially where conservation tillage is more limited, as the most effective, practical, and economically feasible measures available for controlling wind erosion on fallow land.

Based on the Schillinger (2001) study it appears realistic that with conservation tillage used in his experiment, enough flat residue can be conserved after sowing in fallow from a 30 bu ac⁻¹ winter wheat crop to provide the 30% cover recommended by the CTIC as a BMP requirement for wind erosion control. Adding roughness through tillage makes the cover requirement less stringent. The Schillinger (2001) experiment employed an undercutter as the primary tillage implement for fallow. The implement is equipped with adjustable-pitch “V” sweeps that cause minimum soil lifting and disturbance as they cut beneath the soil surface to disrupt capillary continuity (see Figs. 4.1 and 4.3). The undercutter significantly increased cover and standing stubble compared with other implements that flatten and partially bury the previous crop’s residue. However, the undercutter used in this experiment is not widely available in the area and many growers may not have access to this machine at the present time. Substitute imple-

ments must be used that may not perform as effectively in conserving residues which needs to be a consideration in the ability to achieve adequate residue cover for protection against wind erosion.

Rotating spring crops into a traditional winter wheat-fallow system to increase cropping intensity when precipitation is normal or higher is also recommended as a BMP, but only if in conjunction with no-till or minimum tillage to conserve adequate amounts of residue for wind erosion control during critical periods. Continuous no-till cropping of cereals, with or without winter wheat provides year-round soil cover for protection against wind erosion. Therefore lack of cover is rarely an issue with this practice. With improved farm economics and/or government farm program support, the practice may offer potential for profitable conservation farming in the low precipitation zones, especially with normal and above normal precipitation.

For example, the recent CP₃ multi-year study conducted in a 11.5-inch average annual precipitation zone concluded for the first time that the profitability of a continuous no-till spring cropping system of soft white wheat was statistically equivalent to that of the traditional winter wheat-fallow (Jurgens et al., 2003). Green cover from early planted winter wheat also provides a window of protection in addition to residue cover during the late summer and early fall on seeded fallow land (Papendick, 1998). Other effective conservation options for growers continue to include CRP grasslands and land in pasture or hay production.

What can be done in terms of best management practices to control wind erosion when unpredictable hazards occur such as drought or inclement weather, winter kill, pest infestations or accidental fire that result in less than optimal residue or plant growth for protective soil cover? In these cases residue amounts may be well under 30% down to near zero cover. The best control measures are to reduce the number of tillage operations during fallow or prior to sowing the next crop and limit them to those that conserve maximum amounts of available residue (including weed residues) on the surface and promote surface roughness. This would include tillage systems in the “reduced-till” category as defined by the CTIC (2002).

Surface roughness of tilled soils can markedly augment the effect of sur-

Table 7.1. Summary of impacts of farm and farmer characteristics in the adoption of multiple conservation practices when nonadoption is defined as zero practices¹.

Characteristic	Impact	
	Probability ²	Direction ³
Knowledge of PM₁₀ educational program	NS ⁴	Positive
Perceives wind erosion problem	NS	Positive
Farm size	0.04	Positive
Acres rented (%)	NS	Positive
Off-farm income	NS	Positive
Level of farmer education	0.10	Positive
Age of farmer	NS	Negative

¹Source: Upadhyay et al. (2003).

²Significance is assumed at the 0.10 probability level. NS indicates not significant.

³Direction in which adopters differ from zero practice adopters.

⁴Approaches significance with a 0.21 probability level.

face cover for wind erosion control. For example, reduced-till (the CTIC 15 to 30% surface residue category) with 15% residue cover and a soil roughness of 0.75 inch gives a soil loss ratio (SLR) of 0.17, or one comparable to 30% cover with a soil roughness of 0.25 inch (very smooth, typical of late fallow condition, see Table 3.1 for SLR values, and Figure 3.1 for photographs of roughness conditions). Options for increasing soil roughness with reduced tillage may require slower tillage speeds, less aggressive tillage (use of equipment that minimizes pulverization of the soil) and crosswind sowing with furrow drills. Foregoing tillage with chemical fallow is another option for controlling wind erosion when crops fail or produce little residue but economics may limit its use in the dry areas. Conventional or intensive-till as defined by the CTIC is not recommended and should be avoided under any hardship conditions.

Traffic areas in fields where soils may be highly pulverized can also be a major source of windblown dust when crops are not growing. An economical and effective treatment is to spread and anchor straw over susceptible areas and keep them covered until they are protected by plant growth.

Options for protecting irrigated lands during critical times include planting cover crops that afford protection against wind erosion during the non-crop season, maintaining crop residue cover, growing vegetative strips perpendicular to the prevailing wind direction, and producing a combination of rough-tilled soil with green or residue cover for late fall-harvested crops. Growers are especially urged to minimize or eliminate tillage that pulverizes the soil and buries significant amounts of crop residue or green cover leaving the soil bare and highly susceptible to blowing. Application of soil stabilizing agents may provide temporary protection against wind erosion as does applying irrigation water to keep the soil moist during extreme wind events.

WHAT FACTORS MOTIVATE GROWERS TO ADOPT CONSERVATION PRACTICES?

Although BMPs for effective control of wind erosion on the Columbia Plateau are available, their adoption by growers has been slow. Willingness to change practices is often complex because of a mix of economic, social-cultural and information vari-

ables (Nowak, 1987). Scientific literature describes three paradigms or models that best explain whether conservation-practices will be adopted by individual growers (Upadhyay et al., 2003). First is income which assumes that new technologies that increase net returns to the farm will be adopted. However, it fails to explain why certain technologies that produce profits are not always accepted. Second is utility which encompasses a broader set of motives in addition to income, e.g., enhancement of environmental quality, social benefits, life style and/or preferences for other factors. The third paradigm in motivating adoption of conservation practices is innovation-diffusion whereby knowledge and successful technology acquired by a few respected, innovative growers or inventors diffuses to the majority via success stories and education, often by grower to grower contact.

Upadhyay et al. (2003) analyzed a random sample survey study of 266 growers in five eastern Washington counties prone to wind erosion (Scott et al., 1997) to determine farm and farmer characteristics that motivate adoption of multiple conservation practices versus a single practice or no practices on a farm. The counties were Adams, Benton, Douglas, Franklin, and Grant. The three practices in the survey were reduced tillage (includes both no-till and minimum-till), continuous spring cropping, and vegetative wind strips. The survey sample was partitioned into three groups: 1) zero practice adopters, i.e., those who do not adopt any of these three conservation practices, 2) single practice adopters, that is those who adopt only one of the three conservation practices, and 3) multiple practice adopters, those who adopt two or three of the conservation practices (Upadhyay et al., 2003).

The objective was to test whether seven specific farm and farmer characteristics could predict differences between adopters and non-adopters of any conservation practice. The characteristics treated as independent variables are a mix from all three adoption paradigms as follows: 1) knowledge of a previous PM₁₀ educational program; 2) farmer's knowledge that an erosion problem exists; 3) number of acres farmed; 4) percentage of farmland rented from other than family members, and 5), age, level of education, and magnitude of off-farm income of the respondent.

Survey data showed that 60.5% of

the 266 farmers were zero practice adopters among the three alternatives surveyed. However, this does not mean that they were not using other conservation practices. The remaining 39.5% of the farmers were adopters of one or more of the three conservation practices. Single practice adopters made up 25.6% of the total. Among the 266 growers, 12.8% were using continuous spring cropping, 8.3% no-till and 4.5% wind strips. Of the same group, 12.5% used two of the conservation practices (9.8% used no-till and continuous spring cropping, 1.9% used continuous spring cropping and wind strips, and 0.8% used wind strips and no-till) and 1.5% of the farms adopted all three practices.

In summary, approximately three-fifths of the 266 survey farms used none of the three conservation practices and of the remaining two-fifths that did, slightly more than one-fourth of the 266 growers adopted continuous spring cropping, one-fifth no-till, and less than one-tenth adopted wind strips (Upadhyay et al., 2003). The survey data did not allow designation of the intensity of adoption of conservation practices in terms of acres applied or duration of use.

Statistical analysis showed no significant differences at the 10% probability level between the seven farm/farmer characteristics and adoption of a single practice versus zero practice adoption. Only farm size (increasing size related positively with single practice adoption) approached significance. However, between multiple and zero practice adopters, both farm size and level of farmer education differed statistically at the 4% and 10%, level, respectively. Upadhyay et al. (2003) suggest that the significance for farm size might imply greater financial resources among multiple than zero practice adopters in the drylands where size varies considerably. With regard to education level, the authors suggest that higher levels may facilitate information acquisition and use.

When non-adopters are defined as zero practice adopters, the variables 'knowledge of PM₁₀', 'farm size', 'off-farm income', and 'level of farmer education' and 'percent of land rented were all positively related to adoption of multiple conservation practices (Table 7.1). However, only 'education' and 'farm size' were statistically significant at the 0.10 probability level. Age was negatively related to adoption. Education might assist growers with collecting and assessing infor-

mation about promising conservation technologies.

The survey study makes clear that adopters of multiple conservation practices contrast more sharply with zero practice adopters than do adopters of a single conservation practice. Moreover, the results indicate that farm size plays a positive and significant role in the adoption of conservation practices by growers and that adopters are more aware of an erosion control educational program than non-adopters.

Upadhyay et al. (2003) conclude that knowledge of characteristics associated with multiple practice adopters should provide criteria for extension specialists and policymakers for targeting educational programs to promote new conservation technologies. These should include innovative growers having above average resources, education and experience. These individuals could serve as opinion leaders during the formative stages of information dissemination for promoting adoption of wind erosion control practices.

SUMMARY OBSERVATIONS

Application of soil conservation practices that minimally disturb the soil, add organic matter to it, and provide cover from crop residues and vegetative growth is fundamental to achieving control of wind erosion and dust emissions, and improving soil quality in both dry and irrigated croplands on the Columbia Plateau. Wind erosion results in double damage to the environment and soil resource by: 1) impairing air quality, and 2) causing selective loss of the most fertile components of the topsoil, i.e., plant nutrients and organic fraction (including beneficial microbes) that are concentrated and bound in the fine particulates carried off by the wind.

CP₃ research is providing documentary evidence that soil quality parameters such as organic matter content and microbial activity are enhanced more by no-till than by residue management alone. Moreover, a simple test indicated that soil disturbance through intensive tillage is extremely detrimental to soil aggregation, an inherent soil property that stabilizes it against wind erosion in fragile, low organic matter soils. Research also indicates that soil quality indicators in Conservation Reserve Program soils (CRP) after 10 years of perennial grass are more similar to long-term no-till than conventionally tilled soils.

After five years of treatment, the soil carbon content, due to more efficient

carbon metabolism, was approximately 10% greater in the soils that were under continuous no-till, spring cereal cropping than in tilled winter wheat-fallow or spring wheat-chemical fallow. Carbon mineralization from soil organic matter was similar in a laboratory incubation study of soils from the continuous no-till and fallow treatments. However, the "priming effect" caused by addition of wheat straw to soils from both tilled and no-till treatments accelerated the decomposition of soil organic matter more than disturbance alone and appeared to become more pronounced as the soil fungal:bacterial ratio increased. A noteworthy observation is whether fallow is achieved by tillage, or by no-till with herbicides, it appears to suppress the net storage or sequestration of carbon in these dryland soils compared with continuous no-till cropping.

Because of its broad applicability, crop residue management continues to be promoted as the lynch pin to soil conservation and best management practices in most farming systems. It is especially effective for controlling suspension-dominated wind erosion on the fine-textured loessial soils of the Columbia Plateau. Long-term research and grower experience indicates that a lower limit of 30% residue cover (equates to 550 lb ac⁻¹ of wheat residues) during the critical periods is required for effective wind erosion control.

A crop residue management survey of seven counties in Washington state conducted by the Conservation Technology Information Center and the USDA's Natural Resources Conservation Service showed that the percentage of farmland acres meeting the 30% residue cover standard ranged from 15% to over 55% during the 13 year (1990 to 2002) study. Only one county showed an increase in conservation acreage during the survey period. CRP was the dominant conservation practice in four counties and percent CRP acreage remained relatively constant in all counties during the 13 years. Counties showing the least use of conservation management were in the lower precipitation zones where wind erosion is most severe. Averaged over the seven counties, the survey results showed no change in the use of crop residue management or CRP during the 13-year study. The percentage of farmland meeting 30% residue cover averaged a relatively constant 37% throughout the period with about 20% in CRP, 11% in planted

cropland and 6% in fallow acres. The survey indicates that there is a need and ample opportunity for applying conservation practices to protect croplands against wind erosion and dust emissions on the Columbia Plateau.

A survey of 266 growers in five wind-erosion prone counties in Washington showed that 1) those who adopted multiple conservation practices (limited to reduced tillage, annual spring cropping, and wind strips) contrasted more sharply with non-adopters than those who adopted a single conservation practice and 2) adopters of a single practice differed more from non-adopters than they did from all other farmers including adopters of other practices. Adopters were associated with larger farm size, higher education level and better knowledge of a conservation education program. The study results indicate that multiple practice adopters should be utilized to the extent possible in the formative stages of extension education programs to promote new technologies for wind erosion control.

REFERENCES

1. Bell, J.M., J.L. Smith, V.L. Bailey, and H. Bolton. 2003. Priming effect and C storage in semi-arid no-till spring crop rotation. *Biol. Fertil. Soils* 37:237-244.
2. CTIC. 2002. National Crop Residue Management Survey. Conservation Technology Information Center, West Lafayette, Indiana. Web site <http://www.ctic.purdue.edu/CTIC/CTIC.html> (Viewed February 2003).
3. Frazier, B.E., and R. Rupp. 2002. Use of Landsat data to distinguish soil cover on erodible dryland soils. 2002 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 77-78.
4. Guggenberger, G.S., D. Frey, J. Six, K. Paustian, and E.T. Elliott. 1999. Bacterial and fungal cell-wall residues in conventional and no-tillage agroecosystems. *Soil Sci. Soc. Amer. J.* 63:1188-1198.
5. Gewin, V.L., A.C. Kennedy, R. Veseth, and B.C. Miller. 1999. Soil quality changes in eastern Washington with Conservation Reserve Program (CRP) take-out. *J. Soil and Water Conserv.* 54:432-438.
6. Hendrix, P.F., D.A. Crossley, J.M. Blair, and D.C. Coleman. 1990. Soil biota as components of sustainable agroecosystems. In C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House (eds.). *Sustainable Agricultural Systems*. Soil and Water Conservation Society, Ankeny, Iowa. p. 637-654.

7. Juergens, L.A., D.L. Young, W.F. Schillinger, and H.R. Hinman. 2003. Economics of alternative no-till spring crop rotations in Washington's wheat-fallow region. *Agonomy J.* 96:154-158.
8. Kennedy, A., W. Schillinger, T. Stubbs, P. Frohne, F. Young, J. Aeschliman, C. Hennings, D. Claassen, J. Peterson, K. Pitts, G. Stubbs, M. Stubbs, and R. Zenner. 2000. Soil quality changes with no-till management adoption for wind erosion control. 2000 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 75-78.
9. Kennedy, A.C. 2001. Soil quality changes with no-till management adoption. 2001 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 67-71.
10. Kennedy, A.C., and W.F. Schillinger. 2002. Soil quality changes with no-till management adoption for wind erosion control. 2002 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 72-76.
11. Lauer, D.A., M. McEachron, and B. Rude. 2003. Regulatory aspects of agricultural particulate matter air pollution on the Columbia River Plateau. Abstract. Soil and Water Conservation Society Annual Meeting, 28-31 July. Soil and Water Conservation Society, Ankeny, Iowa. p. 20.
12. Lindstrom, M.J., T.E. Schumacher, and M.L. Blecha. 1994. Management considerations for returning grass lands to crop production. *J. Soil and Water Conserv.* 49:420-425.
13. Nichols, M.D. 1996. Natural Events Policy. Memorandum. Office of Air & Radiation, US Environmental Protection Agency, Washington, DC. Web site: <http://www.state.sd.us/denr/DES/AirQuality/NEAP/nep.htm> (Viewed 19 February 2003).
14. Nowak, P.J. 1987. The adoption of agricultural conservation technologies: Economic and diffusion explanations. *Rural Sociol.* 52:208-220.
15. Pan, W.L., F.L. Young, and K.K. Kidwell. 2001. Carbon and nitrogen cycling in direct-seeded spring cereal alternatives to summer fallow. In B. Brown (ed.). *Proceedings of the Western Nutrient Management Conference*. Vol. 4:202-209.
16. Papendick, R.I. (ed.). 1998. *Farming with the Wind: Best Management Practices for Controlling Wind Erosion and Air Quality on Columbia Plateau Croplands*. Misc. Pub. No. MISC0208. Washington State University College of Agriculture and Home Economics, Pullman.
17. Schillinger, W.F. 2001. Minimum and delayed conservation tillage for wheat-fallow farming. *Soil Sci. Soc. Amer. J.* 65:1203-1209.
18. Scott, R.D., P. Wandschneider, D. Fultz, and M. Klungland. 1997. Focusing on wind erosion and PM-10 knowledge and practices: A dry land farmer survey. Monograph, Dept. of Agricultural Economics, Washington State University, Pullman.
19. Upadhyay, B.M., D.L. Young, H.H. Wang, and P. Wandschneider. 2003. How do farmers who adopt multiple conservation practices differ from their neighbors? *Amer. J. Alternative Agric.* 18:27-36.
20. US Congress. 1985. *The Food Security Act and Agricultural Productivity Act of 1985*. Public Law 99-198. US Government Printing Office, Washington, DC.
21. US Congress. 1990. *Food Agriculture Conservation and Trade Act of 1990*. Public Law 101-624. US Government Printing Office, Washington, DC.