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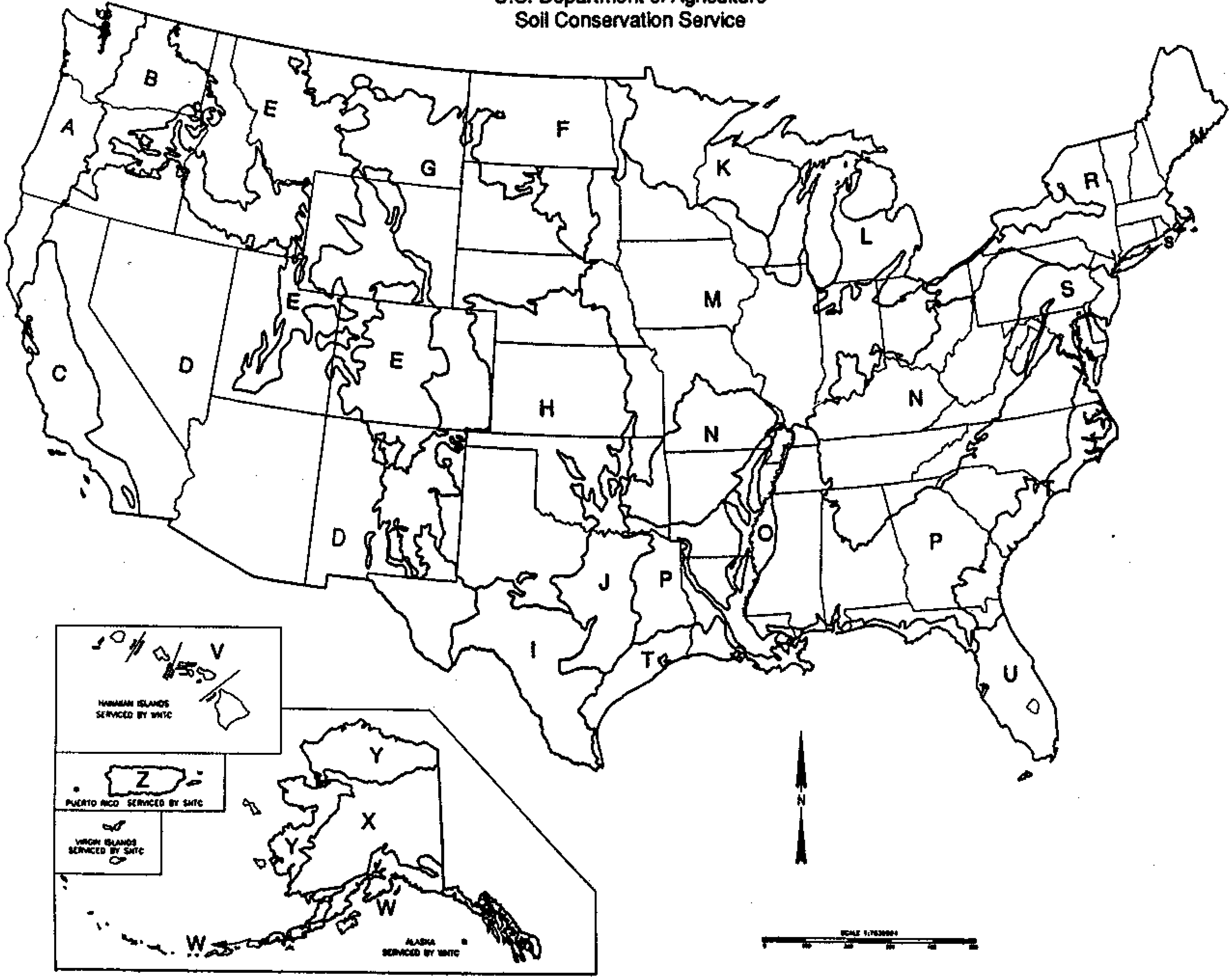
May 1995

Crop Residue Management To Reduce Erosion and Improve Soil Quality

Northwest

Crop Residue Management
Land Resource Regions of the United States

U.S. Department of Agriculture
Soil Conservation Service



Source: Map prepared using automated map construction. Albers equal area projection. National Cartography and Geographic Information System Center, Fort Worth, Texas 1993.

Resource Regions and Areas as of January 1984
Land Resource Regions (LRR)

- **A** NW Forest, Forage and Specialty Crops
- **B** NW Wheat and Range
- **C** California Subtropical Fruit, Truck and Specialty Crops
- **D** W. Range and Irrigated
- **E** Rocky Mtn. Range and Forest
- **F** N. Great Plains Spring Wheat
- **G** W. Great Plains Range and Irrigated
- **H** C. Great Plains Winter Wheat and Range
- **I** SW Plateaus and Plains Range and Cotton
- **J** SW Prairies Cotton and Forage
- **K** N. Lake State Forest and Forage
- **L** Lake States Fruit, Truck and Dairy
- **M** Central Feed Grains and Livestock
- **N** East and Central Farming and Forest
- **O** Miss. Delta Cotton and Feed Grains
- **P** S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock
- **R** NE Forage and Forest
- **S** N. Atlantic Slope Diversified Farming
- **T** Atlantic and Gulf Coast Lowland Forest and Crop
- **U** Florida Subtropical Fruit, Truck Crop and Range
- **V** Hawaii
- **W** S. Alaska
- **X** Interior Alaska
- **Y** Arctic and W. Alaska
- **Z** Caribbean Area

Major Land Resource Areas (MLRA)
MLRAs and number designation (see Agriculture Handbook 296)

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R.I. Papendick and W.C. Moldenhauer, Editors

Abstract

Papendick, R.I., and W.C. Moldenhauer, eds. 1995. Crop Residue Management To Reduce Erosion and Improve Soil Quality: Northwest. U.S. Department of Agriculture, Agricultural Research Service, CRR–40, 68 pp.

Leaving crop residue on the soil surface during cropping has a number of clear advantages over tillage that leaves the soil surface bare. Most obvious is the greatly reduced erosion from wind and water. This advantage alone makes the change worthwhile. Mandated conservation compliance by 1995 is a further incentive to adopt surface crop residue management. Other advantages include increased yield due to water conserved by surface residue, lower soil temperatures, higher quality soil over time due to increased soil organic matter levels, and, in many cases, reduced input of time, labor, and fuel.

The feasibility of farming while leaving residues on the surface is indicated by the rapid rate at which farmers are adopting these management practices. Success is due in large part to greater effectiveness and reduced cost of herbicides and the improvement of planting equipment available on the market.

Keywords: Agricultural economics, conservation tillage, crop rotation, farming methods, erosion, mulch tillage, no-till, nutrient cycling, pest management, raindrop erosion, ridge tillage, soil compaction, soil conservation, soil erosion, surface residue tillage, sweep tillage, tillage, water conservation, wind erosion.

While supplies last, single copies of this publication may be obtained at no cost from a Natural Resources Conservation Service District office. Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone (703) 487–4650.

This is one of six regional publications designed to bring research results and experience of experts in the field of crop residue management to the attention of farmers and their advisers. A copy of the five other regional reports on *Crop Residue Management To Reduce Erosion and Improve Soil Quality* can be obtained from the Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906 (fax 317–494–5969, telephone 317–494–9555). The other five regions are Appalachia and Northeast, North Central, Northern Great Plains, Southeast, and Southern Great Plains.

Issued May 1995

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1 Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and R.I. Papendick

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large windstorms or rainstorms selectively remove material high in organic matter and nutrients. The result is surface soil depleted of plant-available nutrients, high in density, and low in porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils are degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA-Soil Conservation Service (now called Natural Resources Conservation Service, NRCS) offices, fully three-fourths of the nation's farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by NRCS and the Conservation Technology Information Center (CTIC)) (see chapter 2 for a more complete definition). Three crop residue management classifications described by CTIC are (1) no-till where soil is left undisturbed from harvest to planting except for during nutrient injection. Planting is done with least possible disturbance, and weed control is primarily with herbicides; (2) ridge tillage where soil is again left undisturbed from harvest to planting except for during nutrient injection. Planting is on the ridges with least possible disturbance. Ridges are rebuilt during a single cultivation; and (3) mulch tillage where the soil is tilled, planted, and cultivated with implements and operations that leave the greatest possible amount of surface residue.

Surface residue cover is known to greatly reduce soil erosion. The percentage of the surface needing residue cover depends on the site and other conservation practices included in a total conservation plan. As residue cover approaches 100 percent, soil erosion approaches 0 percent; with 50 percent residue cover, erosion reduction is about 83 percent; when residue cover is 10 percent, erosion reduction is still about 30 percent.

Farmers' willingness to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. Efforts of equipment companies and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management. Another major factor that accelerated the adoption of crop residue management is the formation of associations and alliances for sharing experiences among farm operators and conservationists. Chemical and equipment companies; the farm press; Federal, state and local governmental research and extension agencies; along with private organizations have all published case studies, farmer experiences, and results of research helpful to farm operators.

The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated, or solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach remaining problems more as challenges than as insurmountable disadvantages. This change of attitude has played a major role in accelerating the acceptance of crop residue management.

Advances in crop residue management provide flexibility for farmers with highly erodible lands in the Conservation Reserve Program (CRP) who are forced back into production when CRP payments are discontinued. Long-term research shows great advantages in switching directly from sod into no-till management. Besides reducing soil erosion by 80 percent (compared with moldboard plowing of sod), no-tillage retains the benefits to soil structure and organic matter that sod imparts. Chapter 10 more fully describes the advantages, challenges, and procedures involved in changing from sod to no-tillage.

This publication summarizes research and experience that show the potential benefits and problems related to decreasing tillage and leaving more residues on the soil surface. In the 10 chapters that follow, experts discuss the equipment, management practices, crop protection chemicals, crop rotations, cover crops, and cropping systems that will enable farmers to control erosion on their lands—so they are in Federal conservation compliance—while simultaneously optimizing their net returns and improving the environment and natural resources.

In 1992 a workshop organized by the Agricultural Research Service (ARS) was held in Kansas City to evaluate the state of knowledge regarding crop residue management. The outcomes of that workshop were (1) a volume entitled *Crops Residue Management*, edited by J.L. Hatfield and B.A. Stewart and published in the *Advances of Soil Science* series by Lewis Publishers in 1994, which contained technical information and was available to the workshop participants in 1992, and (2) this series of Regional Reports, which are written in a less technical format and report a broad spectrum of recent findings and observations from scientists, farmers, and NRCS and Extension Service personnel.

This Northwest report is one of six regional reports. Some of the technology in these reports is suited specifically to the climate and soils of particular regions. However, due to their recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface residue management technologies used in other regions and discussed in the other five reports may apply to the Northwest region. A copy of these other reports may be obtained from the Conservation Technology Information Center (see abstract in this publication for complete address and telephone number) for a nominal shipping and handling charge.

Other Pacific Northwest Information Sources

Many sources of information are available on management technologies for conservation farming. These include research and extension publications from Oregon State University, University of Idaho, and Washington State University and educational materials from other agricultural support agencies and industries. A few examples are described below.

The Pacific Northwest Conservation Tillage Handbook is a major up-to-date reference on conservation farming technologies for the region. The handbook currently contains 122 handbook series publications, 20 of which have been published since 1989 when the original handbook was released. The handbook includes much of the new management technology developed through STEEP (Solutions to Environmental and Economic Problems) and STEEP II research programs and other Pacific Northwest research projects. It can be purchased for $20 through county extension offices in the three states or ordered directly from: UI Ag Publications, Building J40, Idaho Street, University of Idaho, Moscow, ID 83844–2240; telephone (208) 885–7982.

New handbook series publications are distributed through issues of the ***Pacific Northwest STEEP II Extension Conservation Farming Update***. This method of advertising and distribution has been an effective means of transferring information on new conservation farming technologies. In addition to the handbook series, the Update includes other current interest articles written from the perspective of adapting new technologies into producer's management systems. For more information on the Update contact Roger Veseth at (208) 885–6386 or Don Wysocki (503) 278–4186.

Wheat Health Management was published in 1991 as the first book in a new series entitled ***Plant Health Management***. The book incorporates much of the new STEEP technology for improving wheat health and production potential in the Pacific Northwest but also covers wheat production systems from a North American perspective. This in-depth book was written to help wheat managers (farmers, farm advisors, and other agricultural support personnel) understand the basic concepts and approaches to managing the health of wheat. An underlying theme is optimizing crop health and yield potential under conservation-tillage systems. The unique "holistic" approach of this book focuses on the whole cropping system, not just on the wheat plant or on individual management choices. Call the American Phytopathological Society Press at 1–800–328–7560 to get more information on the book or to order a copy. The price of the book is currently $45 (within the United States).

2 Terminology

David L. Schertz and John Becherer

In the early 1960's the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. The terms did not quantify the amount of surface residue left or any resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984 the Soil Conservation Service (now the Natural Resources Conservation Service) defined *conservation tillage* as follows: any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting or at least 1,000 lb/acre of flat small-grain residue equivalent are left on the soil surface during the critical wind-erosion period.

The objective of this conservation tillage was to leave residue on the surface to intercept the eroding forces of rain and wind. This definition remained standard through the early 1990's.

Conservation tillage comprises no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

- **No tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides; cultivation may be used for emergency weed control.

- **Ridge tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.

- **Mulch tillage.** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. Even so, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may reduce erosion considerably even though, by definition, this amount is not considered conservation tillage.

Most farmers chose to comply with the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected conservation tillage practices that left sufficient crop residue on the surface to meet their conservation goals. However, some of these tillage practices left less than the amount required to be classified as conservation tillage but were combined with other practices to achieve their conservation goals. Adding to the confusion, some people referred to conservation tillage as meaning only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year. (1) It begins with planting a crop that will provide sufficient residue to achieve a specified goal (that is, controlling erosion to less than 5 tons/acre/yr). A cover crop is often used with low-residue crops to achieve additional residue cover. (2) An essential component is good distribution of residue at harvest. (3) It requires carefully planning the depth and speed of any tillage operation to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows:

Any tillage and planting system that uses no-till, ridge tillage, mulch tillage, or another system designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that may be included in the farmer's total conservation plan.

Throughout this publication, the terms *reduced tillage*, *minimum tillage*, *conservation tillage*, and *crop residue management* are used interchangeably. Each term refers to systems that leave all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Description of the Region

R.I. Papendick, F.L. Young, K.S. Pike, and R.J. Cook

Most of the highly erodible lands in the Northwest are found in a contiguous belt of about 8 million acres extending across northern Idaho, eastern Washington, and north-central Oregon (see map in pocket of back cover). The remaining acreage shown in the map experiences less erosion and is largely in the intermountain area of southern and southeastern Idaho. This Northwest report specifically addresses the wheat region of eastern Washington, Oregon, and northern Idaho. However, much of the information would be applicable for the Idaho intermountain area in the appropriate precipitation zone. A major difference between the two areas is that the precipitation in the intermountain area is distributed more uniformly throughout the year whereas most of the precipitation in Oregon, Washington, and northern Idaho occurs during winter.

Because of high rates of wind and/or water erosion, over 60 percent of the farms in the region are required to use a conservation plan to meet U.S. Government Farm Bill requirements. Winter wheat or its replacement spring wheat is the dominant crop in all areas. Pea, lentil, and seed grass are important crops in the higher precipitation zones. Barley is grown in all zones but to a lesser extent in the crop-fallow areas. Minor crops include winter rapeseed, spring canola, mustard, chickpea, and hay where precipitation is more plentiful.

Climate

The climate varies from semiarid at the western edge to subhumid approaching the mountainous areas to the east. Land elevation ranges from 1,100–4,500 ft. The entire region has a Mediterranean-type climate with cold, wet winters and warm-to-hot, dry summers. Between 60 and 70 percent of the annual precipitation occurs during November through April. Mean annual precipitation ranges from about 9 inches in the southwestern part of the wheat-fallow loess soil zone to more than 25 inches east of Moscow, ID, and parts of Spokane County, Washington. Snowfall is 20–25 percent of the total precipitation at the higher elevations and decreases from the north and east to the south and west. Soil freezing may occur to a depth of 4 inches several times each winter and to 16 inches or more during some winters. These events are often interrupted by partial or complete thaws frequently accompanied by rain. Though the rainfall intensities are low (less than 0.2 inch/hr), considerable runoff can occur while the soils are frozen, especially if they are initially snow covered.

The region is also subject to high winds in the spring and fall. These winds create a wind erosion hazard in the drier areas where residue cover is sparse and where soils contain a higher sand content than the silt loam soils in the higher precipitation zones. Because of the rolling topography the wind speeds above and near the ground surface are likely to be more variable than those surrounding flat terrain. Wind erosion, however, has not been studied in the region.

Topography and Soils

The topography in the higher precipitation areas is steeply rolling with dune-like hills and steep north and east slopes. Most slopes range from 8 to 30 percent, but some slopes in excess of 45 percent are cultivated. The primary hazard is water erosion. In the drier areas, the topography is more gently rolling, and less land is classified as highly erodible for water erosion and more for wind erosion.

Soils are derived from loess mixed with varying amounts of volcanic ash. When not frozen, the soils are generally permeable and well drained and can store the annual precipitation. Some soils in north-central Oregon are shallow and have limited storage capacity. Soils tend to be sandy in the drier areas and tend to be silt loams and silty clay loams in areas with more precipitation.

Traditional Cropping and Tillage Practices

Cropping systems depend primarily on annual precipitation. The region's croplands can be grouped into three precipitation zones based on the number of inches of precipitation received. These groups are high (more than 17 inches), intermediate (13–17 inches), and low (9–13 inches).

In the high-precipitation zone, annual cropping is practiced, and most commonly winter wheat is grown in rotation with spring crops of pea, lentil, barley, and wheat. Typically this zone is planted 50 percent to winter wheat, 20 percent to pea and lentil, 20 percent to spring barley and wheat, and 10 percent to other (set-aside grass or fallow). The usual cropping system in the intermediate-precipitation zone is winter wheat-spring barley, wheat-fallow, or winter wheat-fallow. The region is typically planted 45 percent to winter wheat, 20 percent to spring barley or wheat, and 35 percent to other or fallow. In the low-precipitation zone (which is approximately one-half of the total cropland area), 50 percent of the region is normally planted to winter wheat and 50 percent is fallow. Some continuous cereal cropping is practiced in all three precipitation zones.

Moldboard plowing has been the conventional primary tillage practice in the higher precipitation zones following cereal crops on fields to be spring cropped. Virtually all winter wheat stubble is plowed under before winter. Secondary tillage for weed control and seedbed preparation is accomplished in several operations with a field cultivator or rod weeder and a harrow. Disking is the usual conventional method of seedbed preparation for a winter wheat crop following spring crops. Most all seeding is done with double disk drills at 6- or 7-inch row spacings.

In the intermediate-precipitation zone, the tillage method used after the winter wheat crop in the 3-yr winter wheat-barley-fallow rotation varies with which end of the intermediate-precipitation zone the grower is located in. In the wetter end, primary tillage has commonly been with the moldboard plow; in the dryer end, the combination of disking and chiseling has been more common. In this same rotation, secondary tillage in the spring before spring barley may include two to three field cultivator and harrow operations, followed by the use of a fertilizer applicator, rod weeder/harrow, and double disk or hoe drill in seeding.

The barley stubble in the winter wheat-barley-fallow rotation is commonly chiseled or disked in the fall or occasionally left standing overwinter. Conventional fallow tillage usually starts in early spring with a field cultivator, commonly involving two to three operations by June. During the remainder of the summer, the rod weeder (often with a harrow attached) is used to set and maintain the dry dust mulch and control weeds. It is not uncommon to rod weed four to seven times before winter wheat seeding. In recent years a significant number of growers have used a nonselective herbicide to control early weed growth and delay the initial tillage until later in the spring. As a result, two or more rod weedings have been eliminated.

The 2-yr wheat-fallow rotation cropping system is most common in the drier end of the intermediate-precipitation zone and throughout the low-precipitation zone. The combination of fall disking and chiseling is the most common primary tillage after winter wheat. Fall tillage is used in many areas to promote infiltration on frozen soils and to control weeds. If stubble is left standing during the winter, tillage is usually done early in the spring by disking or chiseling or both. If surface residues are less than 2,500 lb/acre, field cultivators or sweeps are recommended to minimize incorporation and burying of stubble. Under high-residue conditions (4,000 lb/acre or greater), a combination of disking and chiseling is used. Subsequent tillage operations generally include two to five rod weedings to control weeds and maintain a loose soil mulch (4–5 inches deep) to minimize evaporation losses. Use of nonselective herbicides has recently helped to delay initial tillage operations in both fall-tillage operations and spring-tillage operations. Virtually all of the winter wheat is sown with deep furrow drills at 16- or 18-inch row spacings.

With continuous spring cereal cropping, if fall tillage is used at all, it is usually by chiseling, particularly in areas with frequent runoff events on frozen soils. Growers often leave the stubble standing over winter to trap snow. These growers also reduce tillage in the spring and typically perform up to three field cultivations, one fertilizer application, and a rod weeding/harrowing before seeding with double-disk drills.

In the higher precipitation zones, fall-planted wheat usually doesn't grow much before it goes dormant for the winter and therefore doesn't provide much ground cover before the winter. Winter wheat is essentially dormant from December until March, and most growth, as with spring crops, occurs from April to mid-July on residual soil moisture. In fallow areas, winter wheat crops can be planted earlier so that there is considerably more growth in the fall (in some cases complete ground cover before winter) and growth will resume earlier in the spring.

Erosion and Water Conservation Problems

The climatic pattern, steep topography, and winter wheat planting with conventional tillage creates a winter runoff and water erosion problem in much of the region. With conventional farming annual erosion rates average 10–20 tons of soil per acre, and it is not uncommon to have rates of 50–100 tons of soil per acre on some slopes in a single season.

Erosion rates are highest on soils that have been frozen and are partially thawed. Soil thawing is common in the Northwest because cold periods are often followed by warm periods with rain. The worst erosion occurs when a snowfall on a frozen soil is followed by rain. The snow provides an extra supply of water to cause erosion as the soil warms during the rain. The initial runoff water may be clear if the soil is frozen, but eventually the surface soil will thaw and erosion rates can be dramatic. Until the impermeable frost is gone from the soil, infiltration is very low and runoff is nearly equal to snowmelt plus rainfall. Under these conditions, runoff from areas containing untilled stubble may be greater than from bare rough-tilled areas because the stubble can hold more drifting snow. However, if 6 to 8 inches of snow occurs before the soil freezes, the snow trapped in the untilled stubble will insulate the soil and prevent freezing whereas the unprotected bare soil will freeze.

In conventional planting systems, erosion rates from wind can exceed those from water. Unprotected wheat fields have lost up to 2–5 inches of topsoil in one winter-spring season to wind erosion.

Evaporation is the major source of water loss. It is estimated that three-fourths of the annual precipitation can be lost by evaporation from a bare, uncropped soil. Although potential evaporation is greatest during the summer, the largest actual loss occurs during the winter rainy season and in the early spring when sunlight intensity increases and the soil surface is still moist.

Pest problems

Weeds

With the reduction or elimination of tillage, a major method of weed control is lost. Tillage aerates the soil, increases weed seed germination, and kills emerged weeds. In conventional-tillage systems, a major flush of weeds occurs shortly after planting, and then herbicides are generally used to supplement tillage for weed control. In contrast, in reduced-tillage systems, weeds tend to germinate over a longer period, and herbicides are used to replace tillage for weed control.

There are specific weed management and control practices that are tailored to the weed population associated with increased residue cover and reduced tillage. In reduced-tillage systems, weed seeds accumulate near the soil surface. Shallow disking and chisel plowing are commonly used to reduce weed popluations in reduced-tillage practices but do not bury weed seeds deeply. On the other hand, these practices do not bring deeply buried seeds to the surface where they can germinate. Therefore these practices help to diminish the number of weed seeds in the upper soil layers over time as germinating weed seedlings are destroyed and as deeper weed seeds remain buried. Highly effective weed control and increased herbicide inputs are especially needed in the initial stages after switching to a reduced-tillage system to make sure weeds stay under control.

Growers need to realize that if they resume deep tillage at any time after starting a reduced-till program, they can expect the weed flora to be similar (except for populations of downy brome grass and perhaps a few other weeds) to that which existed before no-till was initiated.

One problem related to weed control in reduced-tillage systems is reduced efficacy of some soil-applied herbicides. Research has shown that residues can intercept up to 30 percent of the herbicide. However, herbicide rates probably do not need to be increased unless more than 3,000 lb of residue per acre are present. It is therefore extremely important that combines be equipped with chaff spreaders and choppers to distribute chaff uniformly rather than concentrating the residue in a windrow.

Reduced-tillage systems should not be used in fields where winter annual grasses or perennial weeds are a major problem. In a reduced-till environment, these weeds may increase and become severe because of a lack of effective in-crop herbicides for winter annual grasses or a lack of tillage, which severs the roots and reduces vigor of perennial weeds.

When tillage is reduced to control soil erosion and herbicide applications are minimized for food and environmental safety, growers will need to increase their weed management skills. Converting from conventional to conservation farming includes a transition period in which weed species shifts will occur. The shift will be subtle initially but ultimately will result in an increase in winter annual grasses and a decrease in most broadleaf weeds. Growers must identify weed species properly, realize that shifts have occurred, and adjust their weed management program to include more timely treatments. They will have to increase field scouting, use special tank mixes for hot spots and special weed problems, and possibly switch from aerial to ground applications to improve their weed management strategies.

Major grass species that will become greater weed problems in reduced-tillage systems include jointed goatgrass, downy brome grass, wild oats, Italian ryegrass, and common rye. Also, volunteer wheat and barley may be problems in reduced-tillage systems. Broadleaf weed species that are likely to increase in number include catchweed bedstraw, ivy leaf speedwell, mayweed chamomile, prickly lettuce, prostrate knotweed, kochia, and Russian thistle. Perennial weeds that are likely to increase in number in reduced-till systems include Canada thistle and field bindweed.

Recently, several of these problem weed species have been found to be resistant to several commonly used herbicides. Populations of prickly lettuce, Russian thistle, and kochia resistant to sulfonylurea herbicides and wild oats resistant to diclofop (for example, Hoelon and Illoxan) and related herbicides have been reported. If weed resistance to specific herbicides is found, growers must switch to herbicides with different modes of action to combat the problem.

Growers must also be aware of environmental and food safety concerns and minimize the amount of herbicides used. Several new sprayer technologies are being researched to reduce herbicide loads. These include a sprayer that automatically turns nozzles on and off as sensors detect the presence or absence of growing weeds. Another type of sprayer—the air-assist sprayer—can reduce carrier volume 15–20 fold. Several variations of these air-assist sprayers may soon be marketable and may allow herbicide rates to be decreased by 50 percent.

Insects

Tillage or the lack of tillage in different cropping systems can be a tool for managing selected arthropods, both pest and beneficial types. Hundreds of species of foliage-dwelling, soil surface, and soil-inhabiting arthropods live in fields of wheat and barley and are influenced by a complex of biotic and abiotic factors. The text that follows gives a synoptic perspective of the effects of conservation tillage on insects and mites in small grains.

Crops grown under conservation tillage, like perennial crops, are less disturbed, which favors greater diversity of species and higher total numbers of arthropods than disturbed lands. Surface residues associated with conservation tillage increase soil moisture and buffer soil temperatures to further enhance species abundance, especially microarthropods [Collembola (springtails), Acarina (mites), and Psocoptera (booklice)] and predatory spiders and ground-dwelling Coleoptera (beetles). The microarthropods are largely beneficial, feeding upon fungi, bacteria, and detritus, and may, in many cases, play a key role in the decomposition of organic matter and the release of nutrients. Predators, such as syrphids, carabids, and spiders, are valuable biocontrol agents for many of the soil-surface and foliage-dwelling pests.

Although the total number of arthropods in small grains is higher under conservation tillage than under conventional tillage, the pest status of a majority of the pest species remains the same. There are exceptions, and table 1 characterizes these.

Insects that overwinter in straw or straw mulch benefit from reduced tillage. Hessian fly, wheat jointworm, and wheat stem sawfly overwinter in straw and, if present, increase in number when crop residues are retained. The level of increase, however, may not be economically important. For example, Hessian fly populations are not likely to increase significantly except in areas where annual precipitation exceeds 26 inches. In areas where Hessian fly is a threat, the threat can be partially or totally offset by growing resistant wheat, by growing winter wheat instead of spring wheat (winter wheat, although susceptible, is less damaged by the fly than spring wheat), by not planting winter grains earlier than October to avoid the fall generation of the fly, or by growing barley instead of wheat (barley is less susceptible to the fly than wheat). Wheat jointworm and wheat stem sawfly are rare insects in Idaho, Oregon, and Washington and have not been a problem to date, even in the presence of conservation tillage. Wheat stem sawfly is a problem in Montana and is magnified by reduced tillage.

Brown wheat mite, wheat curl mite, and winter grain mite on small grains are not widespread problems in the Northwest but can be locally injurious. Their frequency and pest potential are increased when volunteer grain, other grasses, and weeds are left uncontrolled in summer fallow. Such plants serve as a reservoir for mites and as a "green bridge" to new plantings in the fall. Chemical fallow measures eliminate the green bridge and therefore eliminate much of the risk of the mite problems.

Cereal aphids in late summer and early fall are also abetted by green plants in fallow lands. Destruction of host plants is recommended but is not a complete safeguard against infestation in new plantings, since problems often arise from winged aphids originating from distant sources.

Conservation tillage in small grains has had little noticeable effect on populations of bird cherry-oat aphid, corn leaf aphid, rose grass aphid, or Russian wheat aphid but can affect populations of greenbug and English grain aphid. In experimental trials, greenbug has been substantially reduced in wheat grown under moderate to high surface residues compared with wheat grown under clean cultivation. The cause of the reduction is not fully understood, but it is theorized that crop residues act as a reflective mulch that repels or masks the attractancy of the crop to settling aphids. English grain aphid, in contrast, increases in number under conservation tillage, at least in winter wheat. The increase, however, does not mean that the aphid population will reach an economic threshold level. In fact, in most years, the English grain aphid seldom causes crop damage.

With few exceptions, the insect and mite problems on small grains have not substantially changed in over a decade of conservation farming in the Northwest. The few arthropod population levels that are increased by conservation tillage are manageable and are more than offset by the gains in soil moisture retention and soil erosion control.

Diseases

Wheat. Most of the important diseases known to wheat occur in the Northwest. This is because of the diverse climate of the region and the different crop production practices. Many of these diseases, such as snow molds and Pseudocercosporella foot rot, are of little or no importance anywhere else in the United States.

Most of the major diseases of wheat in the Northwest are caused by fungi. These fungi fall into two groups: those that move as spores through the air and those that carry over in the soil and crop residue. Crop residues have little or no direct effect on diseases caused by airborne fungi; residues may, however, have some indirect effect relating to their effects on stands and foliage characteristics.

The fungi that carry over in soil and crop residue can be further subdivided into the following groups: (1) those that use crop residue as a food base and springboard for attack of leaves and stems aboveground and (2) those that use crop residue as a food base or live free of residue as dormant propagules (spores or sclerotia) in soil and attack roots. One fungus, *Cephalosporium gramineum*, does not fall into either of these groups. It survives in crop residue and infects crops through roots but produces a disease of the vascular system that causes plants to die very shortly after heading.

The fungi that live in crop residue but infect wheat aboveground include those responsible for snow molds and strawbreaker foot rot, one of the most widespread and important diseases of wheat seeded early on fallow or in 2-yr rotations. The fungi that live in the soil or crop residue and infect roots include those responsible for Fusarium root and crown rot (under low-rainfall conditions), Pythium seed and root rot, Rhizoctonia root rot, and take-all.

Barley. In contrast to wheat, barley is remarkably free of diseases in the Northwest. All of the economically important diseases of barley are root diseases. Take-all and Pythium root rot occur on barley but are less damaging to this crop than to wheat. Rhizoctonia root rot, however, is more severe on barley than on wheat. It can be devastating on spring barley seeded no-till into standing wheat or barley stubble, especially where volunteer plants of these crops are sprayed with an herbicide only 2 or 3 days prior to planting.

Pea, lentil, and chick pea. These cool-season pulse crops grown in the intermediate and higher precipitation areas are subject to several leaf, stem, and root diseases. Of the leaf and stem diseases, Ascochyta leaf blights are important on pea and chickpea. These fungi produce spores from infested surface residue, and these spores spread the disease to the next pea or chickpea crop. In addition, the leaf blight of pea produces sclerotia, chlamydospores, and pycnidia on straw fragments, each of which can help this causative fungus live in the soil after the residue is decomposed.

Ascochyta blight can drastically decrease the production of chickpea. The fungus produces two spore types on crop residue. One type (ascospores) is windborne and can result in outbreaks of this disease in fields downwind from fields cropped the previous year to chickpea. The other spore type (conidia) is water-splashed—a process that disseminates the pathogen from surface residues to foliage above the crop residue.

Pea is also affected during the seedling stage by *Phoma medicaginis*, which produces a foot rot that causes the plants to remain small or kills them at a young stage. This fungus survives both in crop residue and as free-living hardy spores (chlamydospores) in the soil. It is most destructive when the soils are cool and wet.

Another important root disease of pea is Fusarium root rot caused by *Fusarium solani* f. sp. *pisi*. This disease, like Fusarium root and crown rot of wheat, is especially important on pea under conditions of water stress, which is typical on hillsides and hilltops. The fungus forms chlamydospores that can survive for many years in the soil and cannot be controlled by crop rotation. Surface residue management should help control the disease by alleviating water stress.

The same fungus that causes Rhizoctonia root rot of wheat and barley causes root rot of pea, lentil, and chickpea under cool (50°F), wet soil conditions. These conditions are typical in the spring and are also more common if surface residues exist. Another fungus, *Rhizoctonia solani* AG4, is also associated with surface residues but causes damping off of these crops under warm (60–70°F), wet soil conditions.

Lentil is relatively free of diseases in the Northwest climate. *Fusarium avenaceum*, a common pathogen of grasses, can cause plant mortality for lentil, especially if the crop is seeded no-till into bluegrass sod.

Relationship of diseases to crop residues. Pathogens that attack aboveground parts of the plants from spores produced in crop residue tend to be favored by surface residues. On the other hand, surface wheat residue has not favored Pseudocercosporella foot rot, possibly because root diseases are more important in this situation and they retard the growth of wheat. This disease is limited when wheat planted in the fall enters the winter as small or spindly plants, whether because of root disease, climate, weather, or late planting.

Pathogens that depend entirely on crop residue as a food base for attack of roots (for example, the pathogens responsible for take-all of wheat, Rhizoctonia root rot of wheat or barley, and possibly Cephalosporium stripe of wheat) tend also to be favored by practices that leave the soil and crop residue relatively undisturbed. Conversely, fragmentation and frequent disturbance of pathogen-infested residue is thought to accelerate the successions of other microorganisms as colonists of this residue and with potential to overrun or displace pathogens.

Pathogens that both infect roots or stem bases and are more important when soils are cool and wet (for example, take-all of wheat, Rhizoctonia root rot of barley, Pythium seed and root rot, and foot rot of pea seedlings) are favored by practices that leave crop residue on the soil surface. The residue retards evaporation, thereby helping to keep the soil cool and wet over a longer period into the spring.

Table 1. Insect and mite pests of small grains in the Northwest region

Pest	Pest Information					Pest Residue Index*		
						Surface Residue Levels		
	Presence	Common Field Density	Damage Potential	Principal Host Crop	Main Season of Damage	Low	Medium	High
Aphids								
Bird cherry-oat aphid	Common	Variable	Major	All grains	Fall	0	0	0
Corn leaf aphid	Common	Variable	Major	Barley	Fall	0	0	0
English grain aphid	Common	Variable	Minor	All grains	Spring	0	+1	+1
Greenbug	Common	Variable	Major	All grains	Fall	0	−1	−1
Rose grass aphid	Common	Variable	Minor	All grains	Fall	0	0	0
Russian wheat aphid	Common	Variable	Major	All grains	Spring/Fall	0	0	0
Armyworm/cutworm	Infrequent	Variable	Major	All grains	Spring/Fall	0	0	0
Barley thrip	Infrequent	Low	Minor	Barley	Spring	0	0	0
Cereal leaf beetle	Restricted	Low	Minor	Wheat	Spring	0	0	0
False wireworm	Infrequent	Low	Minor	All grains	Spring/Fall	0	0	0
Grasshopper	Infrequent	Variable	Major	All grains	Spring/Fall	0	0	0
Hessian fly	Infrequent	Variable	Major	Wheat	Spring/Fall	+1	+2	+2
Wheat blossom midge	Restricted	Low	Minor	Wheat	Spring	0	0	0
Wheat jointworm	Infrequent	Low	Minor	Wheat	Spring/Fall	0	+1	+1
Wheat sawfly	Infrequent	Low	Minor	Wheat	Spring	0	0	0
Wheat stem maggot	Infrequent	Low	Minor	Wheat	Spring	0	0	0
Wheat stem sawfly	Restricted	Variable	Major	Wheat	Spring	+1	+2	+2
Wheat strawworm	Infrequent	Low	Minor	Wheat	Spring	0	+1	+1
White grub	Infrequent	Low	Minor	All grains	Spring/Fall	0	0	0
Wireworm	Common	Variable	Major	All grains	Spring/Fall	0	0	0
Mites								
Brown wheat mite	Infrequent	Low	Minor	All grains	Spring	0	0	0
Wheat curl mite	Common	Low	Minor	Wheat	Spring/Fall	0	0	0
Winter grain mite	Infrequent	Low	Minor	Wheat	Spring/Fall	0	0	0

*Pest-residue index measures the change in pest population or pest impact from having residue on the surface, that is, the change from switching from conventional- to reduced- or no-till: −1=decrease in the pest population or pest impact, 0=no change, +1=small increase, and +2=marked increase.

4 Surface Residue Management

D.K. McCool, J.E. Hammel, and R.I. Papendick

Effectiveness of Residues for Controlling Erosion from Wind and Water

The benefits of surface residues for reducing soil erosion from water are well established. In the Northwest the main effect of surface residue on erosion from water is in reducing the transport capacity of runoff. The effectiveness of residue cover for reducing erosion by water is shown in figure 1. In this figure the relative soil loss for a given percent cover is a ratio between the soil lost at that percent residue cover and the soil lost with no residue cover. The relationship shows that residue cover is highly effective for erosion control and is even more so in the Northwest than in the north-central region. The reason for this is that surface residues are apparently more effective for control of rill erosion, which is the dominant type of erosion on cropland in the Northwest (whereas mixed interrill/rill erosion is the dominant type in the north-central region).

Effects of incorporated residue on erosion control are not as well documented. The effect on water erosion of incorporated residue depends on prior land use, the amount of disruption of the soil surface, mass of incorporated residues, and the type of erosion process (rill or interrill). Roots from previous crops count as incorporated residue. A graph of the relative soil loss ratio (ratio of soil loss with residue vs. without) from water erosion on land with surface and incorporated residue is presented in figure 2. The figure shows that there is a significant benefit from incorporated residues for erosion control but that the effect is considerably less than that from surface residue.

Wind erosion, like water erosion, can be effectively controlled with residue cover. Studies conducted in Texas by Fryrear (1985) show a relationship between soil loss ratio and percent cover that resembles the relationship for water erosion (fig. 3). The graph in figure 3 has not been validated for the Northwest, but there is no reason to believe that it should not have wide applicability. As long as the residue remains intact on the soil surface, neither the type of residue nor its characteristics have any influence on the effectiveness of the residue. Moreover, the available data support the concept that the most important factor in reducing soil loss is the percentage of soil cover, not the mass of the residues. Any tillage practice that maintains residues on the soil surface will help control wind erosion. One important consideration for wind erosion control is that residues must be anchored so that they remain in place and are not blown away by wind.

Residue Effects on Soil Water and Temperature

Surface residues combined with proper tillage can aid in conserving soil water and increasing crop yields in the Northwest's winter rainfall climate. About 70 percent of the variation in wheat yield in the region can be explained on the basis of early storage of soil water in the spring. Water conservation during the winter and early spring is very important for crop production in this region. Residue cover also affects soil temperatures, sometimes to the detriment of plant growth but usually to the benefit of water conservation.

Surface residues act as a heat barrier by reflecting sunlight, decreasing evaporation, and reducing air movement next to the soil surface. Average temperatures near the soil surface are always lower by as much as several degrees during the day in the spring and summer if the surface is covered or partially covered with residues as opposed to bare. The lower soil temperatures associated with residues keep the surface layers more moist for a longer time than if the soil were bare and therefore may also increase weed seed germination and occurence of certain soilborne diseases of crops. Although lower temperatures from residues can slow plant growth in the early spring, the additional moisture saved with residues can compensate for the slow early growth by promoting growth later on. As the soils cool down in the fall (or at night), the crop residue helps to maintain slightly higher average soil temperatures than are found on bare soil by limiting heat loss from the soil. Residue cover also helps reduce the depth of soil freezing. However, if the soil is frozen and then snow falls on it, the frost may persist longer under the residue cover during thawing because of the insulation effect provided by the residue.

Residues on the surface increase infiltration of rain and snowmelt on sloping lands by slowing runoff and therefore providing more time for water to enter the soil. Infiltration is especially a problem when soils are frozen, which may occur several times during the winter when the soils are very wet. Rough tillage of stubble (such as fall chiseling that extends through the normal frost depth) creates a high macroporosity in the surface layers. The change in macroporosity is highly effective in reducing runoff and increasing infiltration in frozen soils. Stubble left standing helps trap snow and increase water storage during the winter. The snow packed in standing stubble also insulates the soil from freezing and helps to absorb more snowmelt. Rough tillage with residue cover or standing stubble can increase water storage during the winter by 2 inches or more, resulting in more water being available for the next crop.

The maximum possible rate of evaporation from a soil is controlled by atmospheric conditions (temperature, wind, and sunlight) but always occurs when the surface is wet. Surface cover always lowers the maximum rate of evaporative loss by shading the soil (keeping the soil surface cooler) and reducing convective transport of water away from the moist soil surface. Thus, for the climate of the Northwest the most effective way to achieve water conservation is to keep the soil covered with residue during the winter and into early spring when the surface is moist most of the time.

When the soil warms and drys in the spring, a residue-covered field can actually have a higher evaporative loss than would occur from a bare field. This happens because the residue cover, though it slows the evaporation rate, keeps the soil surface moist for a longer time. With a bare soil, a dry layer is formed rather quickly and the evaporation rate is slowed very quickly. In addition, tilling a soil breaks the upward liquid flow from the deeper layers and encourages surface drying under the residues; therefore tilling can markedly slow the evaporation rate. However, repeated tillage that exposes moist soil to the surface increases water loss. Residue cover, unless unusually high in amount, has little effect on water conservation during the summer because evaporation is almost entirely controlled by the dry surface layers.

Measuring and Reporting Residue Amount

Traditionally, surface residue was measured in terms of weight or mass per unit area. This was particularly true in areas where wind erosion is the primary means of erosion. The residue within a 1 yd^2 or 1 m^2 area was clipped (if needed) or gathered, then dried and weighed. This is an extremely time-consuming process, and with the possible exception of the period after harvest and prior to primary tillage, has been abandoned in favor of measuring percent of the ground surface covered by residue.

Percent cover can be measured by a number of techniques, from very simple to very complicated. One simple field method is to photograph the residue and then project the resulting slide on a gridded screen and count grid corner and residue intersections. This gives a permanent record but does not provide an immediate value while in the field. Another simple field technique giving an immediate value is to use a point intersect method, which involves the use of a tape line or a 50-ft line with 100 knots or beads on it. The line is laid on the soil surface at an angle to tillage or row direction. The coincidence of a point on the line with residue underneath is counted as a hit. The number of hits for the 100 knots is totaled to give the percent residue cover. For each knot, the entire bead or knot area should not be used to decide if it lies over residue. Instead only one corner of the beads or knots should be selected for observation. (For example, just the top right corner of each bead or knot should be evaluated to see whether it has residue under it to determine whether or not to count a residue hit). A number of automatic means to determine residue cover are under development, but they are not yet commercially available.

In any method using the coincidence of a small point and residue, statistical reliability is a concern. A large number of measurements may be required depending on the desired level of statistical reliability. If the observed residue hits total 25 percent and if 300 points are used, the 95 percent confidence interval is 20 to 30 percent; if 500 points are used, the 95 percent confidence interval is 21 to 29 percent. To reduce the confidence limit to 23 to 27 percent requires 2000 points. This is a factor to consider when the point intersect method is used to determine if a crop producer is in compliance with the requirements of the Food Security Act.

A known relationship between residue cover and weight per unit area is needed. In erosion models, residue effectiveness is determined from percent cover, whereas residue decomposition models work with mass or weight of residue per unit area. A general relationship for common small grains and annual legumes in the nonirrigated areas of the Northwest is found in the exponential form: $y=(1-e^{-0.000644x})100$. In this equation y is the percent surface cover, and x is the weight per unit area in pounds per acre. A graph of the relationship is presented in figure 4 and can be used for estimating purposes. Wide variations from this equation can be found, depending upon crop and variety. Easy-to-use tables for converting percent cover to residue weight per unit area are available locally through Natural Resource Conservation Service field offices.

Residue Reductions by Implements and Tools

The amount of residue incorporated with a specific tillage tool is dependent on the quantity, stem length, strength, moisture content, and state of decomposition of the residue and on soil moisture content and speed of tillage. Less residue is incorporated when residues are fresh and not decomposed, soils are dry, and tillage speed is lower.

Residue incorporation is sometimes reported as percent by weight and sometimes as percent by cover. Either is correct, but the two should not be confused because the numbers are generally not interchangeable. The fraction of before-operation mass incorporated will always be greater than the fraction of before-operation cover incorporated. The discrepancy between the two will be greater for higher initial quantities of residue and higher percentages of incorporation such as with the moldboard plow. For use in conservation planning, the effect of a particular tillage operation is usually reported as the percent of the before-operation mass or cover left after the operation.

The percentage of residue mass retained on the surface after tillage tools are used in the Northwest is as follows:

Tillage tool or operation	Residue mass retained* (percent)
Chaff and awn deduction	70
Overwinter residue decomposition	70–80
Tandem disc, one-way & offset	
4–6 inches deep	60–75
6 or more inches deep	40–60
4 inches deep (for pea, bean, and lentil residue)	10–30
Chisel plow	
Straight points, 12-inch spacing	70–80
Straight points, 18-inch spacing	75–85
Twisted points, 18-inch spacing	50–70
Moldboard plow	
8 or more inches deep	0–15
6–8 inches deep, no trash boards	20–30
Uphill furrow, 6–8 inches deep	30–40
Chisel-disc or cultimulcher	45–65
Secondary tillage	
Field cultivator	75–85
Cultivator, sweeps 16 inches apart, tilling 8 inches deep after moldboard plowing	100–120
Rod weeder	85–95
Rod weeder with sweeps	75–85
Harrow, 10-bar spike	80–90
Harrow, 10-bar tine	85–95
Drills	
Double disc	80–90
Deep furrow or hoe	75–85
No-till, light double disc	75–90
No-till, heavy double disc	50–75
No-till, heavy double disc (for pea, bean, and lentil residue)	30–50
Chisel point or air seeder	50–75
Fertilizer and Herbicide Application	
Fertilizer shank applicator	80–90
Herbicide application	100
Grazing stubble	40–80

* Minimum residue retention occurs when residue levels are lower, soil moisture is higher, operating speed is faster, and tillage is deeper. Maximum residue retention occurs during opposite conditions.

SOURCE: Monsanto Company (1992).

The range in the retention values in the information above accounts for the vast range of conditions encountered and crops used in the field. For instance, spring grain, spring pea, and lentil residues are less resistant to tillage and disappear rapidly; for these residues, therefore, the lower residue retention values in the data above are likely to be more accurate. The higher retention values are more accurate for fields in which the residue is from winter wheat or winter barley.

Critical Erosion Period

Most water erosion in the nonirrigated area of the Northwest generally occurs between late November and late March in fields that were fall seeded to winter wheat or barley. The majority of the precipitation occurs during this period, but more importantly, this is the period when soil freezes and thaws and is frequently in a highly erodible condition (lacks residue cover, roughness, or strength) when snow melts or rain occurs. Furthermore, formation of frozen surface layers that are nearly impermeable to water is common because of the high moisture content in the surface layers. Approximately 90 percent of the annual water erosion hazard occurs during this winter period.

The critical period for wind erosion in the low-precipitation areas is in the fall, depending on when fall rains begin, and again in April and May. These periods in the winter wheat-fallow cropping systems coincide with probabilities for high winds and vulnerable soil conditions. Serious wind erosion can also occur during the winter months if precipitation is below normal and residue cover is low on fields sown to winter wheat after fallow.

Adequate surface protection is very important in preventing water erosion during the winter from fall-seeded fields. Surface residue, canopy cover, and surface roughness affect runoff on a thawing soil. For example, a residue cover of 20 percent will reduce water erosion to approximately 37 percent of that occurring from no residue cover. A crop canopy cover of just 20 percent can reduce water erosion to 80 percent of that occurring from no canopy cover. Similarly, a change in random roughness from a fine to a medium seedbed will reduce water erosion to about 70 percent of that occurring from a fine seedbed. The cumulative effect of all three of these changes is considered to be multiplicative (that is, it can be determined by multiplying 0.37 times 0.8 times 0.7 times 100). Therefore, the combined effect of all three of these changes would be a reduction in soil loss to approximately 21 percent of that occurring from no residue, no canopy cover, and a fine seedbed.

Although less is known about residue effects on wind erosion control in the Northwest, there is reason to believe that these should be similar to the relationships established in the Great Plains (see fig. 3). Little information is available on alternative wind erosion control methods that can be used to supplement residues.

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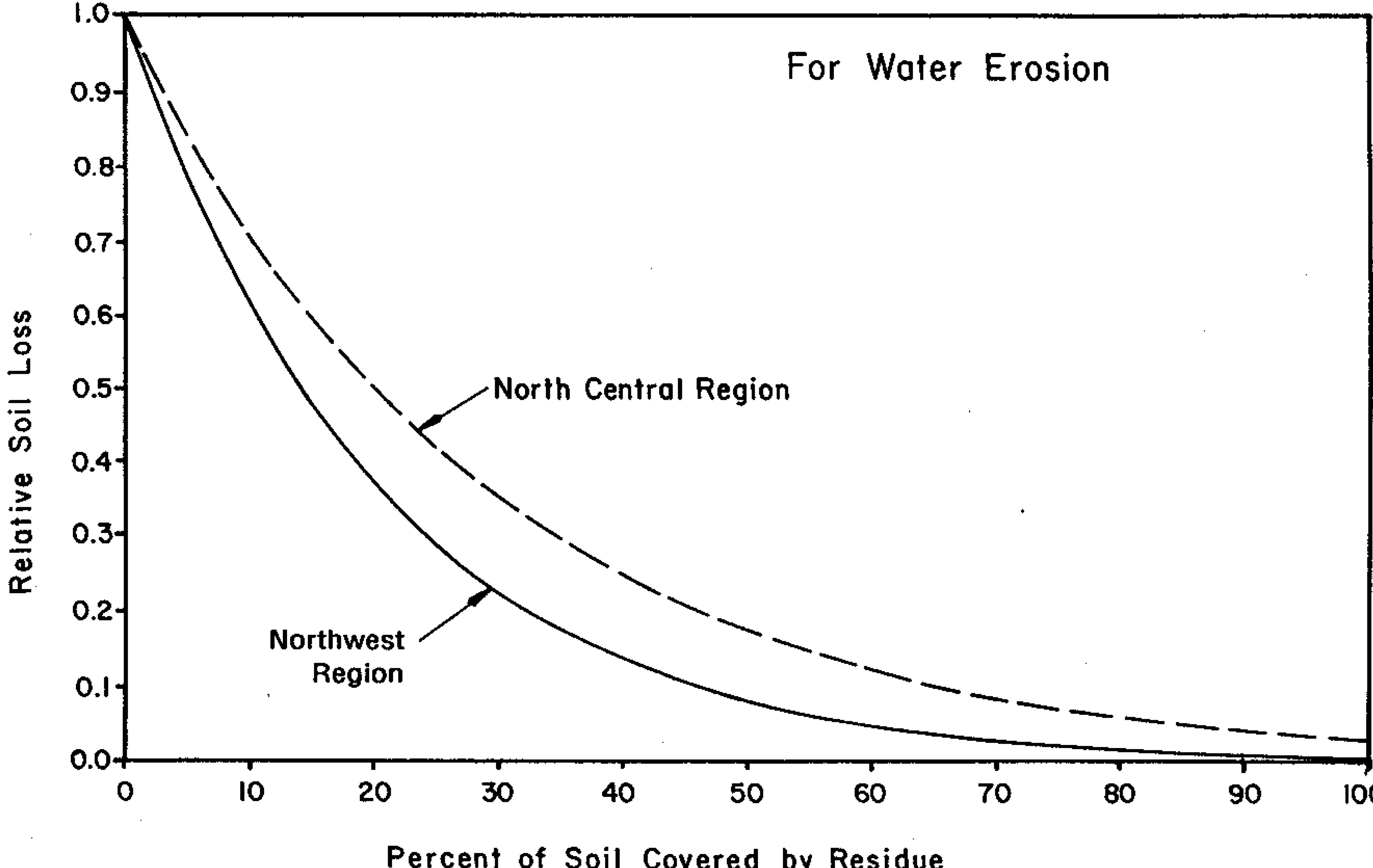

Figure 1. Relationship between relative soil loss from water erosion and percent of soil covered by small-grain residue (for the North Central and Northwest regions)

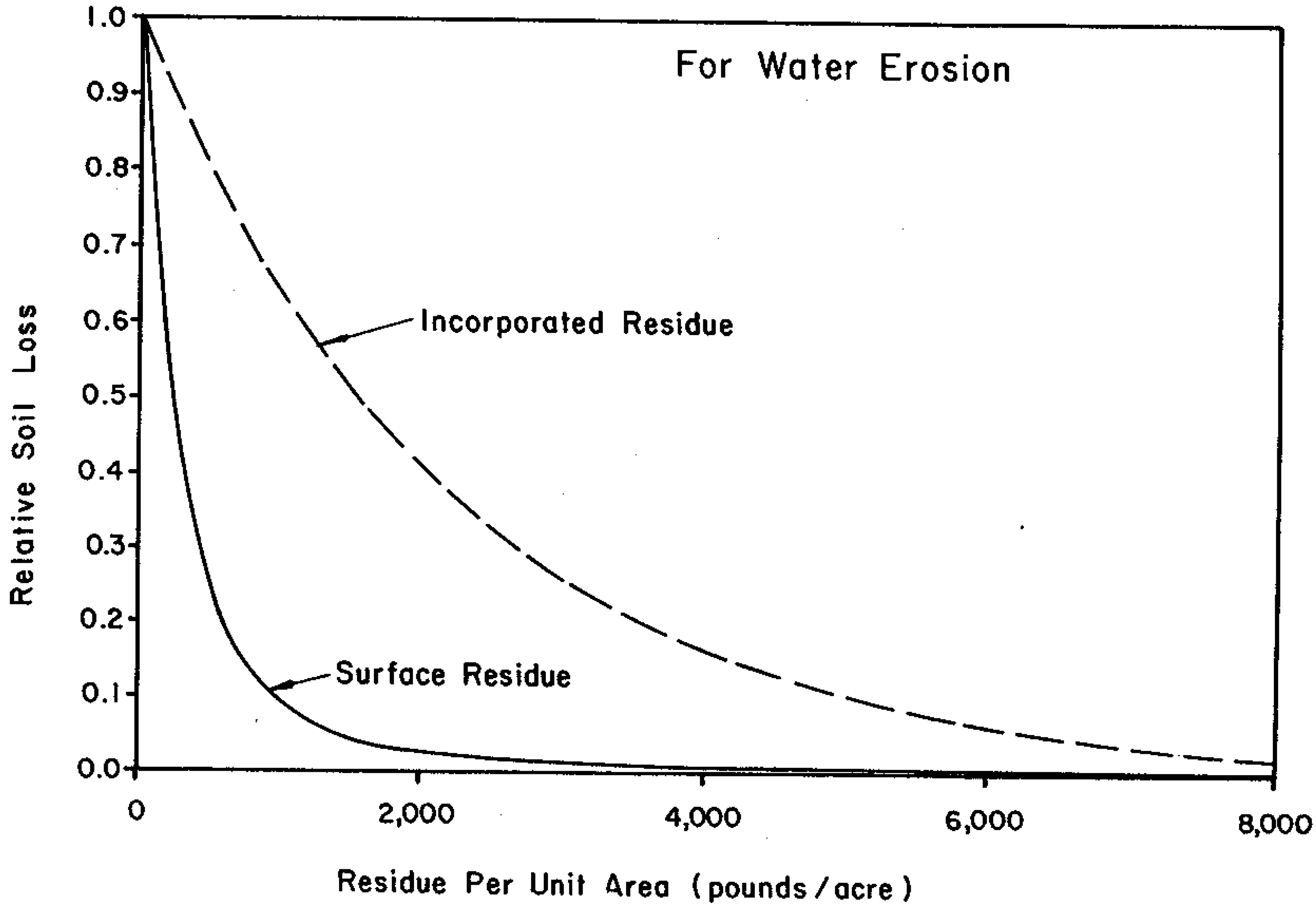

Figure 2. Relative soil loss from water erosion on land with surface and incorporated residues (for the Northwest region)

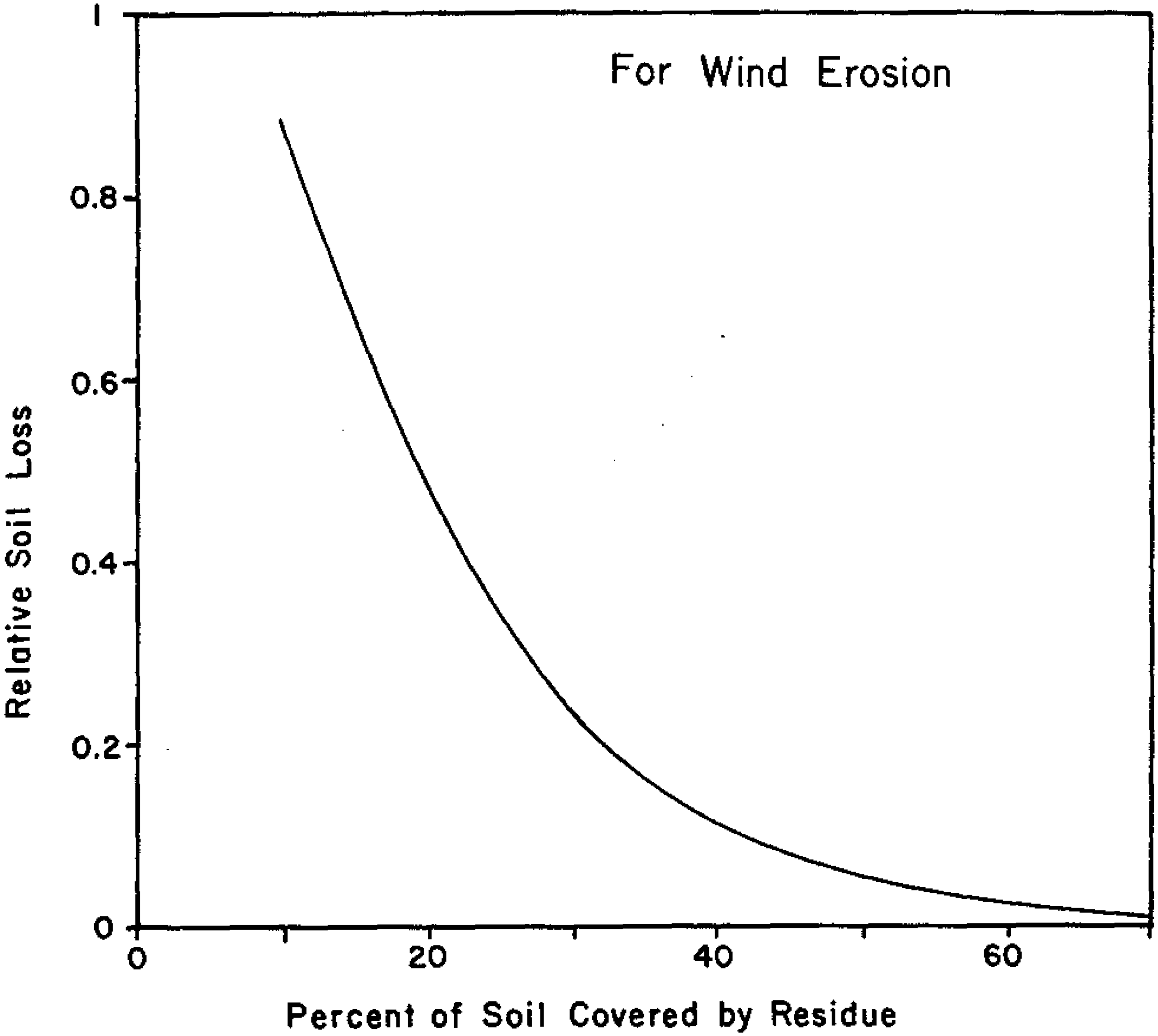

Figure 3. Relationship between relative soil loss from wind erosion and percent of soil covered by residue. SOURCE: Fryrear (1985).

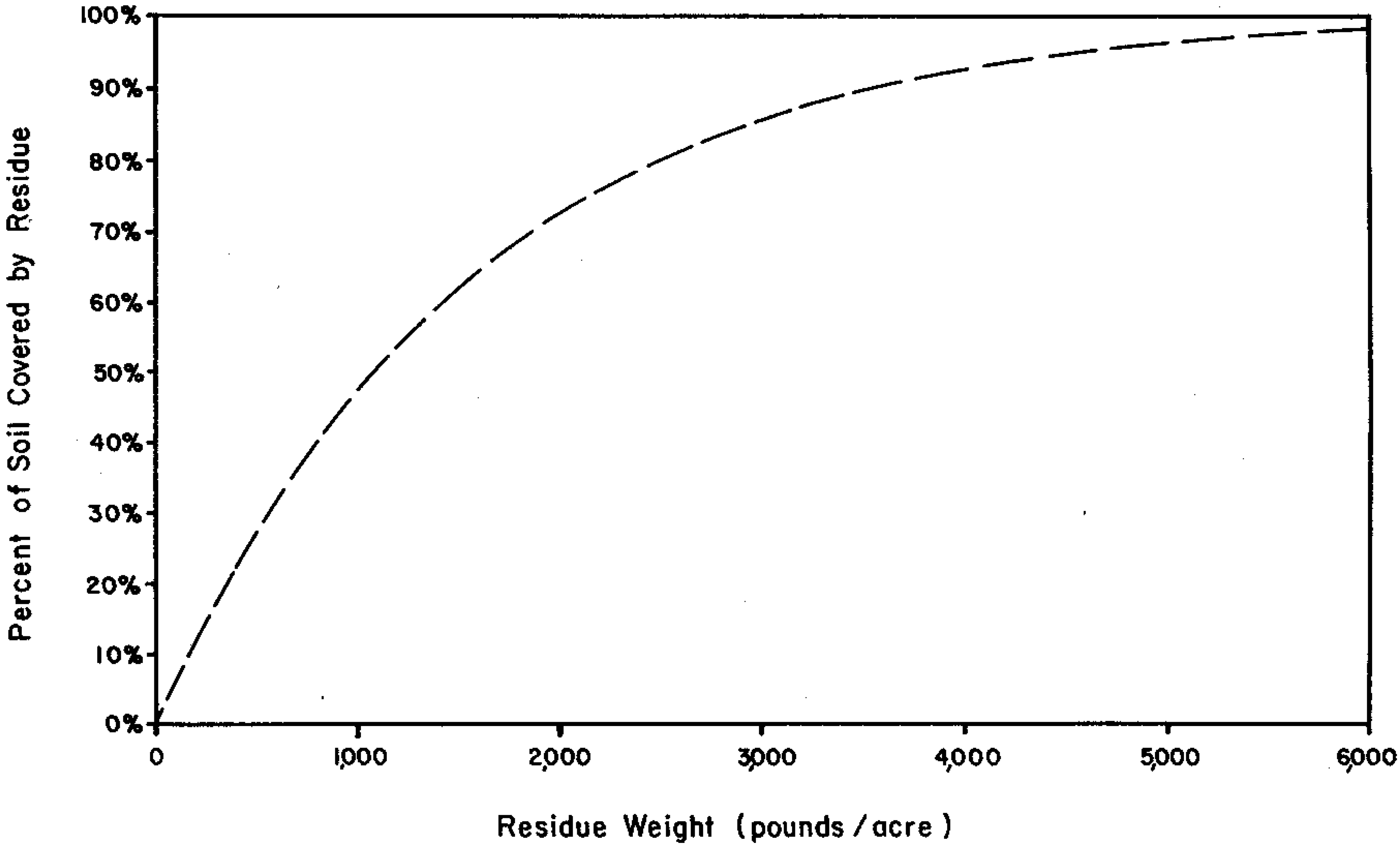

Figure 4. A general relationship between percent cover and residue weight per acre for common small grains and annual legumes in the nonirrigated areas of the Northwest

5 Achieving Conservation Compliance with Residue Farming in the High-Precipitation Zone

R.J. Veseth, P.E. Rasmussen, F.L. Young, R.J. Cook, D.L. Young, and R.I. Papendick

Rotations in Use

The principal crops in the high-precipitation zone of the Northwest are winter and spring wheat, winter and spring barley, pea, lentil, spring canola, and winter rapeseed. Farmers generally use 2- or 3-yr rotations but use some continuous cropping and some fallow of set-aside acres. The cropping system is influenced by base acres for wheat and barley in the farm program. The 3-yr rotation of wheat-barley-pea (or lentil) has gained popularity mainly for reasons of weed and disease control. However, many farmers are limited to the 2-yr rotation of wheat-pea (or lentil) or continuous cereal cropping in order to maintain their base acreage allotments. Cropping sequences commonly used by farmers in the high-precipitation zone of the Northwest are as follows:

3-Yr Rotation
- Winter wheat-spring cereal-pea (or lentil)
- Winter wheat-spring cereal-spring canola
- Winter wheat-fallow-winter rapeseed

2-Yr Rotation
- Winter wheat-pea (or lentil)

Continuous Cereal Cropping
- Winter wheat-winter wheat*
- Winter wheat-spring cereal*

*To a minor extent fall barley is substituted for winter wheat.

Residue Production

Straw production from winter wheat ranges from 3,000 to 5,000 lb/acre in the poorer producing parts of the field (ridgetops and upper slopes) and from 6,000 to 11,000 lb/acre in the better producing areas (lower slopes and bottom lands). Production from fall barley is 80–90 percent of that from winter wheat. Stubble produced by spring barley and wheat ranges from 50 to 70 percent of that produced by the winter crops. Pea and lentil residue generally ranges from 1,500 to 2,000 lb/acre at harvest. Because these legume residues shatter under dry harvest conditions and degrade rapidly, the amounts of residue remaining by seeding time may be only 500–1,500 lb/acre.

Fertility Management

Fertility requirements in conservation tillage do not differ appreciably from those in conventional tillage, but nutrient availability and methods of fertilizer application are often different. Conservation tillage using reduced- and no-till practices will eventually concentrate nutrients in the top 3 inches of soil rather than distributing them through the top 8–10 inches as is typical of conventional tillage. Soil samples taken from conventional- and no-till fields should be taken from the same sampling depth if comparisons are to be made between the two practices. The two most important factors affecting fertilizer recommendations involve selecting a realistic yield goal and performing soil testing procedures that determine available nutrient levels in the soil. Conservation tillage tends to produce a cooler and wetter soil environment, which can affect root density, pathogen survival, and dilution of nutrients within the root zone of plants, especially during the early stages of growth.

Nitrogen and to a lesser extent sulfur, the elements that are the most deficient for crops in the high-precipitation zone, are the elements most likely to change in availability after a change from conventional till to conservation till. These elements are primarily derived from the organic rather than inorganic fraction of the soil; thus their availability is altered by any change in residue placement. Nitrogen and sulfur requirements may be 5–15 percent greater in the first 5 yr after switching to conservation tillage and surface residue management because of a change in residue decomposition timing. After 5 yr, there should be little difference in crop nutrient requirements with the conservation system, provided the yield is similar to that in the conventional-tillage system. Phosphorus and most of the other elements are derived primarily from the inorganic fraction of soil. Therefore, their sufficiency is more affected by plant root access.

The top 3 inches of soil will become acidic more rapidly under conservation-till than under conventional-till. This has the potential to more readily affect soil pathogen activity in the seed zone. If soil pH in the normal tillage zone is at or near critically low levels for pea (5.3) or wheat (5.6), the farmer should consider applying lime when switching to a conservation-tillage surface-residue farming system. Broadcasting is preferred to banding of lime. In a no-till system, up to 5 mo may be required for lime to become fully effective for increasing the soil pH.

Nutrient placement is more critical in conservation tillage than in conventional tillage. Surface broadcasting of fertilizer is less satisfactory for fall applications on winter wheat or barley. Fall broadcast nitrogen tends to stimulate grassy-weed growth and is frequently immobilized and thus less available to plants. In the 18- to 22-inch precipitation zone, growers should apply 75–80 percent of the nitrogen as a subsurface band in the fall near seeding time, and 20–25 percent as a spring topdress when wheat is tillering. Where precipitation is above 22 inches, only 50 percent of the nitrogen should be applied in the fall and the remainder in the spring to reduce the potential for deep leaching.

If nutrient deficiency is anticipated during early growth of cereals, fertilizer should be placed in a band below and no more than 4 inches to the side of the seed row. If this is not possible, starter fertilizer with the seed should be applied at the recommended rate. Growers should be aware that starter fertilizer with the seed can be toxic, and the amount of nitrogen (or nitrogen plus sulfur) applied in this manner should be kept below 25 lb/acre. Spring cereals are usually more sensitive to nitrogen or sulfur deficiency, especially when planted early following another cereal.

Any increase in intensity of cropping in the rotation will increase nutrient requirements substantially, whether it be in conventional or conservation tillage. Rotations that increase the frequency of cereal cropping are especially affected. Thus, a winter wheat-spring barley-spring pea rotation will require more fertilizer than a winter wheat-spring pea rotation over a 6-yr period.

Tillage and Planting Options for Managing Residue Levels

In a 3-Yr Rotation

Three-year crop rotations give growers considerable flexibility in designing conservation-tillage systems. The text that follows provides tillage options for various periods of a typical 3-yr rotation—a rotation of winter wheat-spring cereal-spring pea (or lentil, canola, or other non-cereal crop instead of pea).

After winter wheat harvest. Wet, cold soil can often delay planting of spring crops. Where this is a common problem, fall tillage can accelerate soil drying and warming in the spring. Where surface residue levels are high, such as on bottomlands and lower slopes, growers can use a moldboard plow to bury a considerable portion of the residue while leaving adequate surface residue and roughness for erosion control. Fall plowing should ideally be done when soils are relatively dry in order to maintain a rough soil surface, minimize the development of a compacted soil layer at plow depth (plow pan), and retain more surface residue.

Uphill plowing (turning the furrow upslope) retains more surface residue and roughness for increased water infiltration compared to downhill plowing. It is also the only tillage practice that will move soil upslope on steep hillsides.

Fall chiseling provides an effective substitute for moldboard plowing after winter wheat harvest in a 3-yr rotation. With heavy residue conditions, wider twisted-shank chisel points can be used to bury more of the residue and increase soil drying and warming in the spring. Straight-shank chisel points can also be used, particularly on areas that are low in residue and more erodible, such as on ridgetops and upper slopes.

Less intensive fall tillage operations should also be considered, depending on residue-handling capacity of the drill for spring planting. One approach is to use light, shallow disking to increase germination of volunteer wheat and weeds and then spray a nonselective herbicide late in the fall after the weeds have germinated. Besides increasing weed seed germination, this process also breaks up the residue for more rapid decomposition and helps increase soil warming and drying in the spring. The new, heavy-duty tillage harrows can also be used for light tillage. In addition, flail chopping could be considered as a management option in heavy residue areas on bottomland and lower slopes.

Stubble can be left standing overwinter, particularly on areas with light residues and higher erosion potential, such as on ridgetops and upper portions of southern slopes. Standing stubble can increase water storage during the winter, especially from snow trapping, and can increase the yield potential of the following spring crop on these typically drier areas of the field. Fall chiseling for improving water storage during the winter is more important on soils that are compacted, finer textured, poorly aggregated, or low in soil organic matter content or that have a greater depth of soil freezing and a higher probability of runoff while frozen.

Variable tillage intensities should be used within fields that have varying degrees of erodibility and residue production. For example, ridgetops and upper slopes with lower residue production and higher erosion potential could be chiseled or left in standing stubble during winter. Bottomland and lower slopes with high residue production and low erosion potential could be moldboard plowed or disked.

Before planting spring cereals. After winter wheat stubble is plowed in during the fall, secondary tillage implements, such as field cultivators, can be used the following spring to bring some of the buried residue back to the surface. Usually only minimal spring field operations are needed to prepare a seedbed for conventional drills and to control weeds before seeding—potentially only one or two field cultivations and a fertilizer application.

If the fall tillage was done by chiseling, about two field cultivator passes and fertilizer injection are often all that are needed the following spring before seeding with conventional drills, although the seedbed may be rough and may contain a significant amount of surface residue. These minimum-tillage spring operations, however, must provide adequate incorporation of soil-active herbicides for wild oat control. Postemergence herbicides are still an option for wild oat control but are generally more expensive.

Where the wheat stubble is left undisturbed over winter or only tilled lightly in the fall, a nonselective herbicide can be applied late in the fall or early in the spring or both to prevent sod formation from volunteer grain and winter annual grass weeds. Early control of the volunteer grain and weeds between harvest and spring planting is also effective in minimizing damage from root diseases associated with this "green bridge." A one-pass drill can then be used to seed the spring cereal crop without prior spring tillage, providing the drill can penetrate the residue and ensure good seed-to-soil contact. This production approach has the greatest potential benefit on more highly erodible field areas and cropping regions with low residue production where yields are most limited by water storage.

One-pass drills have increased the potential for direct seeding of spring cereals after winter wheat. These drills place fertilizer below or just to the side of the seeds, and this placement helps to reduce damage from root diseases. The ability of these drills to penetrate residue during direct spring seeding has been improved. Drills for no-till seeding, however, should not be used when the soil water content is too high. If the water level is too high, the soil is prone to compaction.

After harvest of spring cereals. The moldboard plow should not be used following harvest of spring cereals because these crops produce less residue than winter cereals. Fall chiseling or similar noninversion tillage operations have been effective primary tillage options. Under some conditions, chiseling improves water infiltration and internal drainage more than leaving the stubble stand during the winter. Chiseling can also help to warm soils in the following spring and therefore allow earlier spring planting of broadleaf crops.

As after winter wheat harvest, variable tillage intensities could be used within fields having varying degrees of erodibility and residue production. For example, ridgetops and upper slopes with lower residue production and high erosion potential could be left in standing stubble during the winter unless fall chiseling would allow more water to be stored. Bottomland and lower slopes with higher residue production and lower erosion potential could be chiseled or tilled with other implements that are similar to a chisel.

Spring cereal residue levels should be maintained as much as possible through planting of the broadleaf crop the following spring. Such maintenance will provide additional erosion control during the upcoming fall and winter when the spring broadleaf crop is followed by a winter cereal crop. Residue from the two prior spring crops (the cereal crop one year and the broadleaf crop the next year) also decrease the potential for Cephalosporium stripe and strawbreaker foot rot in winter wheat, have little or no affect on other diseases of winter wheat, and increase soil water storage and erosion protection.

Before planting spring broadleaf crops. In the fall the soil and stubble from the previous spring's cereal crop could be chiseled. If this chiseling is done, as few as two field cultivations may be needed the following spring for seedbed preparation and incorporation of soil-active herbicides before planting of spring broadleaf crops. Research on the USDA's Integrated Pest Management Project near Pullman demonstrated that this tillage approach for planting peas after barley is chiseled in the fall resulted in higher yields than if more intensive tillage was used.

Direct seeding of spring broadleaf crops after a previous spring's cereal crop may become more popular with the availability of more-effective, affordable postemergence herbicides, especially if these herbicides do not require soil incorporation. In the direct-seeding process, good seed-to-soil contact is critical. Early control of volunteer grains and weeds is important for root disease suppression and water conservation for crop production.

After harvest of spring broadleaf crops. Two effective conservation-tillage approaches are being used for planting winter wheat after spring broadleaf crops. One is direct seeding with a one-pass drill, and the other includes various minimum-tillage systems, usually beginning with direct shanking of fertilizer without prior tillage.

There are a wide variety of one-pass no-till drills available for direct seeding winter wheat after pea, lentil, or other low-residue crops. Some important drill characteristics include the ability to penetrate hard dry soil, the ability to apply a deep band of fertilizer below seeding depth and near seed rows, and the ability to penetrate crop residue to prevent hair-pinning of residue in the seed row or plugging the drill.

Drill options also vary considerably in the degree of soil disturbance and residue retention. Pacific Northwest research has shown that deep banding of fertilizer increases yield potential under conservation tillage. Consequently, most no-till drills in the region can now perform deep banding. The importance of fertilizer placement is determined in part by the risk and level of root disease. For example, where winter wheat is seeded after a non-cereal crop in a 3-yr rotation, such as a wheat-barley-pea rotation, the incidence of root diseases and other soilborne diseases is relatively low and therefore the placement of the fertilizer in relation to the seed row is less critical. In contrast, in a shorter, less diverse rotation in which cereals are seeded after cereals and in which the risk of disease is much higher, fertilizer placement is critical and deep banding near the seed row is beneficial.

One problem with direct seeding after spring broadleaf crops is the potential for carryover of soil compaction problems. Compaction usually occurs when seedbed preparation is done when soils are wet. A no-till seeding may not improve water infiltration and internal drainage adequately to provide effective runoff and erosion control. Any improvement in infiltration and drainage from no-till seeding is dependent on the degree of soil roughness and fracturing of the compacted soil because these factors control the amount of water that enters the soil and the amount of runoff. If infiltration and drainage are not improved during seeding, their rates are solely based on the limited amount of surface residue. Seeding slightly earlier is more feasible in 3-yr rotations than in 2-yr rotations (because there is less risk of disease in an early seeding in a 3-yr rotation) and can provide additional runoff and soil erosion protection under no-till conditions regardless of whether soil compaction is a problem.

Heavy-duty, direct-shank fertilizer applicators have eliminated the need for primary tillage (commonly done by disk) before seeding winter wheat after broadleaf or other low-residue crops. Most fertilizer dealers in the inland Northwest have their own version of direct-shank fertilizer applicators available to growers. Growers have also added fertilizer injection equipment to chisels and cultivators. These fertilizer equipment options allow growers to use their conventional drills for seeding in minimum-tillage systems without having to invest in a no-till drill.

These equipment options have enabled the development of "shank (fertilizer)-and-seed" systems, which are now used extensively for planting after low-residue crops in the inland Northwest. In the strictest sense, these systems involve a direct shanking of fertilizer (fertilizer application done without prior tillage), followed by a nonselective herbicide application before seeding. However, a rod weeder or cultivator-rod weeder combination is often used in place of the herbicide with usually only a minor reduction in surface residue and surface roughness.

Direct shanking of fertilizer can often maintain about 90 percent or more of the residue on the surface and create a relatively rough cloddy surface. Residue levels and surface roughness are affected by the type and depth of applicator shanks, the speed of application, and soil conditions. If the shank depth is adequate, the shanks can help fracture compacted surface soil, improving water infiltration and internal drainage. Direct shanking often provides better runoff and erosion protection than no-till seeding with a disk drill on soils compacted during establishment of the previous crop.

In a 3-Yr Rotation of Winter Wheat-Fallow-Winter Rapeseed

In a winter wheat-fallow-winter rapeseed rotation, winter rapeseed is sown in early to mid August and usually provides good surface cover during the critical fall and winter erosion period. Because rapeseed establishes much faster than winter wheat, the residue levels present at the time of rapeseed establishment are much less critical than the levels present during winter wheat establishment. During this rotation, however, sufficient residue levels are critical following winter wheat harvest and during the short summer fallow period to protect the soil from erosion until the rapeseed crop is established.

Fall chiseling and other noninversion tillage operations can be substituted for moldboard plowing after winter wheat is harvested. Straight-shank chisel points are desirable on fields or areas where residue production is low and erosion potential is high, that is, ridgetops and upper slopes. Conversely, in areas with heavier residue production and lower erosion potential, more residue can be buried without significantly increasing erosion potential. In these areas chisels with wider twisted-shank points, disk-chisel combinations, or the moldboard plow could be used. In the spring of the fallow season, field cultivations may help return some of the residue previously buried by plowing or disking back to the surface.

Chemical fallow is used in some areas to maintain residue on the surface prior to planting winter rapeseed. While this practice maximizes the amount of residue on the surface, some farmers find it difficult to plant through these residues with their present seeding equipment. There is a widespread belief, supported by some experimental data, that disrupting the soil surface by tillage develops a barrier to capillary movement of the soil water and thereby keeps the soil from drying to as great a depth as when the surface soil is left undisturbed. A problem arises if the cultivation and associated residue burial leaves the surface unprotected and subject to erosion. As with winter wheat plantings on fallow, it is important to maintain adequate seed zone water content with winter rapeseed plantings on fallow. Consequently, growers often use partial chemical fallow or a minimum-tillage fallow system without herbicides to help maintain seed zone soil water. Rod weeders are often used to kill weeds and disrupt the desired shallow layer of soil, while leaving sufficient residue on the surface to provide adequate erosion protection. Use of rod weeders often results in a thin disrupted and distinctly dry layer at the surface, underlain by an undisrupted and moister layer. Farmers find that when they seed winter rapeseed into that moister layer, it will germinate and have extensive ground cover by late fall. This often results in better erosion control and yields than if germination was delayed until the sparse and random rains wet the dry soil.

Planting of winter wheat after winter rapeseed is similar to planting winter wheat after pea, lentil, spring canola, or other low-residue crops in a 2- or 3-yr rotation. Planting can either be done with a one-pass-drill system or a "shank (fertilizer)-and-seed" minimum-tillage system. An important planting objective should be to optimize retention of rapeseed residue on the surface. The rapeseed crop is believed to be fairly effective in loosening compacted soil for improved water infiltration and internal drainage, so surface roughness is not as important as after pea or lentil. Seeding dates of winter wheat in this rotation are similar to those in other 3-yr rotations and earlier than those in 2-yr rotations because of improved control of soilborne diseases.

In a 2-Yr Rotation

In higher precipitation areas with annual cropping, tillage and residue management practices for 2-yr rotations are similar to those of 3-yr rotations. In the 2-yr rotation, however, the seeding dates should be delayed to reduce Cephalosporium stripe and strawbreaker foot rot in winter wheat.

On bottomland and lower slopes, where residue production is high and erosion potential is low, growers might consider a more intensive tillage system after winter wheat in a 2-yr rotation than would be needed in a 3-yr rotation. This system would accelerate residue decomposition and decrease carryover of soilborne diseases, helping to partially offset the effect of the shortened (that is, 2-yr as opposed to 3-yr) rotation on disease control.

The most common 2-yr rotation is winter wheat-spring pea or lentil, but other rotations are used.

After harvest of winter wheat. In high-residue or low-erosion areas, the 2-yr rotation tends to rely on the moldboard plow after winter wheat more than the 3-yr rotation. Uphill plowing should still be an important management tool to slow or help reverse the problem of tillage erosion. Twisted-shank chisels or other minimum-tillage implements can provide the desired amount of residue incorporation, but still retain sufficient residue for erosion control. Standard straight-shank chisels could also be considered on areas that have lighter residue or are more erodible.

Flailing the wheat stubble enhances residue incorporation and decomposition and reduces the need of increased tillage intensity. It can, however, reduce water storage potential associated with snow trapping on ridgetops and upper slopes, if that is an important consideration.

Spring operations for spring broadleaf crops. After fall moldboard plowing of winter wheat stubble, secondary tillage implements, such as field cultivators, can bring some of the buried residue back to the surface the following spring. Minimal spring field operations would be needed to prepare a seedbed for conventional drills and control weeds before seeding—commonly only about two field cultivations and a fertilizer application. Similarly, with fall chiseling of winter wheat stubble, particularly in areas that have less residue or are more erodible, as few as two field cultivations may be needed for seedbed preparation and incorporation of soil-active herbicides before planting of spring broadleaf crops.

Direct seeding of spring broadleaf crops after winter wheat has not been common, although it may become more feasible with the availability of more-effective, affordable post-emergence herbicides or herbicides that do not require soil incorporation. Good seed-to-soil contact is critical.

Early control of volunteer wheat and weeds for root disease suppression may also improve the success of these production systems. Three-year rotations will, however, be more conducive to direct seeding of spring broadleaf crops because residue levels and pest problems in the 3-yr rotation are reduced compared to those in the 2-yr rotation.

After harvest of spring broadleaf crops. The procedures for planting winter wheat after spring broadleaf crops in a 2-yr rotation are the same as those of a 3-yr rotation except that the seeding date is delayed in the 2-yr rotation. Planting systems could include either direct seeding with a one-pass drill or a type of "shank (fertilizer)-and-seed" system. Important planting objectives should include optimizing retention of surface residue (non-cereal), increasing surface roughness, and loosening compacted surface soil to effectively increase water infiltration and internal drainage.

In a Continuous Cropping of Small Grains

Continuous cropping of cereals in the high-precipitation zone predominantly involves winter wheat but can also include spring wheat or barley every second or third year with winter wheat. Spring wheat, spring barley, and others can also be continuosly cropped. Soil erosion is generally not a major problem because residue production is high and soil water levels are low at planting, particularly for continuous winter wheat. With continuous spring cereal, the critical fall-winter erosion period is largely avoided.

Although it is only partially effective, intensive tillage is perceived by some farmers and researchers to replace the role of crop rotation for pest control in continuous winter wheat. Conservation-tillage systems under continuous cereals have the greatest chance of success in continuous spring cereals. Effective control of volunteer and weeds with a nonselective herbicide in the fall and early spring are very important in minimizing root diseases while optimizing water storage potential.

After harvest of winter wheat. Tillage and residue management practices between crops of winter wheat are similar to practices used after winter wheat in a 2-yr rotation. Both the continuous cropping system and the 2-yr rotation require more intensive tillage after winter wheat is harvested. The intensive tillage buries more of the weed seeds and reduces winter annual grass weeds normally controlled by spring cropping in a 3-yr rotation. Residue incorporation in the continuous-cropped system accelerates decomposition and therefore helps to reduce residue levels and the potential for soilborne diseases to levels normally achieved by the 2-yr rotation.

However, in a continuous cropping system, tillage alone is **much less effective** than 2- and 3-yr rotations at reducing residue levels and soilborne diseases. Delaying the seeding dates helps to reduce Cephalosporium stripe and strawbreaker foot rot. Deep banding of fertilizer below seeding depth or near the seed row increases crop tolerance to root diseases. Flailing of the winter wheat stubble enhances residue incorporation and decomposition and reduces the need for increased tillage intensity.

Residue can be removed by burning to allow no-till recropping of winter wheat or switching to a spring cereal. Although yields following burning remain high, at least in the short term, and erosion losses are generally low, this is a questionable method of reducing residue from the standpoint of long-term soil productivity. Long-term studies of the combined practices of burning and tillage indicate that this combination significantly decreases crop yield, soil organic matter, and other soil properties. Although combining burning with no-till is less detrimental to soil productivity, this combination also does not allow the return of adequate organic material to the soil to sustain long-term soil productivity. Another problem with burning is that air quality regulations are becoming increasingly restrictive of stubble burning.

In the spring following harvest of a winter wheat crop, a spring cereal may be planted. If seedbed preparation (tillage) is delayed until after the critical winter precipitation and erosion period, it can be fairly intensive without subjecting the land to much danger of erosion. The tillage options recommended are the same as those mentioned for 2-yr rotations after winter wheat. Regardless of the option chosen, care must be taken to optimize water storage and yield potential and protect the environment during and after the transition from winter wheat to spring cereal.

After harvest of spring cereals. The grower may choose to switch to a winter wheat crop in the fall or to wait until the next spring and plant spring wheat again. If the switch to winter wheat is made, residue levels should be sufficient during the winter to provide protection from runoff and soil erosion. The procedures for planting the winter wheat in the continuous cereal rotation are similar to those used for the no-till and shank-and-seed systems described in the 2- and 3-yr rotations for planting wheat after a broadleaf crop. However, fertilizer placement for early root access is more important when planting continuous cereals. Drill design for residue penetration and good seed-to-soil contact is also very important.

If a spring crop is planned, the potential for runoff on frozen ground needs to be considered in the decision of fall tillage versus overwinter standing stubble. With frozen-soil runoff, fall chiseling would help minimize runoff losses. Without frozen-soil runoff, standing stubble can provide slightly more overwinter water storage. In either case, control of volunteer grain and weeds, beginning in the fall and again in the early spring, is important for pest management. If the stubble is left standing during the winter, no-till and shank-and-seed systems described in the 3-yr rotation for planting winter wheat after a broadleaf crop could largely be applied to planting the spring cereal in the continuous cereal rotation. Fertilizer placement for early root access, however, would again be more important for tolerance of root diseases under continuous cereals than under wheat after a non-cereal crop. Drill design for residue penetration and good seed-to-soil contact is also very important.

If fall chiseling is used between spring cereal crops to control runoff, shank-and-seed systems (possibly preceded by one or two field cultivations) can be used in the following spring. Fertilizer placement and drill design considerations should be similar to those of systems with no fall tillage.

In fields with variable residue levels, erodibility, production potential, and pest problems, growers should again consider variable tillage intensities to address those production concerns.

Risk and Management of Weeds in Conservation Till

In a 3-Yr Rotation

Winter annual grass weeds such as downy brome and jointed goatgrass are major weed problems in winter wheat and are more severe in conservation tillage than in conventional tillage. A 3-yr crop rotation reduces the infestation of winter annual grass weeds by disrupting their life cycle. Two years out of winter wheat allows the grassy weeds of winter wheat to be controlled. Sethoxydim (for example, Poast or Poast Plus) is registered for the control of grass weeds in pea.

During the 2-yr period of the 3-yr cycle when spring crops are being grown instead of winter wheat, the species of weeds that are a problem are likely to change. Wild oat will increase, especially in the spring barley and spring pea crops. Studies have shown that an increased seeding rate of barley will decrease weed competition of wild oat. Recent research has indicated that effective wild oat control with reduced rates of herbicides depends on the herbicide used. Broadleaf weeds such as prickly lettuce and catchweed bedstraw can also be a problem. Both of these species will increase but should not be a problem in the small-grains portion of the rotation if they are recognized and controlled early in the transition period.

In a 2-Yr Rotation

Wild oats and winter annual grasses are major problems in conservation-tillage, 2-yr rotations. Having only 1 yr out of winter wheat is not enough time to adequately control winter annual grass weeds because seed longevity of these weeds can be 2 or more years. For example, the longevity of downy brome grass seed is 2–3 yr and of jointed goatgrass is 3–5 yr. In the 2-yr rotation, wild oat is a major problem in spring legumes.

In a Continuous Cropping of Small Grains

A tremendous increase in winter annual grass weed populations occurs in reduced-tillage continuously planted fall grains because the life cycles of the crop and weeds are similar. Weed populations build more rapidly after dry autumns if moisture for weed seed germination is not available until winter. In recent studies in the Northwest, downy brome grass replaced wild oat as the major grass weed species after 3 yr of no-till winter wheat. In a similar study, growing no-till spring wheat every third year in no-till monoculture wheat was not sufficient to reduce the downy brome grass problem in winter wheat. In this system wild oat was the primary problem in spring wheat, and after two complete crop rotations both wild oat and downy brome grass were severe weed problems.

Risk and Management of Crop Disease in Conservation Till

In a 3-Yr Rotation

The safest crop rotation in the high-precipitation zone is a 3-yr rotation of winter wheat-spring barley-cool season grain legume. In this type of 3-yr rotation, the crop changes each year and pathogens that survive in the stem tissue are not likely to survive 2 yr without access to the host. This includes the pathogens responsible for two of the worst diseases of winter wheat, namely Cephalosporium stripe and Pseudocercosporella (strawbreaker) foot rot, and also includes the pathogen for Ascochyta blight of pea and chickpea. Take-all occurs on spring barley but is also not a problem in a 3-yr rotation. The fungus responsible for the disease is limited mainly to barley roots, and these do not last in the soil as a food base for a full year while the field is planted to a grain legume crop.

The crop most likely to become diseased in the 3-yr rotation involving spring barley after winter wheat is the spring barley, especially if planted no-till into standing stubble of winter wheat. Rhizoctonia root rot is the most important disease on barley and is mainly a problem when volunteer wheat and weeds serve as a "green bridge" for the pathogen—a continual source of living susceptible roots. The disease is most severe when volunteers and weeds are sprayed 1-3 days before spring barley is direct drilled. The disease is best managed by spraying at least 10 days and preferably 2-3 wk before planting. Spraying during the previous fall may further reduce disease potential.

In a 2-Yr Rotation

Two-year rotations (such as winter wheat-cool season grain legume) present some of the greatest risks for diseases of any cropping system in the high-precipitation zone. These rotations are especially favorable to Cephalosporium stripe and Pseudocercosporella foot rot of winter wheat for two reasons. First, the pathogens can survive 1 yr in wheat stubble in the soil without winter wheat. Second, winter wheat is typically planted early after a cool-season grain legume crop, and this early planting favors these diseases.

Several options are available for controlling these diseases. Late planting provides control but is not a suitable option, since it reduces the yield potential of winter wheat and soil erosion can be greater. One critical control method is to use wheat cultivars that are most resistant to Cephalosporium and Pseudocercosporella. In addition, it may be necessary to apply a fungicide to control Pseudocercosporella foot rot.

Two-year rotations of winter wheat-pea or chickpea are conducive to Pythium seed and root rot of wheat in the high-precipitation zone for two reasons. First, both crop species support populations of the *Pythium ultimum* pathogenic to their germinating seeds and emerging seedlings. Second, this zone is also characterized by acid, clay-type soils most favorable to *Pythium*.

The seed-infecting but not the root-infecting stage of *Pythium* damage can be controlled by a seed treatment fungicide, either a broad-spectrum fungicide such as captan (for example, Vitavax-200) or a *Pythium*-specific fungicide such as metalaxyl (for example, Apron). It is even more important to use a seed treatment fungicide on pea or chickpea than on wheat, since these crops are especially susceptible to Pythium seed rot.

In a Continuous Cropping of Small Grains

Continuous cropping of small grains raises the risk of root disease for wheat and barley but decreases the risk for wheat diseases favored by vigorous crop growth, for example, Cephalosporium stripe, Pseudocercosporella foot rot, and rusts. The wheat and barley root diseases are favored by the continual presence of roots of the host plants. These root diseases result in retarded and spindly plant growth and poor tillering. The decreased plant growth, in turn, reduces the occurrence of diseases favored by vigorous plant growth.

Stubble burning can provide some degree of control of root diseases associated with continuous no-till winter wheat.

Removal of stubble by burning allows increased drying and warming of the top layer of soil. Unless the rate of straw is extremely high (for example, 20 tons/acre or greater), burning has no direct or permanent effect on the pathogens in the soil. Although burning can be effective in emergency situations for reducing residue levels, it is not recommended as a routine practice because of its adverse effects on long-term soil productivity.

Continuous cropping of small grains is less risky from a disease standpoint if all of the crops involved in the rotation are spring cereals. If each crop is a spring cereal, the period between the harvest of one crop and planting of the next crop may be up to 6 mo, providing a long break for the soil to become "sanitized" between crops. This sanitization period can be nullified if volunteer cereals and grass weeds are allowed to grow during much of that period and are killed by tillage or spraying just prior to planting in the spring.

There are no wheat or barley cultivars resistant to Pythium root rot, Rhizoctonia root rot, and take-all, and no seed treatment chemicals are effective against these diseases. The only management practices known to control these root diseases are 2-yr and preferably 3-yr rotations. Development of resistant cultivars and microbial agents for control of these diseases is currently a high-priority research objective.

Other Soil Conservation Practices

The primary and most effective conservation tool in much of the Northwest is through tillage management to retain more of the surface residue and, where needed, to fracture compacted soil and create surface roughness. The major benefit of surface residue and rough fractured soil is increased water infiltration to prevent runoff and store more of the precipitation in the soil. Compared to other conservation practices, conservation tillage has the greatest potential to control wind and water erosion, maintain soil productivity, and optimize yield potential with the available water. Consequently, conservation tillage offers the greatest economic return to the grower. Other practices discussed in this section are "supporting practices" for conservation tillage.

Supporting conservation practices can provide additional benefits, particularly in reducing off-site impacts of runoff and erosion. These practices generally have less direct benefit on maintaining soil productivity compared to tillage and residue management practices. The main purpose of most supporting conservation practices is to slow or stop runoff and soil movement.

There are a number of supporting conservation practices in the high-precipitation zone, some of which also apply to the intermediate- and low-precipitation zones under most crop rotations. These practices are discussed in the text that follows.

- **Contour farming.** In sloping cropland, all conservation systems should include contour farming as much as possible. This support practice is the only one that complements the effects of surface residue and soil roughness to help prevent the initial movement of soil in erosion. The main factor determining the extent to which contour farming is used in a given field is the particular landscape and layout of that field. Because of the irregular shape and landscape of some fields, it can be extremely difficult or impossible to contour farm the entire field.

- **Contour field strips.** The use of two or more contour strips of different crops and cover conditions provides two conservation benefits: (1) reduction in slope length, which reduces the concentration of water flow and therefore the potential for erosion, and (2) alternating surface cover and/or roughness conditions between strips so that soil eroded from a higher strip can be caught by a lower strip. For example, if strips of winter wheat planted after spring pea alternate with strips of harvested wheat stubble, soil eroded from the strips of winter wheat may be trapped in the wheat stubble below. Soil loss from a strip still reduces soil productivity on that strip, but at least the soil is not lost from the field. However, if erosion occurs on the lowest strip, the soil may be potentially moved off the field. Field strips are particularly useful for reducing erosion and runoff where adequate control cannot be provided by tillage and residue management practices alone.

  Contour strips are most adapted to areas with long, broad uniform slopes; for example, they are used extensively in Columbia County, WA. This conservation practice will probably not be used extensively in much of the Palouse region because of the shorter steep slopes and typically highly irregular landscape. In this region, divided slope systems, discussed next, may be more appropriate.

- **Divided slopes.** Divided slopes are a modified version of contour field strips and can be used when multiple field strips are not feasible. In fields with shorter slopes, the slope can be divided into two areas, and different crops can be planted on each area or different tillage and residue management conditions can be used on each area. This practice can provide an effective type of contour field strip to provide water conservation and erosion control. Dividing of slopes also helps to keep field operations more nearly on the contour.

- **Terraces.** Terraces in the Northwest are typically farmed-over terraces. The most common terrace in the high-precipitation zone is the gradient terrace. It slows runoff water, allowing more time for sediment to settle out, and routes the water to a protected channel, such as a grass waterway. Level terraces are designed on the contour and do not have a water outlet. In the Northwest, level terraces have generally been limited to the drier regions because storage of water greater than the terrace capacity can cause overtopping and severe gully erosion.

- **Permanent grass in highly erodible areas.** Some eroded ridgetops and steep north slopes in the Northwest have been planted to permanent grass to reduce erosion from those critical sites and to minimize the impacts of runoff and erosion on lower field areas and the watershed. Since these field areas typically have lower production potential and are difficult to farm, permanent grass can provide an economic conservation alternative.

- **Grass waterways.** The effectiveness and use of grass waterways is highly dependent on field landscape. They have little value for maintaining soil productivity in the field but are effective in filtering out sediment from runoff water and preventing gully erosion. They can be somewhat more difficult to farm around and can be a source of weed, insect, and rodent problems. However, the benefits generally exceed the disadvantages, and more growers should include them in their conservation program.

All of these supporting practices should be considered for conservation farming systems and most crop rotations in the high-precipitation zone. Although field strip or divided-slope systems do not include different crops in continuous cropping of small grains, different tillage practices could still be used on different parts of the landscapes within those slope divisions. For example, ridgetops could be left in standing stubble during the winter, upper slopes could be chiseled, and lower slopes and bottomland could be plowed or disked and chiseled to compensate for different levels of residue production, erosion potential, and the need for increased water storage.

Economic Advantages and Risks of Conservation Production Systems

The 3-yr winter wheat-spring barley-cool season grain legume rotation has grown in popularity in the annual cropping zone in recent years. This 3-yr rotation has also been shown to increase profitability and to stabilize farm income relative to a continuous wheat rotation. The wheat-barley-cool season grain legume rotation contains a residue-producing grain crop 2 yr out of 3 compared to 1 yr out of 2 for the common winter wheat-cool season grain legume rotation. When grown with conservation tillage, the 3-yr rotation can easily meet conservation compliance requirements in the Palouse region.

In addition to the pest control advantages discussed in preceding sections of this chapter, the crop diversification in the 3-yr rotation cushions both production and price variability. Particularly low yields or prices in one crop may be offset by stronger yields or prices in another.

However, growers often lack the barley base necessary to move to the wheat-barley-cool season grain legume rotation. Recent surveys in the Palouse showed that growers in the zone receiving 18 inches or more precipitation had an average of 46 percent of their cropland in wheat base and only 21 percent in barley base. Even with the recent introduction of the unpaid 15 percent flexibility provision in each crop base, many growers may not be able to accommodate the required barley and remain in the financially important wheat and barley programs. Unless growers have exceptionally high wheat and/or barley bases, switching to a continuous grains program may be prohibitive due to base limitations. Uncertainty about the permanence of future base flexibility provisions and set-aside requirements can also make growers cautious in modifying rotations to meet conservation requirements.

Growers will base their decision to switch to new crop rotations for compliance purposes on riskiness and future long-term price trends for different crops. For example, if growers believe that wheat prices (and/or government deficiency payments) are likely to be higher in the future relative to barley or other crop prices, growers will be unwilling to sacrifice their wheat base. Historically, prices for spring canola, winter rapeseed, bluegrass seed, and lentils have been extremely unstable, and therefore many growers may consider these crops too risky to include in their rotation.

Switching crop rotations to achieve conservation compliance can also be impeded by shortages in the necessary labor, machinery, or management skills required for the new rotation being considered. Moving from the traditional 2-yr rotation of winter wheat-pea or lentil to a 3-yr rotation increases the annual spring planting workload from 50–67 percent. In most areas, the window for spring work is considerably shorter than that for fall work. The additional workload of the 3-yr rotation can require the purchase of additional, expensive machinery or the hiring of employees. New management skills may also be required for adopting new rotations or new cultural practices, such as no-tillage or minimum tillage.

6 Achieving Conservation Compliance with Residue Farming in the Intermediate-Precipitation Zone

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Rotations in Use

The principal crops in the intermediate-precipitation zone of the Northwest are winter wheat, winter and spring barley, spring wheat, and spring canola. Growers most commonly use a 3-yr crop rotation of wheat-barley-fallow, which differs from the 3-yr rotation in the high-precipitation zone in that summer fallow is used instead of the cool-season grain legume before planting winter wheat. The winter wheat is usually followed by spring barley but occasionally by spring wheat. In recent years, spring canola has become more popular as a substitute for spring cereals.

A 2-yr rotation of winter wheat-fallow is most common in the drier end of the intermediate-precipitation zone. The 2-yr rotation has higher risks of diseases and grassy weeds than the 3-yr rotation. Moreover, the wheat-fallow rotation has a critical erosion period (between the fallow and wheat) every other year instead of every third year.

Recropping spring cereals, either spring barley or spring wheat, is practiced by some growers in this zone. This cropping system is most common in regions or field areas having shallow soil, low-residue production, low water-storage potential, or high erosion potential, thus limiting their use for winter wheat-fallow rotations. Water conservation during the winter and in the spring is critical to spring recropping with cereals. Recropping is particularly advantageous in areas infested with downy brome grass or jointed goatgrass and also helps avoid crop losses from soilborne diseases such as Cephalosporium stripe and strawbreaker foot rot in winter wheat.

Residue Production

On ridgetops, upper south slopes, and other lower producing areas of fields, winter wheat produces 2,000–5,000 lb/acre crop residue. On lower slopes, bottom lands, and other higher producing areas, residue yields range from 5,400–8,500 lb/acre. Spring wheat residue production ranges from 1,400–3,200 lb/acre in the lower producing areas to 3,200–5,400 lb/acre in higher producing areas. Barley produces less residue than wheat. Production of barley ranges from 650–1,350 lb/acre in the lower producing areas to 2,500–4,500 lb/acre in higher producing areas. Since barley residue decomposes more rapidly than wheat residue, extra attention must be paid to tillage practices used in barley to retain as much residue of this crop as possible, particularly when summer fallowing.

Fertility Management

Nutrient requirements in conservation tillage are similar to those in conventional tillage except that more nitrogen and sulfur may be needed in conservation-tillage systems. More nitrogen and sulfur is needed because fewer of these elements are being made available by tillage-accelerated oxidation of soil organic matter. In the first 5–8 yr after switching from a conventional cropping system to a conservation-tillage system, 5–15 percent more fertilizer may be required.

Fertilizer can be applied with either the first or last fallow tillage operation by modifying existing equipment. Summer and fall fertilizer should always be banded at least 4 inches deep. Spring cereals may require starter fertilizer with the seed or close banding of fertilizer within 4 inches of the seed when they follow another cereal crop. Generally, phosphate deficiency only occurs when wheat yields are above 50 bu/acre or on areas where most of the topsoil is eroded. Lime is not needed until the pH of the top 8 inches of soil drops to near 5.5.

When nitrogen is applied early in fallow, above-normal winter precipitation may move nitrate nitrogen down in the soil profile. Growers should test their soil in the spring and topdress with 10–20 lb/acre of nitrogen when little nitrate nitrogen is found in the top 2 ft of soil. Spring topdressing should be avoided when there is a grassy-weed problem, which is more likely to occur in the first 4–5 yr after converting to conservation tillage and residue farming systems.

When cereals are grown for 2 consecutive years, some soil disturbance below the seed may be beneficial for reducing the intensity of certain root rot diseases. Some drills and drill-tillage combinations have the capability to band fertilizer below the seed row, thereby accomplishing both fertilizer application and soil disturbance.

Tillage and Planting Options for Managing Residue Levels

In a 3-Yr Rotation (Winter Wheat-Spring Barley-Fallow)

The most common 3-yr rotation in the intermediate zone is winter wheat-spring barley-fallow. This rotation allows two crops to be harvested in 3 yr rather than one every other year as in wheat-fallow. This higher crop production is beneficial from a soil conservation standpoint because crop residue is produced 2 of 3 yr, and fallow, which is most prone to erosion, occurs less frequently. Winter wheat planted after fallow is the most susceptible crop to erosion because a partially or fully recharged soil profile often cannot store a second winter's precipitation.

A winter wheat-spring barley-fallow rotation also has advantages in weed and disease control. Tillage and broad-spectrum contact herbicides used prior to planting spring barley provide early spring control of weeds such as downy brome grass and goatgrass. Three-year rotations are used in some areas to control Cephalosporium stripe in winter wheat. A 2-yr rotation without wheat eliminates or greatly reduces the problem. Areas particularly prone to Cephalosporium stripe are those subject to frost heaving in the seedbed. Heaving breaks the roots of wheat plants, providing points of entry for the fungus.

The tillage and planting procedures during a wheat-spring barley-fallow rotation vary for each crop. Because spring barley produces less residue than winter wheat and is more easily broken down by tillage and decomposition, two very different residue management strategies must be used for these crops. Planting spring barley after winter wheat usually requires fall tillage of wheat residue to allow spring barley to be planted on a timely basis. Fallow after spring barley requires careful management of the barley stubble to save sufficient residue for erosion control in the subsequent wheat crop. Tillage and planting operations for a wheat-spring barley-fallow rotation are discussed in the text that follows.

Fall tillage after wheat harvest. The high amount of residue produced by winter wheat and the short winter interval before spring planting generally necessitates tillage after wheat harvest in order to maximize yields of the barley crop. The intensity of fall tillage required will depend upon the amount of wheat residue, type of seedbed condition needed, and the planting options available. The fall tillage must ensure erosion control during the winter and allow proper and timely preparation of the seedbed in the spring. Usually tillage is done to reduce surface residue levels and aid soil drying and warm-up in the spring.

Chiseling or disking, which usually leaves the soil surface rough and residue covered, is recommended in the fall. If wheat residue is heavy and quick warm-up of soil in the spring is necessary, uphill moldboard plowing, which does not completely invert the stubble, may be used. These practices control erosion because they leave some residue cover and increase soil roughness and surface storage of water. In addition to erosion control, proper tillage reduces the amount and size of residue and is the start of proper seedbed preparation.

If the soil surface is frozen and residue levels are not too high, adequate fall tillage can be provided by subsoiling. In some cases tillage is combined with stubble flailing to get sufficient reduction in residue. No-till systems are being encouraged in the Northwest. In these systems, residue is left undisturbed during winter, and the spring crop is sown directly into the standing stubble. However, questions regarding yield levels and risks to net returns in the Northwest from no-till have not been adequately resolved.

Spring tillage prior to sowing barley. Options for spring seedbed preparation are dependent on the soil and residue condition. All of the tillage options used in the spring should have the same objective—to reduce the wheat residue to a manageable level before planting, to seed spring barley on a timely basis, and to maintain wheat residue levels through the barley crop for erosion control during the subsequent fallow period.

A nonselective herbicide should be applied as early as possible in the spring to kill weeds and volunteer grain. Research has shown that a period of at least 2 wk between this spray application and seeding is best to avoid carryover of root pathogens in the newly killed weeds. Fields that were disked or chiseled in the fall usually require disking, followed by a field cultivation, fertilization, harrowing, and sowing. Disking in the fall usually leaves sufficient underground residue that can be uncovered by secondary tillage in the spring. Fields with light residue that were mowed in the fall or fields with stubble left standing can be cultivated with a heavy shank-type fertilizer applicator and sown.

Tillage after barley harvest. After barley is harvested, the barley stubble may be allowed to stand during winter without fall tillage. Because spring barley does not produce as much residue as winter wheat, care must be taken to maintain sufficient residue through the fallow period, while maintaining effective water conservation and weed control. Primary tillage should be done in the spring to kill winter weeds and volunteer grain, mix crop residues in the shallow soil layers, and begin seedbed preparation. Primary tillage tools should include the chisel plow or cultivator with only limited use of the disk. Depending upon the weather conditions and elevation, primary tillage should take place in March, April, or May.

A nonselective herbicide is usually applied in advance of primary tillage. This application delays tillage, retains more residue during fallow, and kills weeds such as downy brome grass before they produce seed.

The primary tillage is followed by secondary operations of field cultivators and rod weeders. Rodweeding operations should be limited to those essential for killing weeds. Implements such as chisel choppers, heavy-shank fertilizer applicators, or cultivator-rod weeders are used to combine operations or reduce the number of trips over the field. These implements are becoming more accepted as the erosion control benefits of leaving more residue on the surface are recognized and insisted on by conservation compliance provisions of the Farm Bill.

Chemical fallow is practiced on some fields but has not gained widespread acceptance. Chemical fallow generally requires two to three applications of a nonselective contact herbicide during the fallow period to control weeds.

Impediments to chemical fallow have been the cost of chemical application, low seedzone water content at planting, and the necessity to seed with a heavier no-till drill. Dry seedbed conditions in chemical fallow result from excessive evaporative loss during the fallow period. In tilled fallow, the soil moisture line is generally held at the rodweeding depth. In chemical fallow the absence of a loose, dry tillage layer results in extensive drying to a depth of 6-8 inches. Consequently, fall planting must be delayed until rain wets the seedbed, and this delay can lower winter wheat yields.

Planting operations. Winter wheat planting options depend on soil moisture and seedbed conditions. Double-disk drills, hoe drills, deep-furrow drills, and no-till drills are used for fall plantings. Double-disk drills are used most frequently, followed by hoe drills, deep-furrow drills, and then no-till drills. In the higher (wetter) end of the intermediate-precipitation zone, seedbed moisture is usually adequate because autumn rains will wet the soil before optimum planting times. Consequently the double-disk drills can be used for shallow planting into moist soil. Hoe drills are preferred if residue amounts are higher and seedbed moisture is too deep to reach with a disk drill. In the drier end of the precipitation zone, deep-furrow drills are more commonly used because deeper seeding depths are required to get the seed down to where the soil is moist. No-till drills are used with the chemical fallow practice.

Spring planting options in the 3-yr rotation depend on seedbed conditions. In the intermediate-precipitation zone, double-disk drills are used for spring seeding. These drills are preferred because they can seed into moist soil with narrow rows and high seeding rates. No-till drills are being used by a small number of producers. These drills can handle heavy residue and usually have the capability to place fertilizer during sowing.

In a 2-Yr Rotation (Wheat-Fallow)

In a wheat-fallow rotation, tillage is used to manage residue levels, control weeds, conserve water, and prepare the seedbed. The tillage method is usually determined by the amount of residue, while the timing of the tillage is based more on the control of weeds and evaporative water loss from fallow. The amount and type of seedbed preparation required depends on the tillage and planting options that are used and the type of drills available to the grower. Double-disk drills cannot operate in as much residue as hoe, deep-furrow, or no-till drills.

Fall tillage after wheat harvest. Generally, fields are not tilled after wheat harvest, and stubble is allowed to stand during the winter. However, fall tillage is sometimes practiced in wheat-fallow rotations for weed control, reducing surface residue or reducing the risk of runoff from frozen soil. Weed control is primarily aimed at downy brome grass. Light harrowing, disking, or skew treading of dry stubble is used to incorporate downy brome grass seed in the fall so that the seed germinates in the winter and is killed in the spring.

One disadvantage to fall tillage is that slightly less water is stored in the soil than if the stubble was left standing during winter (unless runoff occurs during the winter when soil is frozen). If fall rains are sufficient to germinate weeds and volunteer grains, a nonselective herbicide can be applied. This application allows the grower to delay tillage in the spring so that residue levels will be maintained during the fallow period.

Improved crop residue management systems rely on medium to shallow tillage to maintain crop residue at the surface. If residue levels are very high, it may be necessary to disk in the fall to reduce residue levels to manageable levels for planting. Fall disking accelerates the decomposition process and can be used selectively to treat areas within fields that have heavy residue. Disking also reduces the size of residue and distributes it more evenly. Heavy, poorly distributed residue interferes with the operation of cultivators and rod weeders during secondary spring tillage. Fall disking is preferred to spring disking because soils are typically drier in the fall. Disking wet soil in the spring can create tillage pans.

Fall chiseling or subsoil tillage is useful in some areas to reduce runoff from frozen soil. At higher elevations or in areas prone to soil freezing, fall chiseling or subsoiling on the contour increases surface storage and provides an avenue for water to enter beneath a frozen layer. These practices can be used selectively within fields on areas prone to runoff. In the case of accidental fire, where crop residue has been burned, chisel or subsoil tillage can serve as an emergency measure to protect against runoff.

Spring tillage. The primary tillage operation in a wheat-fallow rotation is normally performed during spring. The purpose is to kill weeds, process crop residues, and begin seedbed preparation. Preferred primary tillage tools for conservation are the disk or chisel plow. Depending upon the weather conditions and location, primary tillage is usually done in March or April, but occasionally in May. A nonselective herbicide is commonly used in advance of primary tillage. The herbicide allows tillage to be delayed and kills weeds such as downy brome grass before they form seed.

The primary tillage is followed by one or two secondary field cultivations and then rodweeding as necessary to control weeds during the summer. Rodweeding may be done as few as two times or as many as four or five times if frequent rains germinate weeds and compact the soil. Implements such as chisel choppers or cultivator/rod weeders, which combine some tillage operations, are becoming more popular as conservation-tillage tools.

Chemical fallow is practiced in some areas but has not gained widespread acceptance. Chemical fallow generally requires two to three applications of a nonselective contact herbicide during fallow to control weeds. Drawbacks to chemical fallow have been the cost of chemical application, low seedzone water content at planting time, and the necessity to seed with a heavier no-till drill. Dry seedbed conditions in chemical fallow result from excessive evaporative water loss during fallow. In tilled fallow the soil moisture line is generally held at rodweeding depth. In chemical fallow the absence of loose dry soil at the surface can cause drying to a depth of 6-8 inches. Consequently, fall planting in chemical fallow is frequently delayed until rain wets the seedbed, and this delay can result in a lower yield of winter wheat.

Planting operations. Planting options in a wheat-fallow depend on the soil water status and seedbed conditions at the time of planting. In this precipitation zone double-disk, hoe, and deep-furrow drills are all used. Double-disk drills cannot seed as deep and cannot operate in as much residue as hoe or deep-furrow drills. If growers want to seed early into dry soil, hoe or deep-furrow drills are typically used. Double-disk drills are preferred when seeding shallow into moist soil or when seeding late. No-till drills are used by a small number of producers. Many of the drills can handle heavy residue and usually have the capability to deep band fertilizer during seeding. There are numerous modifications and attachments for all types of drills for handling more residue and placing fertilizer or insecticide.

In a Continuous Cropping of Small Grains

The acreage of continuously cropped small grains in the intermediate-precipitation zone is small. The recommended system for continuously cropped acres is no-till, which provides excellent erosion control. No-till drills should be able to deep band fertilizer and seed in heavy crop residue. Nonselective, contact herbicides are used to control weeds and volunteer grain before planting.

The continuous cropping system relies on autumn rain to provide sufficient water for planting fall cereals. When autumn rains are not sufficient for fall planting, planting is delayed until spring. Thus the rotation can vary between fall and spring cereals depending on weather conditions. Spring cropping helps to control downy brome grass, the principal weed in this rotation.

Risk and Management of Weeds in Conservation Till

In a 3-Yr Rotation (Fall Cereal, Spring Cereal, Fallow)

In a 3-yr rotation, the 2-yr period in which wheat is not grown provides several early spring and late-fall opportunities for cost-effective control of downy bromegrass, rye, and volunteer barley and wheat. Burn-down spraying and cultivation are sometimes used to provide this control. Jointed goatgrass, however, tends to increase in reduced-tillage systems. If sufficient moisture is present, land can be chemically fallowed and wheat no-tilled to control erosion. In fallow, grasses should be controlled in the fall (if emerged) to prevent their growth during winter. The Russian thistle, kochia, and prostrate knotweed problem tends to increase with reduced tillage because the surface residue increases moisture at the soil surface and provides excellent germination conditions for shallow-germinating weeds. Some kochia, Russian thistle, prickly lettuce, and other weeds have developed resistance to sulfonylurea herbicides in the intermediate-precipitation zone, and alternatives such as phenoxy (for example, 2,4–D), dicamba (for example, Banvel), and clopyralid (for example, Curtail) herbicides should be considered.

In a 2-Yr Wheat-Fallow Rotation

In general, winter annual grasses and volunteer wheat and barley in a wheat-fallow rotation will be more troublesome in conservation-till than in conventional-till systems. Depending on location and annual precipitation, weeds in the fallow year can either be controlled by chemical fallow or stubble mulching. If weeds are controlled with herbicides in the fall or winter, spring primary tillage can be delayed, and subsequently the number of rodweeding operations reduced.

Recent research has shown that an early wheat planting with a deep-furrow drill in the intermediate-precipitation zone suppresses the growth of and reduces competition of winter annual grass weeds and increases wheat yields, compared to results of delayed planting with a conventional double-disk drill. Wheat planted earlier establishes before the weeds and outcompetes them. Russian thistle can be a severe problem and requires additional control if the winter wheat stands are poor or if winter kill occurs to the winter wheat and the field requires replanting in the spring with spring grains.

In a Continuous Cropping of Small Grains

The continuous small grain system (winter/spring) would be hindered by winter annual grass weeds in the fall-sown crop and Russian thistle in the spring-sown crop. This rotation does not allow sufficient time to control winter annual grasses in only one spring crop before planting fall grains again. Prickly lettuce will be a problem in both crops in reduced-tillage systems.

Risk and Management of Crop Disease in Conservation Till

In a 3-Yr Rotation (Winter Wheat-Spring Barley-Fallow)

As they do in the high-precipitation zone, 3-yr rotations such as winter wheat-spring barley (or spring wheat)-fallow offer the least risk of crop diseases in the intermediate-precipitation zone. In fact, the 3-yr rotation may be even more critical in the intermediate zone than in the high zone for control of pathogens in wheat stubble because the stubble may last longer as a food base for the pathogens in the drier zone.

Although a 3-yr rotation of winter wheat-spring barley (direct-drilled)-mulch fallow has a good chance of being successful in the high-precipitation zone, it probably has an even better chance for success in the intermediate-precipitation zone. This success in the intermediate zone is due to the early-spring elimination (through herbicide use) of the green bridge for Rhizoctonia root rot of barley. Spring barley also benefits from direct drilling in the intermediate zone because tillage and the subsequent evaporation of soil water is eliminated.

In a 2-Yr Wheat-Fallow Rotation

In a wheat-fallow rotation, Cephalosporium stripe and Pseudocercosporella foot rot are especially important in the intermediate-precipitation zone. Seeding dates must be delayed significantly to control these two diseases, which allows the potential for more soil erosion and a lower yield potential. It is important to use the cultivars that are most resistant to these diseases, and it is usually also necessary to spray with a fungicide in early spring for control of Pseudocercosporella foot rot if the winter wheat is seeded very early.

Stripe rust is a major risk in this rotation if the winter wheat is seeded early. Cultivars chosen must be resistant to stripe rust.

In a Continuous Cropping of Small Grains

Continuous cropping of small grains in the intermediate-precipitation zone presents few disease problems unless the crops are planted no-till. In no-till soils, the top few inches are inhabited by the take-all fungus and *Rhizoctonia solani* AG 8, and the pathogens are maintained at ideal conditions. The cool, moist environment under no-till allows these pathogens to remain active for longer into the spring; thus, there is a high risk of these two diseases. No-till also increases the occurrence of volunteer grains and grass weeds, and these weeds promote the development of root disease on spring grains more than on winter wheats.

In a no-till practice, rotations and planting equipment can make a difference in providing disease control. A spring wheat-spring barley rotation should be less risky than continuous spring wheat or continuous spring barley. The rotation should provide better control of take-all on the spring wheat and Rhizoctonia root rot on the spring barley. One-pass drills can give some additional disease control if they cause considerable disturbance of the soil in the seed row and if they band fertilizer directly beneath the seed, all in a one-pass operation.

Other Soil Conservation Practices

Several other options are available to producers for conserving and managing soil. These include cross-slope cultivation, field strip cropping, terraces, grass waterways, roughing the soil surface, and green cover. Most of these options are useful in a 2- or 3-yr rotation. In a continuous-cropping system, however, field strip cropping and green cover generally are not used. Cross-slope cultivation and seeding are important practices with continuous cropping, particularly for winter cereals. Continuously cropped winter cereals are usually seeded late, and consequently crop development is slow. Thus there is little green cover to protect the soil during the critical winter period. If seedbeds are planted late, they can be made rough or cloddy to provide additional surface storage and help increase infiltration and reduce runoff.

The conservation options that work best for producers vary with topographic, soil, and environmental conditions across the region, sometimes without regard to specific rainfall zones. Supporting conservation practices must be chosen on the basis of the type of tillage used and the problems arising from such tillage. Most supporting practices act to catch soil losses from runoff at specific landscape positions.

Economic Advantages and Risks of Conservation Production Systems

The most popular crop rotation in the intermediate-precipitation zone is winter wheat-spring grain-fallow. This rotation, with two residue-producing grain crops, is capable of producing adequate residue when combined with appropriate tillage. The presence of two grain crops in the rotation that are supported by government programs also stabilizes economic returns. The fallow period in the rotation provides weed control and moisture conservation, which boosts production and reduces income variability as well. In some locations, however, the fallow year in this 3-yr rotation makes it difficult to achieve adequate residue for meeting conservation plans.

Some growers have experimented with continuous grain cropping in the intermediate-precipitation zone. At present, however, this option is not economically attractive because most farmers do not have acreage allotments that will cover continuous cropping of all of their land. Consequently they would be selling a large part of their grain without government commodity support payments. Another disadvantage to continuous annual cropping is that moisture shortages in dry years can also result in low yields and economic losses under this cropping system.

Switching to a new crop rotation or changing tillage practices can sometimes be impeded by machinery, labor, or management shortages. Increasing the amount of spring cropping can lead to a labor or machinery bottleneck in the short spring planting season. The additional machinery and labor needed to overcome this bottleneck can be costly.

7 Achieving Conservation Compliance with Residue Farming in the Low-Precipitation Zone

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Rotations in Use

Winter wheat-fallow is the most commonly used cropping system in this zone. Fallow is essential to ensure adequate available water for more stable crop production in areas where annual precipitation does not exceed 12 inches. Winter wheat is the main crop in this zone; however, winter barley, spring wheat, and spring barley are also grown.

Annual cropping is sometimes used as an alternative to the normal crop-fallow rotation. This practice is used where the soil texture, depth of the soil profile, or restricting layers limit moisture storage in the profile to precipitation from one winter season. In these situations, spring wheat is normally grown, and minimum- or no-till practices are generally the most successful. Weed control is achieved through effective use and timing of herbicides.

Residue Production

Amounts of surface residues under summer fallow management in low-precipitation zones vary considerably. Amounts of crop residues generated depend upon type of crop grown, annual precipitation, and management variables such as amount of fertilizer applied. Winter wheat residue production ranges between 1,500 and 5,500 lb/acre, whereas winter barley residue production ranges between 1,000 and 4,000 lb/acre. Residue production of spring wheat, annually cropped, ranges between 1,000 and 3,000 lb/acre, and spring barley produces about one-half to two-thirds of these amounts.

Fertility Management

In the low-precipitation zone, fertilization practices for conventional tillage will generally work for conservation tillage. Broadcasting nitrogen is not recommended, except for spring topdressing. In this drier zone there is greater opportunity to combine fertilizing with tillage or seeding operations.

For spring cereals, fertilizer can be applied with or near the seed when soil moisture is adequate, when the soil temperature is below 50 °F, and when the combined nitrogen and sulfur requirement of the crop is less than 30 lb/acre (which is not high enough to cause damage to the seed). Conservation tillage offers potential for higher yield because more soil water is stored. Higher amounts of stored water may increase the crop's nitrogen requirement slightly. However, over application of nitrogen must be avoided, since high nitrogen levels stimulate vegetative growth and water consumption and thus may accentuate drought stress and decrease grain yield.

Sulfur and phosphorus deficiency occur only rarely, even with conservation tillage. Soil pH in the low-precipitation zone is generally neutral to calcareous, and therefore lime is not usually required.

Tillage and Planting Options for Managing Residue Levels

In a 2-Yr Wheat-Fallow Rotation

The tillage and planting options in conservation-farming systems in the low-precipitation zone are similar to those in the intermediate-precipitation zone. However, water conservation is more critical in the low-precipitation zone. The extent and timing of tillage is important in creating soil conditions that reduce evaporative soil water loss, runoff, or erosion. If tillage is too aggressive, crop residues will be insufficient for effective erosion control.

Tillage should be performed to control weeds and evenly disribute mulch at the surface. If mulch levels are sufficient, the mulch will reduce evaporative water loss and control erosion. Both wind and water erosion are problems in this zone; however, wind erosion is usually the main concern.

Fall tillage after wheat harvest. Generally fall tillage after wheat harvest should be avoided, and grain stubble should be allowed to stand during winter. However, weed problems and excessive runoff on frozen soils may encourage some postharvest tillage. Stubble may be under cut with a field cultivator equipped with wide sweeps or blades to control Russian thistle after harvest. This process cuts off the thistles without burying the residue. Fall tillage should retain as much residue as possible.

Light harrowing, disking, or skew treading of dry stubble is sometimes used to incorporate downy brome grass seed in the fall to initiate winter germination and obtain better weed control in the spring. However, less storage of soil water occurs following cultivation than would occur if the stubble was left standing.

Fall chiseling or subsoil tillage is effective for reducing runoff from frozen soil. In areas prone to soil freezing, fall chiseling or subsoiling on the contour increases surface storage and can provide large pores that allow water to bypass a frozen layer. This practice can be applied selectively within fields (on the contour) to treat areas that are prone to runoff. In the case of accidental fire where crop residues have been burned off, chisel or subsoil tillage can serve as an emergency measure to protect against runoff.

Spring tillage. Primary tillage in the wheat-fallow rotation is conducted during spring to kill weeds, begin seedbed preparation, and conserve soil water. The primary tillage tool is the chisel plow with sweeps (straight or twisted points), but sometimes a disk is used. A tine harrow may be used behind the chisel plow for leveling. Depending upon the weather conditions and location, primary tillage usually takes place in February, March, or April. Application of a nonselective contact herbicide in advance of primary tillage allows tillage to be delayed until later in the spring.

Secondary tillage is limited and is used to kill weeds and form a soil mulch to maintain seed zone moisture. Primary tillage is usually followed by one operation with a cultivator with sweeps. If residues are light, this cultivation is omitted. The final secondary tillage operation is a rodweeding to control weeds. Implements such as chisel choppers or cultivator-rod weeders can be used to combine some tillage operations and improve crop residue management systems.

Chemical fallow has potential for reducing runoff and soil erosion. Two to three applications of a nonselective contact herbicide are needed to provide good weed control. Late-summer weeds such as Russian thistle are difficult to control in chemical fallow, and consequently a third application of herbicide may be needed. The expense of the herbicide and the dry seedbed conditions at optimum planting times often limit the use of no-till in low-rainfall areas.

Planting operations. Planting options in a wheat-fallow system depend on the soil water status and seedbed conditions at the time of planting. Deep-furrow drills work best because of the thickness of the dry tillage mulch. These drills can penetrate soil to a depth of 5–6 inches. Placing the seed this deep is necessary in some cases to ensure adequate moisture for germination. These drills leave a furrow where the seed is planted not more than 3–4 inches deep. There are numerous modifications and attachments built for drills to help them handle more residue, place fertilizer or pesticide, and create surface conditions for erosion control. One example of a modification is notching the press wheel on deep-furrow split-packer-wheel drills. This notch improves residue handling and creates mini dams in the seed furrow to prevent runoff and increase infiltration.

In a Continuous Cropping of Small Grains

A unique continuous-cropping system is proving successful in some of the drier areas of the low-precipitation zone. In this system, spring wheat or barley is grown annually using no-till or minimum tillage. Planting is done as early as conditions permit, generally during January or February. Using no-till or minimum tillage allows planting on soils that are normally too wet for conventional-till plantings this early in the season. Nonselective herbicides are used to kill winter-germinated weeds and volunteer cereals as early as possible prior to planting (ideally beginning in the fall), and fertilizer is applied with the drill during planting in a one-pass operation.

Both soft white wheat and hard red wheat have been used in the continuous-cropping system. Hard red wheat has an economic advantage because it is possible to produce high-protein grain from this crop. The protein level is likely to be high if all of the nitrogen is applied at seeding and the crop is stressed by lack of water (which typically occurs in the low-precipitation zone) at grain filling.

Spring cropping eliminates weed problems with downy brome grass and goat grass. Russian thistle can be a problem later in the season and may require an herbicide application or an undercutting cultivation with sweeps or blades.

Risk and Management of Weeds in Conservation Till

In a 2-Yr Wheat-Fallow Rotation

In general, the weed problems and management of the wheat-fallow rotation in the low-rainfall zone are similar to those for the same rotation in the intermediate-rainfall zone. In the low-rainfall zone, however, common rye is prevalent and can be as troublesome as downy brome grass, jointed goatgrass, and volunteer grains. If sufficient weed growth has occurred, postharvest control of weeds is essential to prevent sod formation of the weeds, to reduce the number of fallow tillage operations, and to allow spring primary tillages to be delayed.

In a Continuous Cropping of Spring Cereals

Russian thistle will increase in a continuous spring cereal cropping system and will therefore require additional herbicide applications. It is one of the major weed species in the low-precipitation zone in spring crops. Germination of Russian thistle can occur in several flushes and be a problem throughout the growing season because no residual herbicide is available to control this weed. Russian thistle is now resistant to the herbicides that originally provided season-long control. Other broadleaf weeds that could increase in a continuous cereal cropping include kochia and prickly lettuce. Wild oat would increase in continuous spring grains in only the wetter parts of the low-precipitation zone.

Risk and Management of Diseases in Conservation Till

In a 2-Yr Wheat-Fallow Rotation

The most important diseases of a winter wheat-fallow rotation in the low-precipitation zone are Fusarium root and crown rot, Pseudocercosporella foot rot, stripe rust, and barley yellow dwarf. None of these diseases are controlled by the fallow period. More importantly, all four of these diseases are specifically favored by the early seeding (late August or early September) typical of the wheat-fallow system in this precipitation zone.

Fusarium root and crown rot can be managed by applying the proper amount of nitrogen fertilizer, which should be estimated from soil test results and from predicted yields based on estimated available water. This disease is favored by plant water stress and overfertilization with nitrogen. Certain wheat cultivars are less prone than others to water stress and tend also to show less damage from this disease. The fungus can live easily for 3–4 yr in the soil, and therefore cannot be controlled by 2-yr crop rotations.

Pseudocercosporella foot rot and stripe rust can be controlled by using resistant cultivars of winter wheat. In emergency situations, both diseases can also be controlled with early-spring applications of fungicides.

In a Continuous Cropping of Small Grains

Continuous cropping of spring grains is possible in the low-precipitation zone if the crops are planted no-till to conserve water. Rhizoctonia root rot has been the only disease of major economic importance in this management system. This disease can be controlled to a significant degree by early elimination of volunteer cereals and grass weeds with an herbicide. Some additional control benefits have been observed with one-pass drills that provide considerable disturbance of the soil in the seed row and band fertilizer directly beneath the seed.

Other Soil Conservation Practices

Most of the supporting soil conservation practices discussed for the high- and intermediate-precipitation zones (in the two chapters preceding this chapter) are applicable in this precipitation zone. The practices used in wheat-fallow systems are especially important because a crop, and therefore residue, is grown only every other year. With continuous cropping, cover is present throughout the year, and cross-slope farming is about the only supporting practice needed.

Most supporting practices act to catch soil eroded during runoff. The soil is caught at specific landscape positions. Supporting practices should be selected to develop an integrated system for controlling both wind and water erosion.

Economic Advantages and Risks of Conservation Production Systems

The winter wheat-fallow rotation is the overwhelming favorite among growers in the low-precipitation zone. This system has many advantages in terms of long-term profitability and stable year-to-year returns. Fallow every other year provides moisture conservation and weed control benefits that stabilize winter wheat crop yields. Furthermore, the even distribution of field work over the spring and summer for fallow maintenance and over the fall for harvesting and planting permits management of large acreages with modest amounts of equipment and labor. The "crush" of work during the short spring planting window is avoided.

Commercially, wheat has been the most profitable crop in dryland cropping regions due to relatively favorable market prices and stronger government price and income supports relative to other crops such as barley. The winter wheat-fallow rotation permits growers in semiarid regions to devote their cropland to the most profitable crop available. Furthermore, the winter wheat-fallow rotation is compatible with the typical wheat base of approximately 50 percent found on most farms in this region.

Unfortunately, the low level of residue produced in dry years coupled with intensively tilled fallow can lead to inadequate soil cover for erosion control in a wheat-fallow rotation. Potential solutions include use of minimum tillage for winter wheat and minimal tillage or chemical weed control during the fallow year. However, chemical fallow can be costly relative to tillage fallow when existing equipment and labor are discounted due to little alternative opportunity for their use.

The alternatives to the wheat-fallow rotation—flex cropping (planting a spring crop every year spring moisture appears to be sufficient) or continuous spring cropping—can be very risky. In low-rainfall regions, spring crops can still fail in some years despite evidence of adequate spring soil moisture early in the season. The short growth cycle of barley makes it a favorable spring crop in such regions, but a shortage of barley base may prevent growers from producing this crop to any great extent.

8 Alternatives to Residue Management

W.D. Kemper, W.C. Moldenhauer, and R.I. Papendick

The 1990 Farm Bill specifies that farmers must control erosion on highly erodible croplands to be eligible for commodity price supports and other USDA programs. This law is based on the premise that society has a right to protect itself from contamination of its air by dust, from contamination of its water by sediment, and from threats to food security from widespread erosion. Many citizens, including environmentalists and farmers, support this societal right. However, some farmers are asking "What constitutes adequate protection? How should that protection be achieved? Who should make these decisions pertaining to protection?"

While many U.S. farmers have asked these questions, those in the Palouse of the Pacific Northwest have articulated them most strongly. Some of them are convinced that tillage such as uphill moldboard plowing or deep chiseling can increase surface roughness, infiltration, and crop production while avoiding most of the runoff and erosion. They argue that uphill plowing and deep chiseling (for which they have the equipment) should be approved as methods for achieving the needed erosion control. The state Soil Conservation Service (now Natural Resources Conservation Service or NRCS) offices are reviewing these arguments with personnel from their regional technical centers and with ARS and state university scientists. There are considerable data on other conservation practices that support the NRCS requirements for having at least 30 percent of the surface covered with crop residue in order to achieve adequate erosion control.

In general, before farmers can use alternative conservation practices, these practices must be documented to achieve erosion control under the climate and soil conditions of that county. Unless documentation is available, NRCS personnel must restrict authorization to practices that have been previously approved. The most extensively documented erosion control practice in the United States has been crop residue management. Keeping crop residues on the soil surface by reducing or eliminating tillage has been proven by the ARS and Land Grant Universities to be effective in controlling erosion in hundreds of locations. Consequently, while awaiting adequate documentation of other cost-effective practices, NRCS has emphasized the use of reduced tillage and surface crop residues for controlling wind and water erosion in the Pacific Northwest.

Farmers in some areas, such as eastern Idaho, are adopting reduced and no-till methods of keeping residues on the soil surface because they improve erosion control, water-use efficiency, and crop yields. Precipitation in eastern Idaho is heaviest in the spring and early summer, and crop residues on the surface during that time period preserve soil moisture for use by the crop.

In the Palouse (west central Idaho and parts of eastern Washington and Oregon), the effectiveness of residues for preserving soil moisture is not as great because precipitation comes primarily in the winter. During the late spring and early summer of the fallow year, a tilled dry surface soil layer tends to restrict movement of deeper water to the soil surface and subsequent evaporation. Fallow tillage, usually using rod weeders or undercutting sweeps, kills weeds, leaves some of the crop residue on the soil surface and by fall generally retains a substantial portion of the previous winter's precipitation to be used to germinate fall-planted wheat. On the negative side, this undercutting tillage brings some weed seeds near the surface where they can germinate if small showers occur. Consequently small showers are commonly followed by additional undercutting tillage passes, each of which breaks up or buries more of the crop residue. By fall this often leaves the land with little protection by surface residue, and creates a surface layer that is often described as a "dust mulch." Wheat seeds planted into moist soil beneath the dust mulch tend to germinate quickly, and if there are no intervening strong winds to move the soil and damage the emerging seedlings, the new seedlings may grow sufficiently in the fall to provide protective cover during the winter months.

The problem is that in the drier areas winds occur fairly commonly during this critical period, "sand blasting" the emerging seedlings and lifting substantial amounts of fine particles into the atmosphere. The EPA is aware of this problem and, in coordination with the ARS and NRCS, is focusing attention on farming practices to prevent this loading of dust into the air.

A practice currently being proposed by some farmers for producing continuous wheat in the higher precipitation areas involves no-tillage following burning. Burning removes a large part of the crop residue from the surface just prior to planting. Perceived benefits of burning include some degree of weed, insect, and disease control and the fact that the land is left in a condition in which it can be sown more readily with a standard drill. These farmers believe that refraining from tillage together with the limited amounts of surface residue that survived the fire provide sufficient resistance to wind or water erosion. The rate of growth of the new seedlings is often accelerated by the warmer soil temperatures accompanying the blackened soils. Increased yields are reported to occur in some years as a result of the more rapid seedling growth.

Based on these perceived benefits of the no-till-burn system, some farmers argue that it should be given credit as an alternative practice that achieves the needed erosion control. However, the erosion-control benefits of this system have not been documented. Recently, NRCS has approved field trials to test this system.

There are two serious environmental objections to a practice that includes burning. The first is that agencies responsible for air quality may disallow agricultural burning because of the smoke produced. The second is that the exceptionally long-term study by ARS at Pendleton, OR, has shown that burning surface residues leads to a more rapid decline of residual soil organic matter than any other treatment. Since soil organic matter content has been correlated positively with infiltration rates, water-use efficiency, adequate nutrient supply, and overall productivity of the soil, burning and any other practice that reduces soil organic matter may not be in the best long-term interests of the farmer or of society.

It must be recognized, however, that the Pendleton studies have involved moldboard plowing which has been shown by recent Minnesota studies to be a primary cause of biologically accelerated oxidation of soil organic matter. The acceleration of biologic oxidation following moldboard plowing appears to oxidize more organic matter within a few weeks of the tillage than is oxidized by burning the residues.

Consequently it is not certain that burning accompanied by no-till crop production will decrease soil organic matter. The original prairies of the Northwest had soils rich in organic matter and were burned occasionally by fires due to natural causes and by Native Americans, accidentally and deliberately. It is possible that roots and their organic exudates play the major role in building organic matter in soils and that residues on the surface are primarily effective in protecting the soils from erosion and improving precipitation-use efficiency.

Research has been initiated by ARS in cooperation with NRCS and Washington State University to evaluate effects of no-till-burn management systems on erosion control, soil organic matter, and crop production. However, due to climatic variability and the slow rate of change of organic matter, it will probably be several years before the needed documentation can be provided.

Meanwhile the NRCS has been given a mandate to reduce erosion throughout the nation including the Palouse area, where cultivation has mobilized large amounts of sediment and facilitated its movement by wind and water. Farmers in this area have possibly not been as concerned about erosion as those in most other parts of the country because the deep loess underlying most of their soils tends to be reasonably productive soil even when the surface is removed. Off-site environmental degradation (that is, dust in the air, siltation of stream beds, and reduction in reservoir capacity) has been of greater concern and value than reduced productive capacity of the land. However, the NRCS, as society's designated protector of our natural resources, is required to develop the rules that will achieve this erosion control, to help farmers develop conservation plans that will reduce erosion, and to report farmers who do not farm according to their approved plans. NRCS has requested the help of ARS and other institutions that have conducted research on factors affecting erosion and that have identified and evaluated the effects of these factors. Much of this information on erosion has been collected in other parts of the United States where climate, soils, and cropping systems are different than in the Palouse area. Moreover, in these other regions no-till management has a longer history, and equipment that facilitates no-till and reduced-till systems is generally more available and understood.

There are innovative farmers in the Palouse and other dryland areas who have developed alternative farming systems that use existing or modified equipment. These farmers understandably feel that their alternative may be better suited to their local situations than the reduced tillage and crop residue management technology, which they feel is "imported by NRCS largely from other regions." However, some NRCS and ARS scientists have observed the pattern of adoption of reduced tillage, no-till, and residue management in other regions of the United States and in other countries such as Brazil, Argentina, Canada, and Chile and have documented long-term effects of these farming practices. They believe that the problems will eventually be solved as the Northwest farmers become more experienced with the program and that erosion control, yields, and net incomes of farmers using reduced till and crop residue management in the Northwest will improve as they have in other regions and countries.

Farmers who depend directly and solely on their land for sustenance are commonly the ones most concerned about conserving and, if possible, enhancing the land. They have also observed its interaction with their climate and have often developed innovative systems that achieve their production and conservation objectives. The NRCS, ARS, and Land Grant Universities are interested in those innovative systems and are interested in cooperating with such farmers to evaluate effects of these alternative systems on infiltration, erosion control, soil organic matter content, and productivity. By cooperative assessments the best systems can be identified, evaluated, and given their proper credits in erosion control programs.

There is also a need to identify cases where no-till and other reduced-till systems have been given fair trials for several years and to evaluate their problems and how well they are providing the benefits predicted by USLE, RUSLE, and related technology.

Meanwhile the NRCS, saddled by society with responsibility to enforce the compliance provisons of the Farm Bill, is providing the farmers with the best counsel, guidelines, and rules available. Moreover the agency is willing to evolve these rules to include alternative practices as soon as the net effects of those practices on society and the farmers are proven to be positive.

9 Crop Residue Management for Soil Conservation on Irrigated Lands of the Northwest

D.L. Carter, W.D. Kemper, R.D. Berg, and M.J. Brown

Irrigated lands comprise a significant portion of the farm economy of the United States. About 14 percent of the area farmed in the United States is irrigated, and this irrigated acreage produces about 38 percent of the total value of crops produced in the country. However, relatively little attention has been given to erosion control on irrigated lands. Only in the last decade has the magnitude of the erosion problem on irrigated lands been fully identified and the technology for developing erosion control initiated. The erosion problem on irrigated land is serious, and further technology for erosion control is needed.

Irrigated areas are generally flatter, occur at lower elevations, and receive less precipitation than adjacent nonirrigated croplands. Many irrigated areas occur in river valleys, and the soils of these areas are commonly alluvial deposits along a flood plain and its immediately adjacent areas. The use of sprinkler irrigation is continually expanding, and this form of irrigation is now being used on steeper and more rolling topography. Use of groundwater aquifers for irrigation has also extended irrigation beyond the river valleys. Most irrigated land is in the western United States. In the northwestern states of Idaho, Oregon, and Washington, approximately 8 million acres are irrigated. Of these acres, 4.85 million are sprinkler irrigated, and about 3.07 million are surface irrigated (table 2). In the past 30 yr, the use of irrigation has increased a lot, and many growers have switched from surface to sprinkler irrigation.

Cereals, pasture, and grass seed crops are grown on both irrigated and nonirrigated lands, but in the Pacific Northwest most row crops and high-value cash crops are grown under irrigation. The number of different crops grown under irrigation is three to four times the number that can be grown without irrigation. Irrigated crops generally produce greater amounts of residue than nonirrigated crops.

Erosion Problems Induced by Furrow Irrigation

Erosion problems associated with furrow irrigation were first recognized in the 1930's and 1940's (Gardner et al. 1946, Gardner and Lauritzen 1946, Israelson et al. 1946). This early research related sediment loss to slope and stream size, and the researchers warned growers not to irrigate slopes that were too steep and cautioned them to use stream sizes as small as possible. These warnings were largely unheeded until water quality legislation in the 1970's focused attention on water quality problems associated with irrigation runoff. This legislation provided some Federal funding for programs directed toward reducing the sediment loads in irrigation runoff or irrigation return flows. At first, most of the effort was directed toward developing methods to remove the sediment from irrigation runoff water before the water entered a navigable stream or river.

Subsequent evaluations of the effects of erosion on soil productivity (Carter et al. 1985, Carter 1993) focused national attention on the severity of the irrigation-induced erosion problem. Irrigation-induced erosion has caused major reductions in crop production potential of soils as topsoil has been washed away. For instance, crop production potential for a large portion of the furrow-irrigated area in Idaho has been reduced 25 percent by 80 yr of irrigation-induced erosion.

Traditional tillage of furrow-irrigated fields has generally included moldboard plowing, resulting in essentially complete burial of crop residues. Soil loss resulting from irrigation-induced erosion of row-cropped fields under these traditional tillage practices commonly ranges from about 3 tons/acre each year at a slope less than 1.0 percent to over 40 tons/acre each year at slopes over 3.0 percent (Berg and Carter 1980, Carter 1990). In addition to this sediment removal from fields, topsoil is often eroded from the inflow ends of furrows and deposited on downslope areas of the fields. This topsoil movement within the field reduces the crop production potential of the eroded area but seldom increases it on the deposition area (Carter 1993). Both soil-loss processes diminish soil productivity.

Residue Management For Erosion Control On Furrow-Irrigated Land

Traditional management practices for furrow-irrigated land commonly include tillage operations that position all crop residues so that subsequent moldboard plowing completely buries them. The original objective of complete burial of the residue was to get it out of the way so that it would not interfere with planting and furrowing and the movement of irrigation water down the furrows. Some farmers have tried to irrigate cereal stubble fields following combining without cleaning the furrows and have had problems. Generally, however, most of these farmers are simply following traditional methods for farming furrow-irrigated lands.

Beneficial effects of residue on the soil surface were observed during the 1970's in studies on conventionally tilled fields at Prosser, WA (Aarstad and Miller 1978, 1981; Miller and Aarstad 1971, 1983). Small amounts of residue such as cereal straw or pieces of cornstalks significantly reduced erosion within the furrow and increased the amount of water infiltrating into the soil along the furrow. Furthermore, these studies demonstrated that conventional-till fields could be effectively furrow irrigated if small amounts of residue existed in the furrows and on the soil surface and were mixed into the surface soil.

These findings from Prosser, WA, were confirmed and expanded on in several studies at Kimberly, ID. In a conventionally tilled corn field, Berg (1984) placed small amounts of wheat straw in sections of furrows having a 4 percent slope. These 4-percent-slope areas were part of a longer furrow that had an average slope of about 1.5 percent. The straw increased the surface roughness, slowed the water velocity, and increased the wetted perimeter in the furrows; and these three factors reduced the erosion and increased infiltration in the steep portion to near that of the flatter portions of the field.

In the study by Berg (1984), corn production increased markedly on straw-treated areas as compared to nontreated areas in the steep portion of the field. Furthermore, straw prevented sediment movement from the steep area to the area immediately downslope where sediment often filled the furrows when straw was not used, allowing water to concentrate in the lower ends of some furrows and miss others. Consequently, using straw in the steep portions of the field resulted in much more uniform irrigation, and the grower harvested the highest corn silage yield ever produced on that field.

Similar studies were conducted on fields of dry edible beans. Excellent yield increases resulted from straw applications in furrows, and these applications made irrigations more uniform and reduced sediment loss 70–90 percent (Brown 1985, Brown and Kemper 1987).

In studies that followed, conservation-tilled rather than conventional-tilled fields were used to evaluate the effects of residue on furrow-irrigated land—a major break from tradition. These studies evaluated the effect of "natural" residue from the previous crop rather than the effect of "artificially spread" residues. Conservation-tillage approaches were tried in split and paired fields operated by farmers with advice from researchers at Kimberly, ID. More than 130 comparisons have been conducted since 1984. During this same period, a number of replicated plot studies have been conducted to evaluate the benefits of changing the sequence of crops in rotations to permit the fewest tillage operations and to best use crop residues for reducing soil erosion and enhancing irrigation uniformity. The conclusions from these studies are discussed in the remainder of this chapter.

No-Till Cropping Options

Row crops such as dry beans, sugarbeets, onions, potatoes, and other vegetables produce relatively small amounts of residue that generally decay rapidly. Cereals and corn under irrigation produce large amounts of residue that are persistent when left on the soil surface. The aboveground residue from alfalfa can vary from 1 to 3 tons/acre depending upon when the alfalfa is harvested and how much regrowth is permitted. The underground residues from alfalfa can be significant. This is also true for cereals. Aboveground cereal residues commonly range between 2 and 6 tons/acre, while dry bean residues may be only a few hundred pounds per acre. High cereal residues present the most difficult residue management problems on furrow-irrigated land, but they also provide some of the best residues for erosion control when the following crop is a row crop.

Disease and insect problems that have been associated with leaving some residues on the soil surface in rainfed areas have not appeared to be serious under irrigated conditions. This may be a result of the large number of crops used in rotation on irrigated lands, which tends to break the life cycles of these pests that are crop specific. Farmers on irrigated land seldom produce the same crop in successive seasons (except for dry edible beans) and rarely produce the same crop on the same land three successive seasons. Many farmers follow a specific rotation, but others often change a rotation to grow a crop that happens to have potential for a high price in any particular year. The key to such flexibility is that water can be applied when it is needed by the crop.

The majority of farmers have alfalfa in their rotation, and it is usually grown in the seeding year plus two or three more. Commonly, row crops such as dry beans are grown following the alfalfa. When this is done, farmers often use 10 or more tillage operations to prepare the land for seeding the row crop. A survey of over 100 farmers who grow dry beans following alfalfa revealed that an average of 10–11 tillage operations were used to kill and bury the alfalfa residues, prepare the land, apply herbicide, furrow the land for preplant irrigation, seed the beans, and furrow them for the first irrigation. Some farmers used as many as 15 tillage operations.

During the past decade, researchers at Kimberly, ID, have experimented with no-till and reduced-tillage systems on furrow-irrigated land in a program aimed at developing conservation-tillage cropping systems that would reduce erosion, sediment loss, and costs of crop production. The text that follows explains procedures and gives results from the more promising cropping system options in their studies.

Corn or wheat grown without tillage following alfalfa. The alfalfa was spray killed in the fall after the hay from the third cutting had been removed and sufficient regrowth had occurred for the herbicide to be effective. Planting time of the crop following the alfalfa was dependent on the crop grown. Winter wheat was seeded almost immediately following the spraying of the alfalfa. Seeding was done parallel to the furrows with regular irrigated land drills. The next spring the furrows that had been used to irrigate the alfalfa during the previous years were cleaned. When corn was the crop to follow alfalfa, the alfalfa was killed with herbicide in the fall and the corn was seeded the following spring. It was necessary to attach a cutting coulter or a chisel point shank ahead of each seeder to assure that the seed was placed in the ground at the proper depth. The corrugates or shallow furrows used for irrigating the previous alfalfa crops were cleaned during the seeding operation.

Results from a number of these studies showed that cereal and corn yields were as high on no-till plots as on conventional-till plots used for comparison. Furthermore, all of the nitrogen needed by the corn was supplied from that symbiotically fixed while the alfalfa was growing on the land. Most of the nitrogen needed by the wheat was also provided from this source, but occasionally the nitrogen requirements early in the spring exceeded the rate at which mineralization from the alfalfa residue could supply it, and a small amount of nitrogen fertilizer was needed. Detailed results of these studies have been published as a recommended practice for controlling irrigation-induced erosion (Carter et al. 1991). Erosion and sediment loss was almost completely eliminated during the season that these no-till crops were grown.

Other crop sequences. Other crop sequences that can be used successfully on furrow-irrigated land without tillage include cereal following corn, corn following cereal, and corn following corn. Erosion and sediment loss can be practically eliminated with no-till management. Production costs are considerably lower for the no-till crops than for those grown with conventional tillage. Crop yields and quality are practically the same for both tillage systems. Growing no-till corn following high-yielding wheat sometimes requires removing part of the straw by dropping the threshed straw behind the combine and baling it. Swathing and baling can remove a larger portion of the straw if there is a market for it.

Reduced-Till Cropping Options

Many reduced-tillage studies were also conducted simultaneously with the no-till studies described in previous paragraphs. In all studies, conventionally tilled plots were included in the same field as reduced-tillage plots. In most cases, these plots extended the full field length because one of the purposes of these studies was to determine whether conservation-tillage fields could be successfully furrow-irrigated over the usual run length. Any residue management practice that precluded successful furrow irrigation over normal irrigation run lengths would not be of value in a furrow-irrigated system.

Moldboard plowing was eliminated from all reduced-tillage treatments so that crop residues would not be completely buried. Most treatments included one or more diskings, but some did not involve disking to prepare for the subsequent crop.

One of the most common problems that farmers perceived was that they would not be able to successfully irrigate dry beans if cereal stubble was not buried. Therefore several studies were conducted to assure that cereal residue could be successfully managed for bean production without moldboard plowing. One or two diskings in the fall followed by one or two diskings in the spring sufficiently mixed the residue with the soil so that only about two roller harrowing operations were needed to prepare a good seedbed for beans or sugarbeets. When dry beans, sugarbeets, or cereal was to follow dry beans or sugarbeets, one roller harrowing was often sufficient to incorporate the herbicide and prepare for seeding.

Reduced tillage decreased sediment loss from fields by 50–100 percent. Sediment losses were measured, and the highest amount of furrow erosion occurred on row-cropped plots following low-residue row crops. No significant differences in average crop yields were found between conventionally tilled and conservation-tilled fields in about 120 field comparisons. However, long-term use of conservation tillage and associated saving and building of topsoil will increase soil productivity and will eventually increase and sustain higher crop yields.

Conservation-tillage cropping systems that change the sequence in which crops are grown have also been evaluated in comparison with traditional cropping systems. One common conventional system has been to grow alfalfa for 3 yr, then dry beans for 2 yr, followed by winter wheat for 1 yr, then corn for 1 yr, and finally spring wheat in combination with alfalfa for 1 yr to reestablish the alfalfa for 3 more years. This rotation results in considerable leaching of nitrate to the groundwater, particularly during the first dry bean year following alfalfa. This conventional system was compared to a conservation-tillage system of no-till corn for 1 yr after alfalfa, followed by no-till wheat the second year, then two successive crops of dry beans, and finally alfalfa with spring wheat as a nurse crop.

The detailed results may be found in Carter and Berg (1991). Briefly, the conservation-tillage system required only about 11 tillage operations during the 7-yr rotation compared to 31 for the traditional tillage system. The conservation-tillage system also lost and used less nitrogen fertilizer, had lower production costs, reduced erosion and sediment loss about 90 percent, and increased farmer net income about $55/acre/yr when averaged over the 5-yr period following the alfalfa. Conservation-tillage practices can be applied to furrow-irrigated land and can improve farm income while they control irrigation-induced erosion.

Effects of Tillage on Furrow Irrigation Uniformity and Efficiency

Influence of Tillage on Infiltration Rate

After traditional-tillage operations are used to prepare the seedbed, the rate at which water infiltrates the soil during the first irrigation is often very high. Consequently, the rate at which the wetted front moves down the furrow is slow. Generally, the soil at the top end of the furrows has absorbed 10–30 inches of water by the time the water reaches the lower ends of the furrows. When the desired 4–6 inches of water has been applied at the bottom ends of the furrows, 15–35 inches of water has often been absorbed at the top ends.

Preplant irrigations are used for some crops such as dry beans, corn, and other vegetable crops. Often the amount of water used for the preplant irrigation is as great or greater than the amount used to irrigate the crop for the remainder of the season. If preplant irrigations are used after moldboard plowing, they will waste water and leach most of the nitrates from the root zone at the top end of the field into the groundwater.

Discontinuing moldboard plowing and other deep-tillage practices often reduces the amount of water used for preplant irrigation (or used for the first irrigation of a seeded crop) by more than 50 percent and eliminates most nitrate leaching. Moldboard plowing buries the crop residue and fractures the soil to the depth of tillage into large clods. When there is water in the furrows, it moves quickly through the large pores between the clods during the first irrigation until it saturates the tilled layer. In this saturated condition, a positive pressure pushes water into worm holes and other large pores that extend deeper into the soil. Shallow, more intense tillage breaks large clods down into smaller size and mixes the crop residues with the surface soil, allowing layers of moderately low permeability to develop near the surface that control infiltration at a moderate rate during first and successive irrigations.

Influence of Tillage Type and Crop Sequence on Water Required for Irrigation

In the past 8 yr, about 130 comparisons of tillage type and crop sequence have been performed. The information that follows is a summary of four of the most important comparisons. These four comparisons evaluated the differences in the amount of water required to irrigate conventional-till, no-till, and reduced-till plots. Various crop sequences were used in the comparisons. The four comparisons discussed and some results from each are as follows:

Inches of Water During First Irrigation

Comparison 1:	
No-till corn following alfalfa	7
Conventional-till corn following alfalfa	23
Comparison 2:	
No-till corn following wheat	6
Conventional-till corn following wheat	19
Comparison 3:*	
Reduced-tillage beans following wheat	7
Conventional-till beans following wheat	24
Comparison 4:*	
Reduced-tillage beans following wheat	3.5
Conventional-till beans following wheat	4.9

* The tillage and cultivation methods for comparisons 3 and 4 were quite different. Methods used in comparison 4 were designed to reduce excess water losses due to excess infiltration. A complete description of the methods for each comparison is given in the text that follows.

The above results were from split fields where one portion of the field was conventionally tilled and another portion either received no tillage or reduced tillage. The procedures used to obtain these results are discussed in the text that follows.

• **Comparison 1.** In the first comparison, alfalfa was spray killed in the fall. The following spring, part of the field was disked, moldboard plowed, disked, roller harrowed twice, and then seeded to silage corn. Another portion was seeded to silage corn without tillage. Chisel-point shanks were placed in front of each seeding unit to assure that the seeding mechanism would place the seed about 2–2.5 inches deep. The furrows that had been used to irrigate the previous alfalfa crops were cleaned during the seeding operation. When the first irrigation was completed, the water reached the lower ends of the furrows (which were 580 ft long) in about 2 hr, and the irrigation appeared to proceed rather uniformly. After about 12 hr, the irrigation was considered adequate based upon observed lateral wetting. By this time an average of about 7 inches of water had been applied to the area served by the furrows. Intake opportunity times indicate that infiltration at the top ends of the furrows was no more than 8 inches, and at the bottom ends was at least 6 inches.

Within the first hour after starting the irrigation on the conventional-till plots, it was obvious that the advance rate was much too slow. Therefore, the inflow rate was doubled, and then later tripled in an effort to speed the advance. These higher inflow rates caused severe erosion in the upper ends of the furrows, even at a slope of only 0.4 percent. After about 8 hr the advance had essentially stopped, and irrigation was terminated before water reached the lower ends of the furrows. Adding water more rapidly to the furrows is often a solution to this problem, but experience has shown that large flow rates in freshly tilled soil move a large amount of soil. Another solution is to stop the irrigation. Stopping irrigation allows tension to develop in water on the wetted soil, consolidating the soil in the plowed layer and reducing its permeability.

In this study the irrigation was stopped, and water was applied again 1 day later. The water ran down the previously wetted and consolidated portion of the furrows quickly, reached the ends of the furrows within a couple of hours, and was allowed to flow for about 6 hr until the lower end was adequately irrigated. Usually when growers follow this practice to complete an irrigation, the water runs for about 12 hr after starting because growers prefer to change water sets in the morning or evening so that other daytime activities are not interrupted. (Observations of this type played a part in the development of present day "surge irrigation." This irrigation process involves an intermittent supply of water to the furrows and can reduce but not eliminate such problems as much more intake at the top than at the bottom ends of furrows and generally too much intake of water during the first irrigation following moldboard plowing or other forms of deep tillage.)

By this time the average application of water to the portion of the field served by these furrows was about 23 inches (see data on page 40). Comparisons of the intake opportunity times and consideration of the consolidation effects provide estimates that infiltration at the top end of the field was about 35 inches of water and at the bottom end was about 10 inches.

• **Comparison 2.** The second comparison was similar to the first except that the previous crop was wheat instead of alfalfa. Again the no-till portion of the field irrigated rather uniformly, and the irrigation was complete in about 12 hr. After 10 hr, and with greater furrow-inflow rates, the water had not reached the lower ends of the furrows in the conventionally tilled portion of the field. Irrigation was discontinued to allow consolidation of the soil adjacent to the wetted portion of the furrows and was resumed 1 day later to get the water to the lower ends of the furrows. When the irrigation was terminated, an average of about 19 inches of water had infiltrated into the conventional-till plots compared to 6 inches for the no-till plots (see data on page 40). Infiltrations were estimated to range from 27 inches at the top end to about 10 inches at the bottom end of the conventional-till treatments and to be within the 7–5 inch range on the no-till treatment.

• **Comparison 3.** The third comparison was between reduced-till and conventional-till plots of dry beans following winter wheat. The reduced-tillage plot was disked twice in the fall, once in the spring, roller harrowed twice in the spring, and seeded to beans. The first irrigation was applied after seeding to provide soil moisture for germination and early growth of the beans. The conventional-tillage plots were disked twice in the fall, and then in the spring they were moldboard plowed, disked, and roller harrowed twice before seeding.

Water reached the lower ends of the furrows on the reduced-tillage plots in about 3 hr, and the irrigation was complete in about 10 hr, as indicated by the wetting front laterally reaching the seedbed rows. The irrigation uniformity appeared to be good based upon the visual observation of lateral wetting. Water had not reached the lower ends of the furrows after 10 hr on the conventional-till plots. At that time the irrigation was discontinued for a day and then initiated again as described for the first two comparisons to permit the consolidation of soil adjacent to the wetted portion of the furrow. The amount of water infiltrated was estimated to have been from about 8 inches on the upper end to about 6 inches on the lower end of the reduced-till plots and about 36 inches at the upper end and 12 inches at the lower end of the conventional-till plots.

In all three of these comparisons, too much water was applied in the first irrigation to the conventional-till plots. Initially high infiltration rates made it necessary for enormous amounts of water to be applied at the upper ends of the furrows to get water to the lower ends. Refraining from moldboard plowing and other deep disruptive types of tillage allows the grower to avoid most of the water and nitrate losses that accompany the first furrow irrigation following this type of tillage.

• **Comparison 4.** The fourth comparison was between reduced-till and conventional-till beans following wheat. Tillage and cultivation methods used in this comparison were designed to reduce excess infiltration associated with large clods and voids from moldboard plowing. In the fall the reduced-till and conventional-till areas of the field were disked twice. In the spring, heavy straw residue from the previous high-yield wheat crop was buried in the conventional-till plots by moldboard plowing, and then these plots were disked almost to the depth of plowing to break up large clods and reduce the void size. Two roller harrowings were then used on the conventional-till plots; the second one was done to incorporate preplant herbicide. The conventional-till plots were then furrowed to prepare them for preplant irrigation.

The reduced-tillage portion of the field had the same operations as the conventional-till portion except that the reduced-till area was not moldboard plowed in the spring. The field used in this fourth comparison had a slope of 1.3 percent, which is steeper than the slopes in the first three comparisons. The steeper slope enhances the advance rate and the probability of the water from the first irrigation reaching the lower ends of the furrows in reasonable time.

A greater infiltration rate was expected on the moldboard plowed land, so furrows on conventionally tilled areas were made larger to carry more water. The average furrow inflow rate on the conventional-till portion was 10 gal/min compared to 7.2 gal/min for the reduced-tillage portion. The average runoff rate was 6.7 and 4.2 gal/min for the conventional- and reduced-tillage portions, respectively. This approach allowed irrigation on the conventional-till and reduced-till areas to be completed in about the same amount of time. Only 1.4 inches more infiltration occurred on the conventional-till treatment, indicating that the disking of moldboard plowed land reduced clod and void size and therefore infiltration. However, a serious erosion problem resulted on conventional-till plots from burying the straw and using the larger furrow inflow streams. Sediment loss from the first irrigation was 22.0 tons/acre for the conventional-till treatment compared to 4.1 tons/acre for the reduced-tillage treatment.

Additional comparisons (similar to the four just discussed) have shown that reducing the tillage depth generally decreases the amounts of excessive infiltration and nitrate leaching that often accompany the first irrigation. These results indicate that moldboard plowing should be avoided, but if plowing must be done, it should be as shallow as possible.

One other observation of significance was that where reduced tillage was used to grow beans after cereal, the presence of crop residues in and on the soil surface apparently increased the amount of water that was stored in the shallow root zone of the beans. Generally water stress symptoms were delayed 1–2 days longer on the reduced-tillage plots than on the conventional-till plots. The residue on the surface reduced evaporation from the soil so that more of this stored water was available to the beans. Long-term evaluations of leaving crop residues on the surface (see chapter 11) indicate that residual organic matter can be increased at rates of about 1,000 lb/acre/yr by no-till management. Since each pound of residual organic matter holds about 4 lb of water for use by the crop, 10 yr of no-till management should enable the soil to hold about 40,000 lb/acre of additional water following each irrigation.

From the 130 comparisons made in the past 8 yr, we can conclude that no-till and other forms of conservation tillage that leave residue on the surface can be successfully applied to furrow-irrigated land to reduce erosion, improve water use efficiency and net returns, and reduce nitrate leaching.

Residue Management Under Sprinkler Irrigation

Some soils have such low infiltration rates that water runs off and causes erosion during sprinkler irrigation. This is particularly true under the outer nozzles of center pivot irrigation systems where the application rate may be up to 4 inches/hr under low-pressure systems and 2 inches/hr under high-pressure systems. These rates of application have increased in many standard sprinkler systems when lower pressure systems were adopted. This runoff can cause significant displacement of topsoil within the system along with some removal.

During the first irrigation following tillage, the fractured soil is initially open and receptive to the sprinkled water. However, the beating action of the water drops disintegrates the surface and fills the large pores with primary particles and therefore tends to seal the soil surface. Leaving crop residues on the surface reduces the rate at which this sealing takes place and also provides incentive for surface-feeding earthworms to burrow holes through the dense surface layer from the more porous underlying soil. These factors arising from the use of surface residues help keep infiltration more uniform and decrease erosion and soil displacement.

Any residue management practice that can be successfully used for rainfed agriculture can generally be applied to sprinkler-irrigated areas. More residue can be managed on the soil surface under sprinkler irrigation than under surface irrigation. Furrow cleaning is not needed under sprinkler irrigation. The primary argument for tillage under sprinkler irrigation has been to provide for sufficient seed-to-soil contact to get water for germination into the seed. A light irrigation can generally accomplish this objective. The same rotations and crop sequences suggested for furrow-irrigated land will be successful under sprinkler irrigation.

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Table 2. Types of irrigation used on farmland in the Northwest and types of crops grown on this irrigated farmland

	Irrigated Area (Thousands of Acres)			
	Idaho	Oregon	Washington	Total
Irrigation Type:				
Gravity-Surface	1,734	820	520	3,074
Center-Pivot, Linear-Move Sprinkler	731	240	465	1,436
Other Sprinkler	1,633	748	1,029	3,410
Drip or Trickle	6	7	48	61
Total	**4,104**	**1,815**	**2,062**	**7,981**
Crop Types:				
Small Grains	1,309	230	330	1,869
Row Crops, Vegetables	806	288	490	1,584
Hay, Grass Seed, Pasture	2,158	1,209	973	4,340
Trees, Horticultural Crops	12	88	269	369

SOURCE: Irrigation Association (1994).

10 National Perspectives on Management Options for Lands Concluding Their Tenure in the Conservation Reserve Program (CRP)

T.E. Schumacher, M.J. Lindstrom, M.L. Blecha, and R.I. Papendick

Most of the highly erodible lands contracted into the Conservation Reserve Program (CRP) suffered much erosion, organic matter loss, and soil structural deterioration while in cultivated crop production prior to the program. In this program the land was returned to grass, and significant improvements toward the structure and organic matter levels of the original grasslands have been achieved. If these improved lands are tilled again following the program, the organic matter level and structure resulting from the period in grass will be rapidly lost.

A critical question for managers of post-CRP land returning to crop production is how to maintain the benefits derived from 10 yr of grass. Going directly into no-till can be a cost-effective method of doing this. No-till reduces the high rate of biological oxidation of organic matter that results from moldboard plowing or other forms of intensive cultivation (Reicosky and Lindstrom 1993). It also maintains the pore geometry and continuity developed under grass. Macropores extending from the soil surface to deep within the root zone are maintained, resulting in high-water-intake rates that reduce runoff and erosion. By keeping crop residue on the surface and a few millimeters of highly organic soil near the surface, no-till also reduces evaporation. This combination of increased infiltration and decreased evaporation makes more water available for crop production and groundwater recharge. The additional groundwater increases the base flow into our streams from springs and seepage faces that sustain the desirable components of our wetland ecosystems. No-till also reduces populations of annual weeds that require soil disturbance for germination.

No-till production systems must be adapted to the conditions of the region and the resources and needs of the producer. Some of the purposes of tillage include control of weeds, insects, and pathogens. When tillage is discontinued, alternative means of controlling these pests must be used. Herbicides provide cost-effective control for most weeds. Other examples of controlling pests include mowing field borders before weed seed set; using disease-free and fungicide-treated seeds; using crop rotations to break life cycles of diseases, insects, and weeds; and narrowing rows to allow earlier interception by the crop of the sunlight and nutrients that otherwise would nurture the weeds. Other chapters in this publication discuss development of successful no-till systems. The following discussion focuses on the CRP—how grass affects soil properties, the rates at which grass improves soil properties, post-CRP management options, the potential impacts of no-till after CRP, and some basic no-till guidelines.

Conservation Reserve Program

The CRP was initiated in 1985 under the Food Security Act with the intention of placing up to 45 million acres of highly erodible farm land under protective cover. Public perceptions of the economic, social, and environmental state of farming prior to the initiation of the farm program influenced this multiyear land retirement program. During this time period, farm prices were low, large crop surpluses existed, farm foreclosures were on the increase, and agricultural exports were decreasing. Lobbyists argued that these surpluses were preventing improvement of grain prices and that due to these surpluses large blocks of highly erodible land could be placed under protective unharvested grass cover. There was also public concern that current farming practices were destructive to both the soil's productive capacity and to wildlife habitat. Economists anticipated that the reduction in acres of grain would reduce grain production so that market prices would rise closer to target prices. Consequently, crop support prices would be lower per bushel and would be paid on fewer bushels. Based on these potentials for improving erosion control, farm prices, and the national budget, the CRP got underway.

Under this program USDA pays CRP participants an annual rent for 10 yr, plus half the cost of establishing a conserving land cover. To be eligible for the program, land has to be potentially highly erodible, actually eroding at an excessive level, or environmentally sensitive. A condition of this enrollment in CRP was that the farmers surrender their use of a proportional amount of their commodity crop base acreage. This subtracted base acreage is "returned" when the land is retired from the CRP.

The objectives of the CRP evolved during the program, and new procedures were developed for selecting lands proposed for the program. The new procedure used a productivity based rental rate and ranked bids based on the ratio of the environmental benefits index to the government cost of the contract. Special provisions for wetland enrollment were made during the 8th and 9th signup periods. U.S. conservation policy is moving to promote broader stewardship of all natural resources on the farm as indicated by the addition of the Wetlands Reserve Program, the Agricultural Water Quality Incentives Program, and the Environmental Easement Program.

Status of CRP

By 1993, 36.4 million acres of highly erodible and environmentally sensitive land were enrolled in the CRP. The first contracts will expire in October 1995. By October 1997 about 24 million of these acres will be released. Over half of the CRP acres are located in the 10 Great Plains States. Commodity crop base acreage was reduced by 23.3 million acres. One of the major payoffs of the CRP has been its significant improvement of wildlife habitat. This benefit has brought a major portion of the environmental groups to support CRP and proposed related programs. Average erosion reduction on CRP lands is estimated to be 19 tons/acre/yr (Osborn 1993). Of the land that went into CRP, 2.4 million acres were planted to trees and most of this was in the Southeast region.

As contracts expire, producers are questioning what the future holds for grassland enrolled in the CRP program. Many of the highly erodible lands accepted in the CRP had previously suffered much erosion and structural deterioration. Organic matter contents, structure, and infiltration rates of soils in these lands have generally improved during their period in grass. However, these improvements will be rapidly lost during and immediately after tillage.

As the CRP acres become eligible for release, landowners have many options, including leaving the acres in grass for hay or livestock production or establishing wildlife or recreation enterprises. Another option available to contract holders is to return all or a portion of the land back into crop production. Surveys indicate that over half of CRP contract holders plan to return their land to cropping upon contract expiration. Many of these producers lack experience in dealing with the grass and large amounts of residue accumulated after the land has been idle for 10 yr.

Effects of Grass on Soil Properties

The most important characteristics of soil structure are the size, distribution, and geometric arrangement of the pores. These properties of soil pores determine infiltration rates, internal drainage and aeration, water-holding capacity, and the portion of soil water that is available to plants. These characteristics tend to become optimized when there is a sod cover. Soils with the best aggregation for crop growth in the United States are soils that have been in grass for many years. These soils have greater amounts of organic matter, structural stability, total pore space, air-filled pore space, higher hydraulic conductivity, and higher infiltration rates than cropped soils that are conventionally tilled. Additionally soils of long-term grasslands tend to have more pores in the size range that contributes to field water-holding capacity than cropped soils. This results in improved water availability for plant growth. Earthworm channels connected to the soil surface reduce runoff and improve infiltration into the root zone. Populations of earthworms have been observed to be 6–9 times higher in established grasslands compared to cultivated soils.

Soils in long-term grass also show improved mechanical properties (for example, an increase in the moisture content at the lower plastic limit) that allow traffic and tillage under wetter conditions. Farmers of fine-textured soils tilled after a long period in grass observe that the time periods between when a soil is too wet to till and when it is too dry to till decrease each year after tillage begins. These farmers plan the timing of their tillage operations based on these observations.

Soil aggregates from North American virgin grasslands are more stable than those of cultivated lands. The differences appear to be due to a cultivation-induced loss of particulate organic matter that helps bind small aggregates into larger aggregates. Particulate organic matter consists primarily of partially decomposed residue and roots. This fraction has a higher turnover than other forms of organic matter and requires continual input into the soil. Grasses that form a sod cover are an excellent source of shoot residue and organic matter associated with continual turnover of an abundant fine root system. The superior aggregation qualities of grasslands result from ideal conditions of simultaneous formation and stabilization of macroaggregates found in the grass rhizosphere. Reduced returns of root system organic matter to the soil and rapid biological oxidation of organic matter induced by tillage appear to account for lower organic carbon and nitrogen found to a depth of 18 inches in long-term cultivated soils compared to virgin grasslands (Bauer and Black 1981).

When grasslands are cultivated, organic carbon and nitrogen decline most rapidly during the first 10 yr of cultivation and then decline more gradually depending on the cropping system and climate (Bauer and Black 1981). Soil structure deteriorates even more rapidly, with the greatest rate of destruction occurring in the first 2–3 yr after cultivation of long-term grasslands. The effects of tillage on soil properties after cultivation depend to some extent on soil type. However, all soil types examined (loamy sand to clay) exhibit degraded soil physical properties resulting from tillage. Long-term tillage in these soils resulted in reduced water availability and aeration within the root zone. Soil pores must be a certain size to hold water at suctions where it is available to crops. On a Crowley soil in Arkansas, the number of pores in the proper size range was reduced 14 percent by 12 yr of tillage (Scott and Wood 1989).

A major objective of the CRP is to protect and improve the soil surface with grass cover. The grass cover protects the soil surface from raindrop impact, traps water temporarily in surface microcatchments, and allows the development of cracks and pores that open up the surface, all of which reduces runoff and associated erosion.

Soil Improvement from CRP (Long-Term Grass)

Soil structure improves when cropped land is put back into grass. This is accounted for by the "land use residual" attributed to grass rotations in the development of cropping factors in the Universal Soil Loss Equation. Improved soil properties after grass can result in increased yields. Significant soil structural improvement has been observed in 3–5 yr. However, more time is required for restoration of soil properties to the state found in the virgin soil. Mazurak and Ramig (1962) estimated that the effects of grass in a medium-textured soil in Nebraska reached its maximum benefit after 10–12 yr. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. A review by Kay (1990) of the effects of grass on the rates of improvement of soil structural stability indicates that significant improvements will continue for at least 10 yr. Improvements are likely to continue after this time period but at a slower rate.

Management of grass influences the benefits of grasses on soil properties. Haying grassland slows the rate of change in soil structure (Mazurak and Ramig 1962). If a legume such as alfalfa is used in the grass mix, haying reduces most of the benefits of alfalfa to the soil nitrogen pool (Haas et al. 1976). Although haying slows the effects of alfalfa and grass on soil structure, improvement continues as shown by increased organic matter and aggregate stability for at least 5 yr.

The degree of soil improvement from 10 yr of grass is likely to be soil and site dependent. As a general rule of thumb, the greater the amount of soil structural deterioration from past cultural practices, the more likely that grass management will effect an improvement in agronomically important soil characteristics. Rasiah and Kay (1994) found that if soils had higher levels of organic matter and other stabilizing materials at the time of grass introduction, the time required for soil structural regeneration was reduced. Soils in CRP generally fit into the category of degraded soils lower in organic matter than surrounding soils, since they were primarily allowed into the program based on their highly erodible classification. Highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and a less-than-ideal environment for root growth (Lindstrom et al. 1992). Soils that tend to be less stable and have less-well-defined soil structure such as sandy loams or compacted clay soils may also benefit from the organic matter inputs of 10 yr of grass. Soils with past deterioration or less-than-ideal physical characteristics are likely to be poorly buffered from tillage-induced changes and are most likely to rapidly lose improvements derived from the CRP when tilled. The surface of these less-than-ideal soils is also more likely to seal following tillage, reducing infiltration and increasing water runoff and soil erosion. A critical question for managers of post-CRP land returned to crop production is how the advantages gained from 10 yr of grass production can be maintained or prolonged.

Although the degradation of structure of soils taken out of sod and tilled is well documented, less is known about the effects of no-till cropping on lands previously in sod. Presumably the rate of decline would not be as great for soils in a no-till practice, since reduction of or abstinence from tillage reduces disturbance of the structure and reduces the rate of biological oxidation of the organic matter.

Post-CRP Options

If funding could be obtained, the best approach environmentally for highly erodible CRP lands would probably be to extend the contracts. This would allow the soils in the program to continue to improve and would keep erosion under control. Another proposal is to subsidize a rotation program that involves 4 yr in grass production followed by 4 yr in grain production. Still another proposal is to lower CRP payments to keep the lands in grass but allow grazing or haying on these lands. The latter proposal has met considerable opposition by farmers who have land already in hay production and who object to subsidized hay production that would compete unfairly with their product. The soundness of their arguments has been acknowledged by administrators and legislators. Consequently, it is unlikely that haying and grazing will be allowed on lands on which CRP payments are being made except in emergencies.

Farmers who choose to use their post-CRP land for haying or grazing operations will have to pay their own way. In some parts of the country such haying and grazing operations on these lands could be economically viable if current hay prices could be sustained. However, demand for hay is declining as red meat consumption declines, local hay markets are limited, transport costs of hay are high, and major increases in hay production may occur after the CRP program is over. The reduced demand and increased supply are likely to result in depressed prices and little profit for the farmer.

Another market that may develop for dry grass is its use as a fuel for power plants. Initial results from studies funded by the Department of Energy are encouraging and indicate that prices in the range of $40–50/ton could be paid for dry hay used for this purpose. However, construction of the power plants and development of this market would take at least 10 yr, so this market will not be available to many, if any, of the farmers at the time when their land comes out of the CRP.

Before deciding what to do with their post-CRP land, individual farmers should evaluate existing and developing markets in their area. Existing commodity support payments will help protect farmers from decreasing prices for their products on the supported crops for which they have base acreage allotments. However, the long-term provisions of GATT will reduce those supports.

The following is a list of possible options for the farmer:

I. *Maintain grass cover on the land.*

a. Produce hay. Use management designed to avoid disturbance of nesting birds (for example, delay the first cutting until danger of disrupting nesting birds is past).

b. Graze animals on the land. Rotate grazing areas to minimize disruption of nesting birds and grass deterioration.

c. Manage the land to preserve wildlife. This could include development of fee hunting preserves, etc., and might be combined with some of the other options where provision of improved wildlife habitat is designed as part of the conservation plan.

d. Extend the CRP contract, if possible.

II. *Return the land to cropping.*

a. Use no-till practices (low-disturbance systems). Plant into dead sod, and use appropriate rotation systems to manage weeds, pests, and fertility without a dramatic increase in purchased inputs. Maintain surface residue and soil structure.

b. Use a wide V-blade sweep to undercut sod. Then use no-till or minimum-till methods of planting and crop production.

c. Use a moldboard or chisel plow prior to a no-till system. After plowing disrupts and buries a major part of the initial residue, no-till will maintain residue of subsequent crops on the surface.

d. Use conservation tillage. If the land has been designated as highly erodible, the tillage system and rotation must be modified to fit the conservation plan developed for conservation compliance.

e. Create a meadow and rotate it with crops. Plant grass, legumes, or a mixture of the two as a meadow. Rotate each field between crops and meadow to reduce average annual erosion rates.

For most of the CRP lands where contracts cannot be renewed, no-till management appears to provide the greatest potential for achieving reasonable net returns while retaining most of the soil quality improvements achieved during the CRP. The section that follows further describes how CRP lands can be cost-effectively transitioned to economically and environmentally sustainable production systems.

No-Till After CRP

Cropping practices that avoid tillage have the advantage of avoiding the rapid mineralization of carbon and nitrogen that occurs when grass or crop residues are mixed with the soil by tillage. Reicosky and Lindstrom (1993) measured successively higher rates of carbon dioxide from wheat stubble plots subjected to no-till, disking, chisel plowing, and moldboard plowing. They found that the carbon loss in 19 days after moldboard plowing was greater than the carbon contained in the stems, leaves, chaff, and roots of the previous wheat crop. Oxidation rate of organic matter from the no-till area was about 15 percent of that from the moldboard plowed area. Lamb et al. (1985) measured soil organic nitrogen losses in the top 12 inches of a soil that had been in native grass and was then cropped to winter wheat for 12 yr in a wheat-fallow system. Nitrogen loss, expressed as a percentage of the nitrogen in the native grass soil, was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for plowed (black fallow).

Evaluation of organic carbon and nitrogen levels after 10 yr of no-till or conventionally tilled corn production in a Kentucky soil that had previously been in bluegrass sod showed approximately twice the carbon and nitrogen amounts in the surface soil layer of no-till (Blevins et al. 1983).

Following development of improved structure during 10 yr of undisturbed grass, as the transition is made to cropping systems, it is obvious that no-till management, by leaving the soil intact, causes less immediate disruption of the improved structure than conventional tillage. Chan and Mead (1989) measured water-transmitting macropores in a permanent pasture that had been lightly grazed. They found that cultivating to a depth of 4 inches for 4 yr completely disrupted the macropore structure, resulting in increased water runoff by reducing preferential flow within the macropore network and altering the pathway of infiltrated water movement. In contrast, the macropore system remained intact with no-till crop production.

In most cropping situations (no-till or conventional tillage) used after grass, the carbon input from root systems of the new crop will be less than that from the roots of the grass. Consequently, some loss of soil structural stability over time should be expected. The exact extent to which no-till can prolong the benefits of grass sod has not yet been determined. However, no-till systems implemented into tilled fields significantly improve soil surface characteristics when abundant residues are produced. This improvement is likely to lead to better infiltration and reduced erosion. Provision of optimum crop nutrients and the use of cover crops with no-till allows additional residue production and carbon input into the soil. A study in Kentucky found that organic carbon content of a soil that had previously been degraded by tillage was restored to near the same level as that of adjacent long-term bluegrass sod after 20 yr of cropping fertilized no-till corn with a rye winter cover crop (Ismail et al. 1994).

Conversion from conventional-till to no-till management systems has increased soil organic matter content and improved soil structure in soils that are low in organic matter or poorly structured; however, the structural improvements achieved during 3 yr of no-till can be eliminated with one moldboard plowing (Kladivko et al. 1986). These improvements in soil structure with no-till are not obtained immediately. As discussed in chapter 11, several years are often required before significant soil structural improvements can be documented. Soil erosion from either wind or water is reduced with the onset of no-till management simply because crop residues on the soil surface protect the soil from erosive forces. Water runoff is generally reduced when the management is changed from conventional tillage to no-till, but not always.

The CRP lands present many opportunities to initiate no-till in a situation where soil organic matter contents, soil structure, and infiltration rates have already been improved.

In eastern South Dakota on land that had been in an alfalfa-bromegrass sod for 6 yr, Lindstrom et al. (1994) initiated moldboard plow, chisel plow, and no-till corn production systems and obtained similar yields from all systems. In the 4th year of production, immediately after planting, artificial rainfall was applied at a rate of 2.5 inches/hr for 1 hr on each of 2 consecutive days to each management system and on adjacent undisturbed alfalfa-bromegrass sod. No water runoff or soil loss occurred from the areas that were still in the sod or from the areas that had been in no-till corn production. An average of 49 percent of the water applied to the crops in the moldboard plow tillage system and 34 percent of that applied to the crop in the chisel plow tillage systems was lost to runoff. Soil loss from the moldboard plow systems was 11.8 tons/acre and 2.4 tons/acre for the chisel plow systems.

In the northern Corn Belt, conversion to no-till management from conventional-tillage crop production systems has in some cases resulted in at least temporary decreases in infiltration (Lindstrom et al. 1981, Mueller et al. 1984). However, no-till row crop production systems following sod (in the Lindstrom et al. 1984 study) sustained much higher rates of infiltration as compared to the tilled systems following sod. The improvement in organic matter, soil structure, and infiltration that occurred under the 6 yr of brome-alfalfa growth was maintained with no-till into the fourth cropping season with no indication of soil degradation with the continued no-till cropping. The no-till system sustained and promoted soil macropores that extended from the surface to deep within the root zone and that were open to the atmosphere and protected by residue cover. These macropores resulted in high infiltration rates, reduced runoff, and subsequently reduced soil loss.

Sorghum yields in the panhandle of Texas in 1993 were much higher for a no-till crop after grass sod than they were for sorghum on soil prepared by moldboard plowing of the same grass sod (Unger, personal communication 1994). Yields under chisel plowing were intermediate. The primary factor responsible for increased yield under no-till was increased water-use efficiency. The no-till production system had no runoff and less soil water loss early in the growing season from evaporation and did not suffer as severely from water deficit at the critical period of flowering and grain fill as did the tilled treatments. A similar study in Colorado (Anderson, personal communications 1994) resulted in lower yields with no-till wheat production compared to where one undercutting tillage pass was used to help kill the grass. This reduced yield under no-till was associated with poor chemical control of the grass species resulting from the grass being under moisture stress when the herbicides were applied. The extreme competition for water in these semiarid areas emphasizes the importance of obtaining a good kill of the grass.

Two of the primary prerequisites for achieving a cost-effective no-till system following a CRP grass crop are to completely kill the grass and to allow sufficient water in the soil to accumulate for germination and sustenance of the new crop. If the new crop is to be planted in the spring, the grass must be killed in the previous fall or sooner depending on when dormancy occurs in the grass (Smith et al. 1992). Systemic herbicides can be used to obtain a good kill of the grass after the grass has been cut and begins vigorous regrowth. However, if the grass is dormant or under stress such as may occur in regions where water is limiting in the summer and fall, then a systemic herbicide will give poor control. In these situations the grass must be killed by tillage or by earlier application of the herbicide before water stress induces dormancy.

In situations where cool- and warm-season grass species are growing together in the CRP land, two applications of a systemic herbicide may be needed to avoid dormant periods of the different grasses.

Recognizing the need of farmers growing winter wheat to plant in the fall and the need for some land preparation before the wheat is seeded, the current rules of the CRP contracts allow farmers to begin such preparation, including tillage up to 3 mo prior to the October 1 release of such lands. If tillage (which buries the residues and disrupts and displaces the sod fabric) takes place, it will expose the soil to erosion and promote rapid decreases in organic matter and infiltration. However, if the needed killing of the grass is accomplished with an herbicide, the grass residues and sod will remain in place and protect the soil from erosion during the period when the soil is accumulating the water needed to germinate the seed and facilitate the growth of the following crop. Many studies have shown that the slowly decaying residues and sod will keep infiltration rates high and control erosion for at least a year following killing of the grass.

Farmers establishing a no-till winter crop in arid regions may need to apply herbicides even earlier than 3 mo prior to October 1. As discussed earlier, the first application is likely to be needed before the grass becomes water stressed. As long as the residues of the dead grass are left on the surface, this process should meet the objectives of the CRP contract, which require the grower to maintain a protective cover on the soil and maintain production capability of the soil. However, CRP rulemakers have not yet, at this writing, granted permission for such an early application, and therefore this transition may not be possible in the more arid regions of the Great Plains without losing a year of production. Producers should check with their local Natural Resources Conservation Service (NRCS) office to obtain the most recent information on when herbicides can be used on CRP acres during the last year of the contract.

One challenge that may occur when planting on no-till CRP land is how to deal with established burrowing animals and the damage that they may have caused during the 10-yr period of grass. They may leave the soil surface quite rough (Kalisz and Stone 1984). The tendency would be to moldboard plow the area before starting no-till. In extreme situations this may be required. However, normally tillage is not needed. Once the grass is killed and a crop has been planted, the food source is removed, the animals disappear, and the mounds tend to level within the year.

Nitrogen management on no-tilled former CRP lands also needs special attention because of changes in nitrogen mineralization patterns (Wood et al. 1991a, 1991b; Lamb et al. 1985). As tillage is imposed on sod, a flush of microbial oxidation and mineralization of organic nitrogen may occur. As tillage intensity is reduced, microbial oxidation of organic matter decreases and more of the organic nitrogen is retained in the soil organic matter. Soil testing is critical and the subsequent soil fertility recommendation must take into account the effects of the 10-yr period of grass and lack of a primary tillage operation. No-till into sod will initially require higher nitrogen rates than if the field was moldboard plowed (Thomas et al. 1973) because the plowing accelerates the biological decomposition of the organic matter and mineralization of its nitrogen.

Design of No-Till Systems

No-till systems must be designed according to the unique conditions of the region and the specific needs of the individual producer. Therefore it is not possible to design a no-till management system that can be applied at all locations across the United States or even within a single region. A successful no-till system must be developed from a whole-system point of view. Three things that need to be considered when designing a no-till system are rotation, sanitation, and competition to help control weeds, insects, and pathogens (Beck and Doerr 1990). Although the specific cultural practices required for each region and farm are likely to vary depending on climate, crop, and local markets, these three broad-based principles are common to the successful establishment of no-till crops. Other chapters in this publication provide additional details on how to adapt no-till and other types of crop residue management to specific soil, climate, and crop situations.

Sanitation involves practices that reduce the movement and spread of pests (weeds, diseases, insects) into a field. An example is the prevention of perennials from producing seed in the field borders by mowing. Another is the use of disease-free seed. The importance of following sanitation practices is more critical in no-till systems because they don't involve tillage (a practice that can help reduce population levels of some pests).

Rotation is especially critical to a properly designed no-till system. Rotation can be beneficial in controlling weeds, disease, and insects by breaking life cycles that are dependent on compatible crops or by increasing the competitive pressure on a pest during a part of the rotation. The use of rotations in no-till generally helps create a stable, low-maintenance cropping system. The design of rotations should optimize the cropping sequence to control diseases, weeds, and insects and to provide adequate soil temperature at planting, seed zone moisture content, residue cover for erosion control, and labor and equipment utilization.

As a field comes out of grass sod and into crop production, the rotation principle can be applied immediately by choosing a broadleaf species (that is, soybeans, peas, lentils, or flax) as the first crop. These crops will not generally succumb to or be a host for diseases that may have infected the grasses and will make weeds, including escaped grass, easier to control than if a small-grain crop was grown. An additional benefit associated with the use of legumes as a first crop is that their growth will not be appreciably restricted if the rapidly decaying grass depletes the soil nitrate supply.

Competition involves the ability of the crop to outcompete weeds for light, water, and nutrients. An example of favoring a crop in such competition is the use of narrow row spacing to achieve earlier crop canopy cover. Cover crops may also be used in the more humid regions of the United States to compete with weeds, add nitrogen, and protect the soil during periods when cash crops are not growing.

Other aspects that should be included in the design of a no-till system include equipment use, livestock needs, personal preferences of the producer, cash flow requirements, market availability, predictable climatic patterns, proximity of the water table to the surface, soil fertility, and risk management. Planners of no-till should study management practices and equipment that are adapted to the region, and they must develop practices and modify equipment to adapt to the unique characteristics of their individual sites.

Conservation Measures for Residue-Deficient Crops

When some of the primary cash crops suited to the area are residue-deficient crops such as peas or lentils and when wind erosion potential is the cause of the highly erodible land designation, there may not be sufficient residue during the year following the cash crop to provide the mandated erosion control. Grass hedges, which reduce wind velocity at the soil surface (Aase and Siddoway 1976) and trap stray soil particles that have been mobilized by the wind, can often complement conservation tillage to achieve the needed erosion control. To be most effective the grass in these hedges should be stiff stemmed and tall because the downwind distance to which they cause significant reductions in wind velocity is limited to about ten times their height. In the few cases where the grass planted into the CRP lands has tall and stiff stems (for example, switch grass or tall wheat grass), the needed hedges can be achieved by leaving living strips of grass 2- or 3-ft wide between strips of planned, cropped area having widths of about 10 times the height of the grass.

If grass on the CRP land is not sufficiently stiff and tall enough to provide the needed reduction in wind velocity, CRP rules allow improvements of the cover during the contract period. Since most perennial grass species require about 2 yr to reach maximum stature and get their roots below those of annual crops, rows of tall grass for hedges will be better prepared to thrive and to protect the cropped area if they are planted a year or two before crops will be planted. This can be accomplished by killing the grass strips within the CRP land with herbicides and planting these strips with the desired tall, stiff-stemmed grasses. When these hedges have reached the desired height and the CRP contract rules allow killing the grass in preparation for planting the crop, the short grasses in the planned crop strips between the hedges can be killed. To avoid the potential for being considered in violation of CRP rules, discuss your plans for installing tall grass hedges in CRP lands with your NRCS District Conservationist before killing the strips of short grass during the CRP period.

Costs of this additional improvement of CRP lands to provide tall grass hedges for erosion control of subsequent crop lands cannot be shared by the CRP. However, since less than 10 percent of the area is in the grass hedges, the cost for herbicide and seed is small.

Grass hedges can also help control water-induced erosion when they are oriented across hillsides, rills, and ephemeral gulleys. Where concentrated runoff meets the hedge, aggregates and coarse sediments settle upstream from the hedge as the water forms ponds (Dabney et al. 1993). The gathering sediments form deltas. Evidence of the effectiveness of grass strips for causing delta formation may be found where long-standing fences or property lines cross low areas and cause runoff deposits to accumulate. If the grass strips are sufficiently persistent and stiff to pond the runoff water, deltas develop on the upstream side of these grass strips; a drop of up to several feet (of elevation) can occur across the grass strip (Kemper et al. 1992). Use of stiff-stemmed species in grass strips where they cross concentrated flow paths can reinforce their ability to retard and disperse runoff and decrease erosion. Interim standards for using grass hedges to help control erosion are under development by NRCS and ARS.

While game birds have been observed nesting and overwintering in tall grass hedges in Idaho, there has been no systematic evaluation of the effects of these hedges on bird populations.

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11 National Perspectives on Long-Term Effects of Tillage and Crop Residue Management

W.C. Moldenhauer, W.D. Kemper, and R.I. Papendick

The Beginnings of Soil Degradation

When Europeans arrived in America, they found soils that were a result of climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed, also contributing to building the organic matter and associated elements that nurtured the natural successions of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots. These bacteria were able to take nitrogen out of the air, fix it into ammonium, and share it with their host plants. Primarily as a result of these legumes, about 10 percent of the residual organic matter in soils is nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter. While most of the native Americans were crop growers, they were few in number. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand.

Friendly natives taught the newly arrived Europeans how to grow corn in the early part of the 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than the natives. Within a few years corn was the staple of their diet, and they were growing enough corn to trade it for animal furs. Arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the breakdown of the residual organic matter, liberating its nutrients for use by the crops. Since there were no commercial fertilizers, this accelerated decomposition of organic matter was the primary source of plant nutrients in those early years. The moldboard plow which turned the soil over completely, burying practically all of the crop residue, became the most popular implement for primary tillage.

Complete burial of the crop residue exposed soils to the beating action of raindrops, which destroyed soil aggregates, filled the large pores, and reduced infiltration, causing runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern portions of the country where rainfall rates were high. In the more arid western Plains, burial of plant residues and subsequent beating from rain created smooth surfaces along which the wind blew loose sand grains until they literally sandblasted the soil, enabling the wind to blow away major portions of our topsoils.

Early in the 20th century concerned farmers and government officials recognized the rapid degradation of our soils from erosion and initiated research and plans to reduce erosion. In the 1920's and 1930's, rotations, strip cropping, and mulch tillage were evaluated. These techniques involved blades that sliced under the surface and killed weeds but left most of the wheat stubble on the surface. They obviously helped reduce wind and water erosion. It took longer to observe their effects on soil organic matter content and fertility. Long-term studies were initiated at several locations across the country. At Urbana, IL, the Morrow plots were established in 1876 to determine long-term effects of various kinds of cropping. They indicate that the soil organic matter level was about 6.4 percent when European Americans began tilling them. Continuous corn, involving plowing each year, reduced the organic matter content to less than 3 percent (fig. 5). The best rotations reduced the rate of organic matter depletion, and legumes in those rotations helped maintain soil fertility; however, levels of organic matter still continued to decline as long as plowing continued.

At Pendleton, OR, the organic matter content in soil formed under grass was also reduced under moldboard plowing, accelerating runoff, erosion, and loss of fertility. Consequently, in 1929, researchers began evaluating a series of crop residue management treatments, ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the decline of residual organic matter, and during the first 20 yr the heavy manure addition each year seemed to slightly increase the organic matter content (fig. 6). However, even with 11–12 tons of organic residue plowed into the soil per acre each growing season, residual organic matter content has not increased during the past 40 yr (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields for 19 days after wheat stubble was moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 7, the amount of carbon oxidized was greatest in fields that were moldboard plowed. In 19 days as much carbon was oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue was not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue provided food to generate high microbial populations, which found access to residual organic matter in the plowed and highly aerated soil and oxidized substantial amounts of it out of the soil.

Other types of tillage, resulted in lower biological oxidation rates than moldboard plowing (fig. 7). Their use is helping slow the rate at which residual organic matter is being oxidized out of our soils. However, during the 19-day study, oxidation of organic matter from all of the tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

Development of wide v-blade sweeps, rod weeders, and other equipment that disrupt the soil and undercut weeds while leaving most of the crop residue on the surface helped control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available in the late 1960's and early 1970's, however, it was no longer necessary to till soils and oxidize organic matter to release needed nutrients. Development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control resulting from leaving residues on the surface, they used these alternatives and reduced tillage. Some of them reasoned that growth of grain crops was now possible in systems more similar to those in natural ecosystems where there is no tillage.

In these natural systems when vegetative growth is good and burning does not occur, the soils generally have continuous cover and protection from the forces of wind and water. The major obstacle remaining was getting seed through the surface residues and into the soil. Equipment companies helped develop coulters, seed placement devices, and press wheels that cut through the residues without disturbing them appreciably and pressed seed into good contact with the soil. Development of no-till drills and seeders provided an alternative to seedbed preparation, the other major purpose of tillage. With these alternatives available, thousands of fields were soon managed without tillage.

The erosion control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to less than 20 percent of that occurring under moldboard plowing systems or in many cases eliminated it completely. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, they found that absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Measurements in laboratories show that bonding forces between soil particles decrease with tillage and increase with time following tillage. Root fabric and the high residual organic matter content that develops in the immediate surface under no-till reduce slaking and disintegration of aggregates when they are wetted.

In the past, scientists felt that incorporating crop residues into the soil was the way to get organic matter into the soils where it could become part of the residual organic matter. Reicosky and Lindstrom (1993) showed this intuitive feeling was wrong. In fact, incorporating crops residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and the residual organic matter, as discussed previously.

Farmers practicing no-till management are noticing their soils becoming darker. In Ohio, Georgia, Alabama, and Colorado measurements showed residual organic matter in no-till soils to be increasing. Wood and Edwards (1992) showed that this increase is greatest in the surface 2 inches (fig. 8), the layer most important for reducing slaking and surface sealing.

Edwards et al. (1988) showed that when tillage is eliminated for 10 or 20 years, the residual organic matter of the top inch of soil can increase to over 10 percent. However, they observed little change below 3 inches. Wood and Edwards (1992) compared conventional tillage to a system that eliminated all tillage except for a light disking prior to seeding through corn (which allowed them to use a standard planter). Minor tillage such as light disking (used by Wood and Edwards 1992) not only mixes the organic matter deeper into the soil but also causes more rapid oxidation of the organic matter.

On the basis of extensive studies of soil water contents under different tillage systems, George Langdale and Bill Edwards have both concluded (personal communication 1994) that organic matter in the top inch of soil is strategically positioned to cause more reduction in evaporation and increase in infiltration than when it is mixed by tillage through the top 8 or 10 inches of soil. Consequently, they believe that leaving residue on the soil surface strongly contributes to long-term increases in productivity, such as those observed by Ismail et al. (1994) (fig. 11).

Effects of Increasing Surface Residues on Residual Organic Matter

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate increases ranging from 200 to 1,500 lb/acre/yr. These rates depend on how much crop residue is left on the surface. The highest rates occur where crop residues were augmented with winter cover crops left on the surface (for example, Langdale et al. 1992). The lower rates were from dry, warm regions where the amount of crop residues was limited and biological oxidation of the organic matter was relatively rapid.

In areas where residual soil organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases result from leaving the organic wastes on the surface (Lu et al. 1994a, 1994b).

Reduction of tillage increases the amounts of organic residues on soil surfaces, decreases the biological oxidation rates of residual organic matter, and reduces soil erosion, all of which cause net increases in residual soil organic matter. No-tillage and reduced tillage not only can conserve our soils, they can also enhance them so that they will be able to sustain the world's growing population.

Effects of Leaving Crop Residue on the Surface

On Soil Fertility, pH, and Rooting Depth

One early concern about no-tillage was getting fertilizer and lime from the surface down to the crop roots. To some extent feeder roots solved this problem by coming nearer to the surface where the soil was moister because crop residues reduced evaporation.

Phosphorus particularly was expected to be a problem because it is normally tightly adsorbed and relatively immobile in soils. However, as Kunishi et al. (1986) found, it apparently forms complexes with organic matter when left on surface residues that leach into the underlying soil where they are readily available to feeder roots. Through mycorrhiza—the beneficial association of fungal mycelium with the roots of a plant—fungi extend their slim hyphae into the soil and allow plants to draw phosphate from those parts of the soil their roots cannot directly reach. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow root channels of the previous crop; this enables the supplemental hyphal system to tie in more quickly, which helps the roots extract water, phosphorus, zinc, and many other elements from the soil (Vivekanandan and Fixin 1991).

For years researchers have recognized the importance of getting more calcium into subsoils and raising subsoil pH. Doing so promotes deeper root systems. Deep plowing and mixing of lime into subsoil has been effective but is too expensive. Calcium has historically been observed to stay close to where the lime was placed in soils, and it has always been a concern that lime applied on the surface stayed primarily in the surface tilled layer, leaving the underlying soils excessively acid and inhospitable to roots of many crops. Some early no-till studies, however, found that the immediate surface of no-till soils was becoming acid sooner when lime was applied on the surface than when equal amounts of lime were mixed through the plow layer. Other studies show that the lime is more mobile in no-till soils than we once thought. In long-term no-till fields on which lime, crop residues, manure, and nitrogen fertilizer have been applied on the surface and not incorporated for 24 yr, acidity of underlying soils has been appreciably neutralized to a depth of about 70 cm (fig. 9). In contrast, in plowed soils the lime affected pH to a depth of about 25 cm.

The mechanisms by which the calcium in the lime is mobilized in no-till soils probably involves concentration of the crop residues, nitrogen fertilizer, and lime at the surface. As ammonium fertilizers are nitrified by microorganisms to nitrates, acid hydrogen ions are produced, and these ions tend to solubilize the calcium in lime when it is close to the fertilizer. The slow and relatively continuous biological breakdown of the residues on the surface produces a continuous source of organic anions. These organic anions, along with the nitrate, act as companions to the positively charged calcium, aluminum, and hydrogen ions in the soil and facilitate downward leaching of these positively charged ions.

Sumner (as reported in Shainberg et al. 1989) applied gypsum to the surface of alfalfa plots without disturbing the soil and was able to increase alfalfa rooting depths in acid soils by 50 percent by getting calcium into acid subsoils. Wang et al. (1986) found that earthworm burrows in the soil facilitated deeper rooting of soybeans. Since long-term no-till management generally increases earthworm populations and depth of calcium penetration, these two factors are probably acting together to facilitate deeper rooting. Deeper rooting provides the plants with access to more soil water, which may account for increased drought tolerance of crops grown under long-term no-till management on fields that initially had acid subsoils.

On Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is improving the water-use efficiency of acid and calcareous soils. In many areas the increases in infiltration rate and decreases in evaporation occur within a year or two, as discussed in previous chapters. However, in soils where earthworm populations were decimated by intense cultivation or harmful pesticides it may take many years to bring their numbers back so their burrows to the surface contribute significantly to infiltration.

In a series of small watersheds near Coshocton, OH, it took earthworms 6 or 7 yr to return in large numbers after beginning no-till management (fig. 10). Results were obtained based on measurements of pores larger than 0.5 mm at the soil surface; earthworms and recent cultivation are commonly responsible for such large pores. Following cessation of cultivation, the percentage of the surface covered by these large pores declined for 5 yr. These large pores, which contributed to rapid entry of water in this soil, returned only when the earthworms returned in large numbers.

Return of worms has been hastened by collecting buckets of them from lawns and edges of rural roads during or immediately following rains and depositing them in groups of four or five in new no-till fields. They will invade a soil at a rate of about 50 ft/yr when conditions are good for their growth. However, their lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them.

Consequently, they are attracted to moist soils where they can quickly rub off the urea and ammonium and to the surface during rainfall events where the rain washes them off. Their tendency to come to the surface during rainfall events contributes to their migration during runoff events, when they float downhill. On cloudy days when canopy cover was reasonably complete and at night, earthworms have been seen floating in tailwater out of furrow-irrigated fields in Idaho at rates of up to 50/hr/furrow. In runoff plots (945 ft^2 each) at Kingdom City, MO, as many as 900 earthworms washed off a single plot in a single rainfall event. While average rates of downstream transfer are generally lower than those given in these examples, introducing worms on the higher portions of fields can significantly increase their rate of return to the whole field.

As soon as crop residues provide cover for most of the surface for a significant part of the year, they help reduce evaporation from the soil. Long-term no-till practitioners report that the amount of crop residue returned to the field increases with time for 10 or more years as crop yields increase. However, some long-term no-tillers note that large populations of night-crawler-type earthworms collect residues in their middens, especially after soybeans, causing a more-rapid-than-normal removal of cover from the soil. Fortunately, this process does not usually bare the soil until the canopy of the succeeding crop has begun protecting the soil from the impact of raindrops. Even when lack of cover allows a major portion of the soil surface to seal, several earthworm middens or holes per square yard drain most water accumulating on the surface into the soil, minimizing runoff.

In the more arid regions of the Great Plains, most of the soils do not remain wet enough to sustain significant populations of earthworms without irrigation.

Another long-term effect of refraining from tillage is the increase in water-holding capacity resulting from the accumulation of residual soil organic matter. Recent analyses by Hudson (1994) have shown that in loam soils the available water-holding capacity of the soil is increased by almost 4 percent of the soil volume by each additional percent of residual organic matter in the soil. For farmers that have topsoils with low organic matter and low water-holding capacities in the 10–12 percent range, this gives them the potential of increasing those capacities up to 14–16 percent in 20 yr. If the organic matter buildup and increased water-holding capacity is restricted to the top 6 inches of soil, this 6-inch layer will hold an extra quarter inch of water each time the soil dries out and is refilled by rain. Most of the crop's feeder roots are in this 6-inch layer, and these roots will be provided with better access to nutrients as well as water during drought-stress periods.

Raising organic matter levels in soils is a long-term process. Generally, accumulation occurs at a rate of about 1,000 lb/yr/acre under good no-till management, so it takes about 20 yr to increase the organic matter content of the top 6 inches of soil by 1 percent. In soils such as those in the Morrow plots in Illinois, which initially had organic matter contents of about 6.4 percent and are now down to 3 percent (fig. 5), it could take most of a century of good no-till production to bring their organic matter back to initial levels.

On Crop Production

Factors that increase the units of crop produced per unit of precipitation include significant increases in infiltration, decreases in evaporation from soils, increased water-holding capacity, increased snow catch and deeper rooting associated with no-tillage, and retention of surface residues for extended periods.

Long-term trends in corn yield under no-till (for example, fig. 11) indicate that the benefits to production derived from long-term no-till are substantial.

Higher residual organic matter contents in soil also increase the general fertility and productive capacity of soils. The organic matter acts as a "bank" into which nutrients may be deposited in times of surplus and withdrawn in times when rainfall or irrigation leaches out most of the soluble and mobile nutrients, especially nitrates. Prolonged nitrogen deficiency can be alleviated with fertilizer nitrogen. Temporary nitrate deficiencies will not reduce crop growth nearly as much in soils with high organic matter content where microorganisms are slowly and continually making nitrogen available "from the bank."

Residual organic matter, which is derived from plants, includes most of the elements essential for crop production, and its slow decay provides a limited but continuing source of these elements. Slow decomposition of this organic matter also furnishes a host of organic molecules or fragments that act as carriers, enabling micronutrients absorbed in the soil minerals to reach the roots. Unlike no-till, tillage accelerates the rate at which nutrients from crop residues and residual soil organic matter are mineralized or made available to crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop root zone by rain. Like stirring the coals, putting in kindling, and opening the draft of a wood stove, tillage accelerates the oxidation of organic matter, liberating its components quickly to the surrounding environment.

Organic matter also darkens soils. They appear dark because they are absorbing more of the sun's radiation, and soils that absorb more of the sun's radiation are warmer. However, because light-colored crop residues reflect more of the radiation and insulate the cold soil from the warmer spring air, covered soils usually stay cooler, which decreases plant growth in the cool early spring but may be better for crops in the late spring or early summer if temperatures rise too high.

If there is good evidence that warmer soil temperatures in the early spring will increase yields, farmers can mount equipment on their tool bars to move residue off seed rows before or at planting time. Removal of the residue from the rows can also enable conventional seeding equipment to achieve good stands, which can allow the farmer to delay purchase of no-till seeders until old equipment is wornout.

On Erosion Control

Residue cover achieves erosion control by (1) intercepting the impact of raindrops, slowing surface sealing, and sustaining higher infiltration; (2) causing water to pond on the surface, which causes wormholes and other macropores to become avenues for infiltration; (3) causing sediment to settle in the temporarily ponded water; and (4) hindering wind shear from reaching the soil surface and detaching particles. Refraining from tillage allows long-term mineralogical processes to strengthen soil with time, in a way similar to the processes that strengthen moist concrete. Strengthened soils are more resistant to movement by wind or water and are also better able to bear tractors and other essential traffic without as much compaction and associated disintegration of the large pores that are effective in maintaining high infiltration rates in soils. On the other hand, if roots, earthworms, and other biotic agents are not creating large pores in untilled soils, they become crusts or hard pans that hinder infiltration and drainage of water and limit the extent of succeeding generations of roots. Residues on the surface and winter cover crops increase populations of these macropore makers. Refraining from tillage helps keep those macropores intact.

Reasons for Limited Tillage

Legitimate arguments for performing some tillage include the following:

- In some cases the cost of a nutrient form, such as the anhydrous form of ammonia, is sufficiently lower than the cost of other sources of nitrogen to economically justify the limited cultivation needed to apply the ammonia.

- Deep chiseling or paratilling in some areas can benefit yields by disrupting restrictive soil layers and allowing plant roots to access more water.

- As mentioned, ridge- or row-till equipment can push residues off the planting strip for row crops, allowing the use of conventional planting equipment and warming the soil to accelerate early growth.

- In some special soils and when insufficient or very low amounts of crop residue are present, shallow tillage to a depth of 2–3 inches can break the capillary pore connections between the soil water and the surface. This operation saves stored water if performed before long, dry, hot summer fallow periods.

- During the initial 2 or 3 yr of no-till, before sufficient soil cohesion has developed to support equipment weight, the soil may become so compacted and rutted during harvest in wet weather that tillage is necessary to22 break up the compaction and smooth the surface.

- Existing regulations in some states or regions require burial of specific wastes and crop residues for control of insects and diseases.

Each farmer must balance these arguments for cultivation against the damage that tillage does in reducing residual organic matter and reversing the benefits of crop residue management. One of the most critical factors that needs to be ėxamined is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control as computed by Soil Conservation Service (now the Natural Resources Conservation Service, NRCS) guidelines and equations. The economic consequences of failing to be in conservation compliance will be devastating for most farmers enrolled in government programs. Consultation with NRCS technicians may help farmers avoid both the loss of erosion control and crop support payments.

Farmers considering the use of tillage should generally try to avoid conventional moldboard plowing, which buries almost all of the crop residues. This form of tillage is so effective in accelerating biological oxidation that a single plowing can oxidize as much organic matter out of a soil as can be accumulated by 5–10 yr of high-residue no-till management. Other types of tillage that result in slower rates of biological oxidation of organic matter should be used if possible.

Environmental Effects of Herbicides Used in Reduced-Tillage Systems

Concern has been expressed in some public sectors that long-term use of herbicides for weed control rather than tillage will add manufactured chemicals to our soil, air, and water, thereby degrading them. A broad survey by Bull et al. (1993) indicates that producers who grow corn use about equal amounts of herbicides whether using tillage or no-till systems. Most farmers recognize that herbicides are often the most cost-effective means to control weeds in corn. Bull et al. (1990) also indicated that the 1990 herbicide use on no-till soybeans averaged about 60 percent higher than that on tilled soybeans; however, by 1992 herbicide use on no-till soybeans averaged only about 20 percent more. Long-term no-tillers say they are learning how to use less herbicide than when they started no-till and are often using even less than when they were tilling. Because adoption of no-till has been doubling about every 3 yr and only 25 percent of no-till farmers have 6 yr or more experience with the system, we anticipate that the amounts of herbicides used in no-till farming will continue to decline.

A factor that plays a significant role in herbicide contamination of water is the use of soil-incorporated (preemergence) versus direct-contact(postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. The chemicals that function best as preemergence herbicides are those that are mobile (not adsorbed) in the soil and persist for long periods of time before they degrade. These traits make the premergence herbicides more likely to contaminate water. On the other hand many of the postemergence herbicides, which are becoming the major choice in no-till management, are sprayed directly on the weeds, are strongly adsorbed to the soil if they miss their target, and are rapidly hydrolyzed or biologically degraded when they contact the soil.

Reduced tillage keeps topsoil on the land and out of streambeds, reservoirs, and lakes. By increasing soil infiltration rates, no-till reduces flood damage, and increases groundwater recharge and base stream flows and therefore improves the environment. In some monitored watersheds, where surface sealing from conventional tillage caused 10–30 percent of the precipitation to run off, long-term no-till has reduced runoff to negligible levels.

As water runs off land surfaces, it carries disease organisms, feces from domestic and wild animals, and a host of organic compounds over 99 percent of which are of natural origin and less than 1 percent of which are of manufactured origin. Surface runoff that enters reservoirs is so heavily laden with contaminants that standard rapid filtration cannot remove them all. Chlorination is commonly required to kill the pathogens before water can be used for drinking. However, chlorination of humic acids and natural organic compounds can increase their carcinogenicity. When reduced tillage enables all precipitation to enter the soil, pathogens and other organic compounds filter out as the water percolates slowly down so that the water entering aquifers is generally safe to drink.

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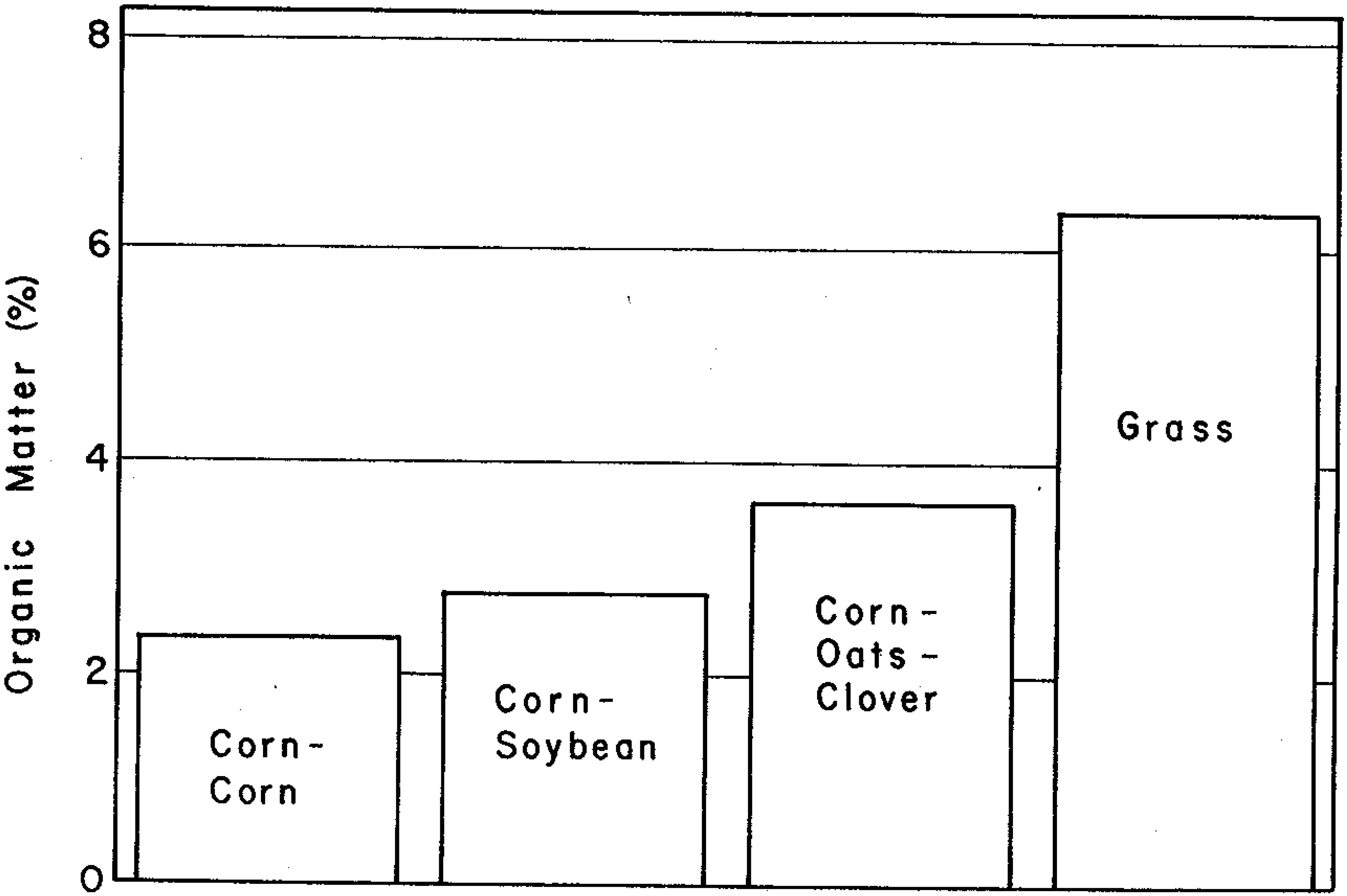

Figure 5. Percentage of organic matter in plowed soils after more than 100 yr in various rotations compared with percentage in untilled soil still in grass. SOURCE: Odell et al. (1984).

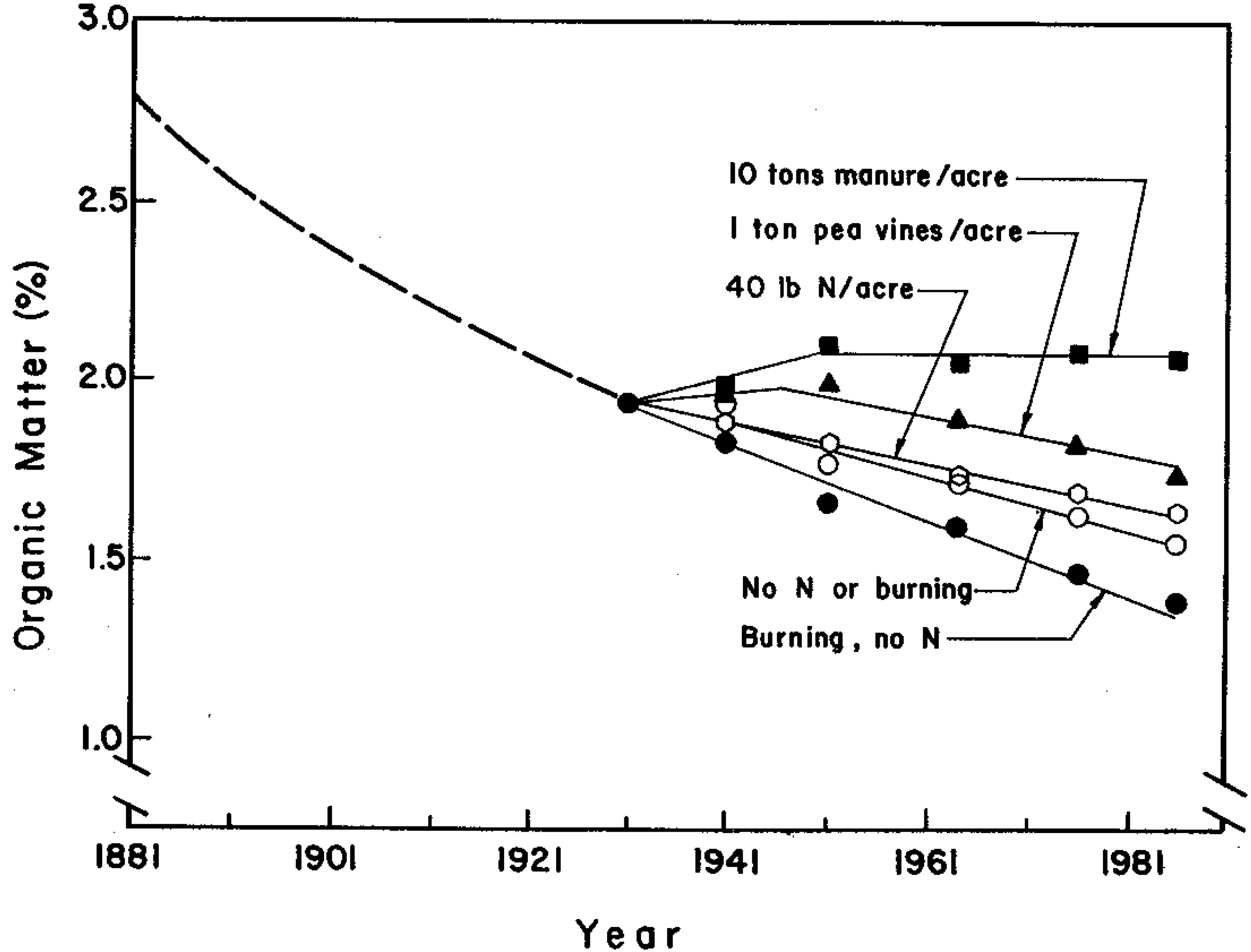

Figure 6. The effect of management practices on long-term changes in organic matter in the top 30 cm of a Haploxeroll soil in Oregon. SOURCE: Rasmussen et al. (1989).

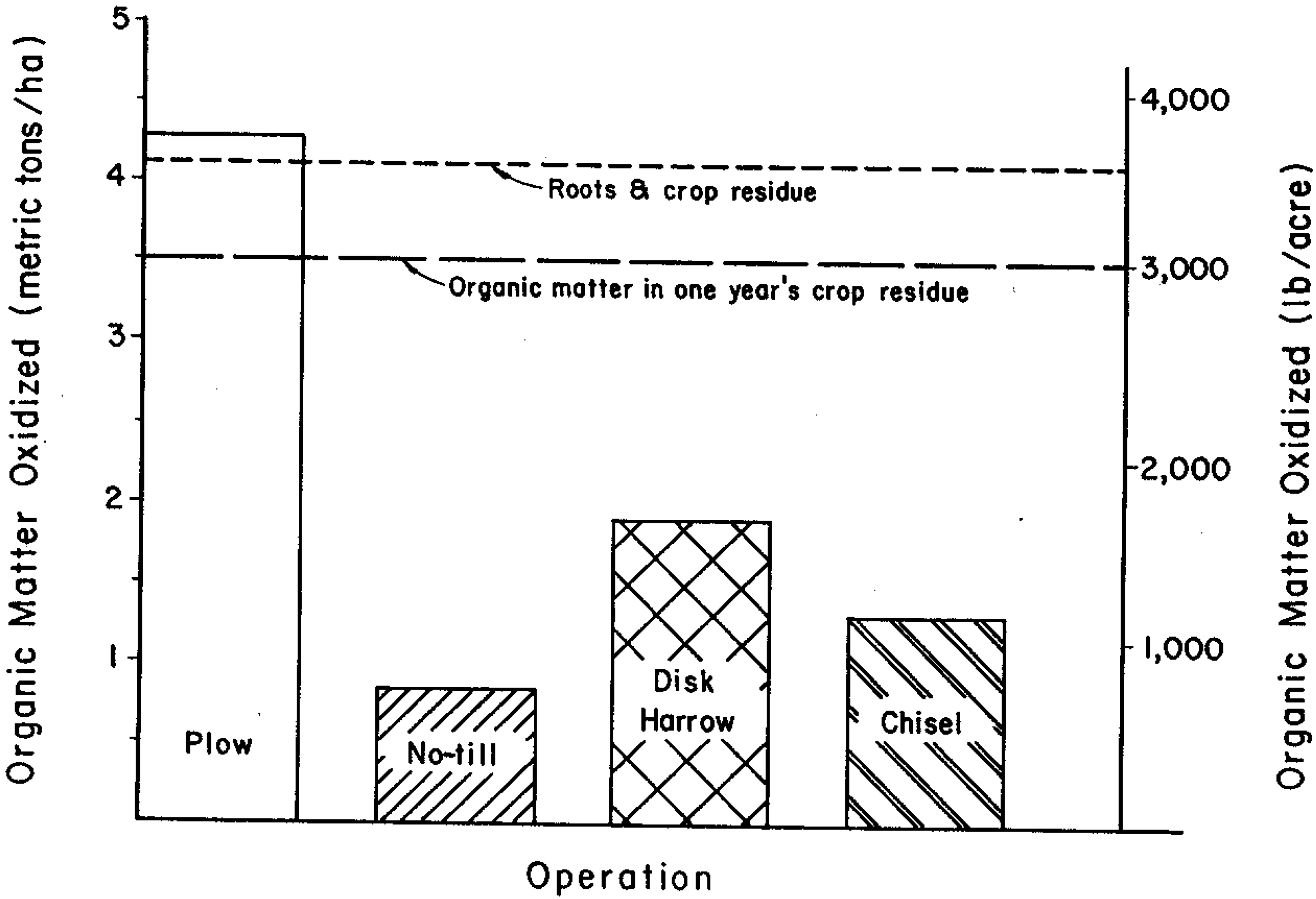

Figure 7. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble in Morris, MN. SOURCE: Reicosky and Lindstrom (1993).

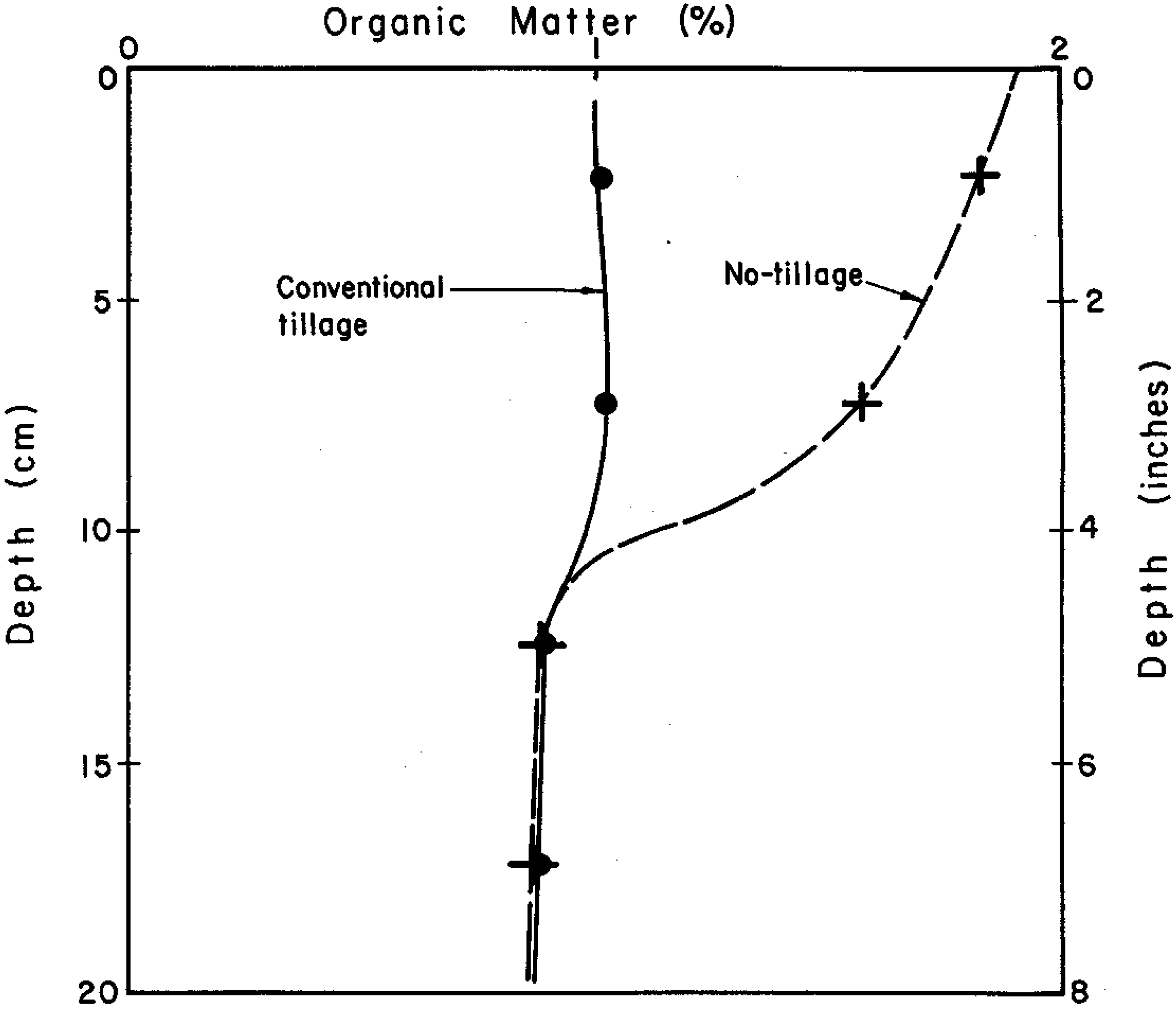

Figure 8. Comparison of organic matter content at various soil depths after 10 yr of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL. SOURCE: Wood and Edwards (1992).

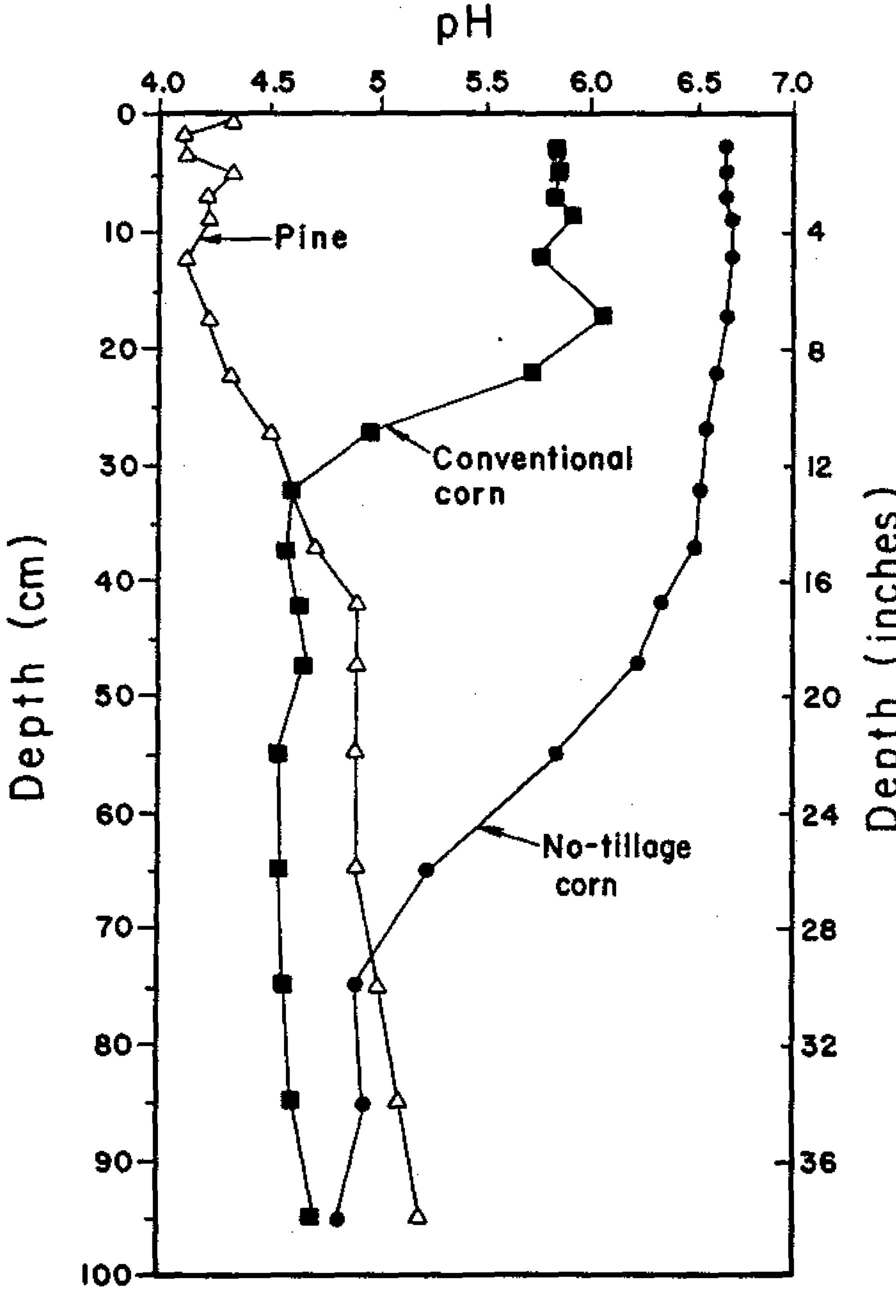

Figure 9. The effect of long-term conventional and no-till management of corn on soil pH at various depths. SOURCE: Edwards et al. (1988).

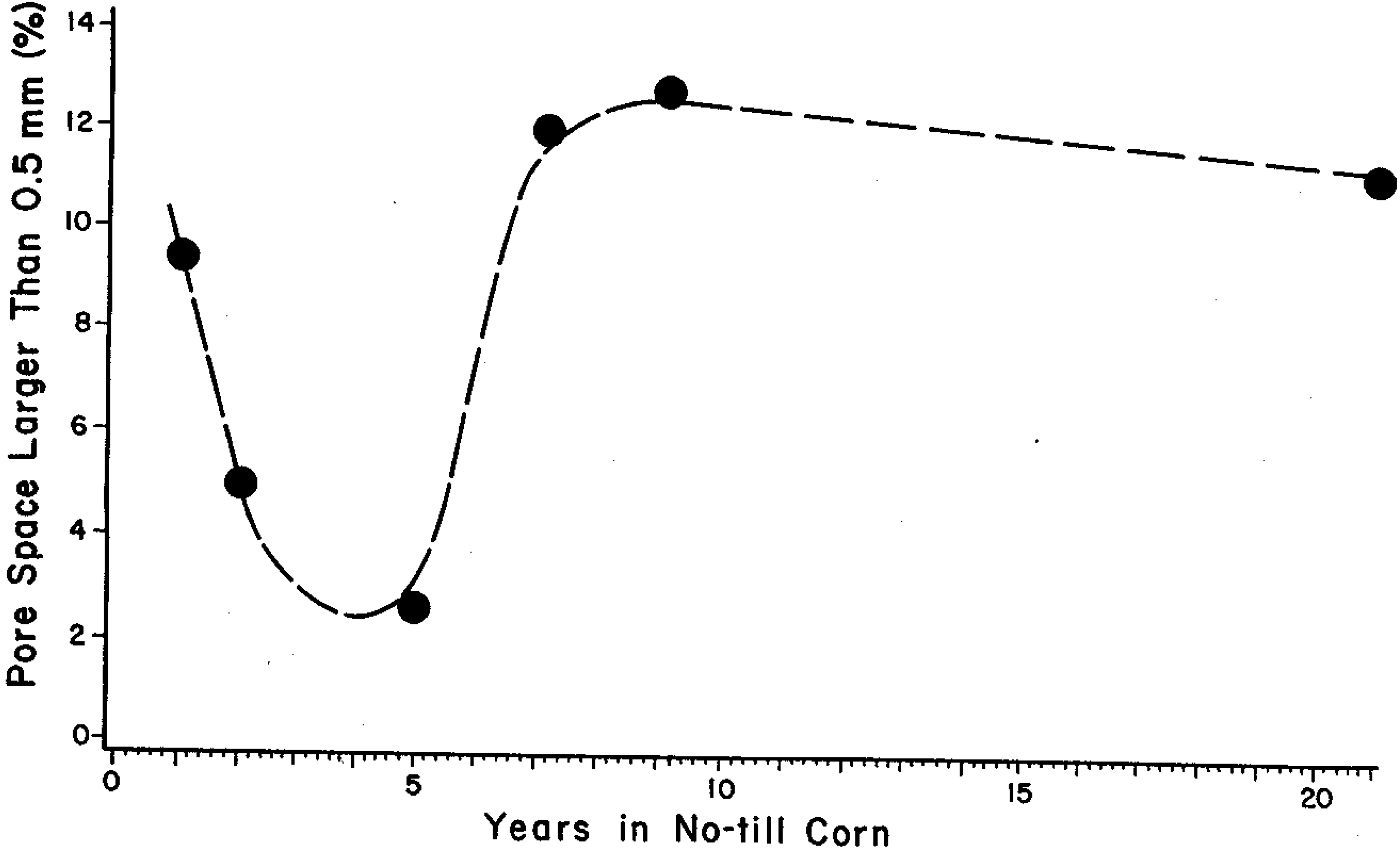

Figure 10. Changes in surface pores larger than 0.5-mm diameter after beginning no-till management in Coshocton, OH.
SOURCE: Norton and Schroeder (1987).

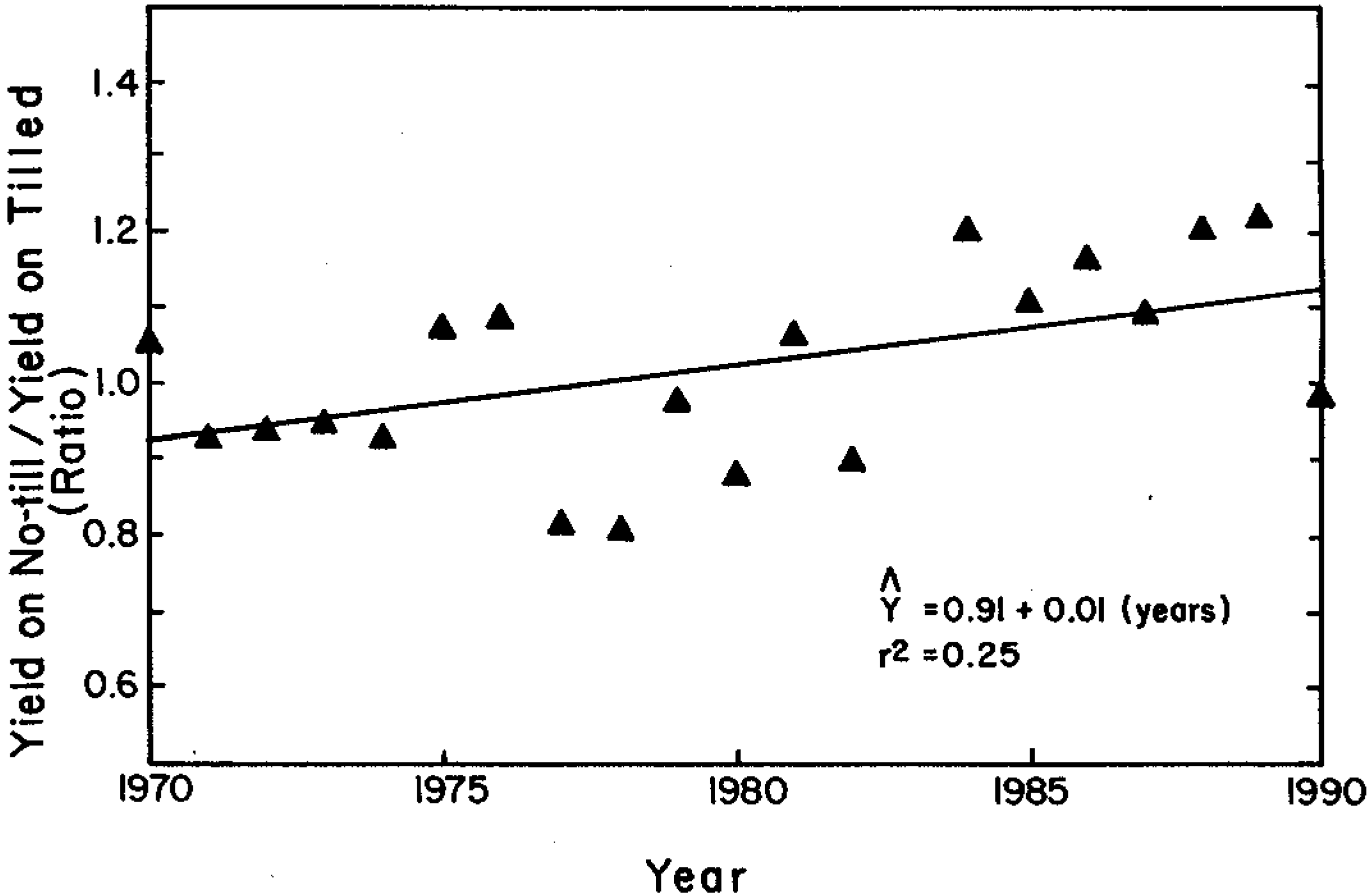

Figure 11. Long-term trends in corn yields under no-till compared to tilled management. SOURCE: Ismail et al. (1994).