Tillage systems

Recent research involving tillage systems has included studies of responses of crops and soils to conservation tillage practices, and of the changes in the rooting patterns of plants that result from different types of tillage.

Conservation Tillage

Tillage is the mechanical manipulation of soil to prepare seedbeds, to control weeds and brush, to bury residues or diseased plants, to loosen and mix the soil for better aeration and water infiltration, and to cause fast breakdown of organic matter and release of minerals for plant nutrition. There are several types of tillage practices because no single one is suitable for all soils and climates. One practice that became important in the mid-1990s is conservation tillage. It is commonly defined as any tillage and planting system that maintains at least 30% of the soil covered by residue after planting to reduce water erosion; or, where erosion by wind is of primary concern, maintains at least 1000 lb/acre (1120 kg/hectare) of flat, small-grain residue equivalent on the surface during the critical wind erosion period. This definition is useful in the United States when determining if a field complies with the 1985 and 1990 Farm Bills.

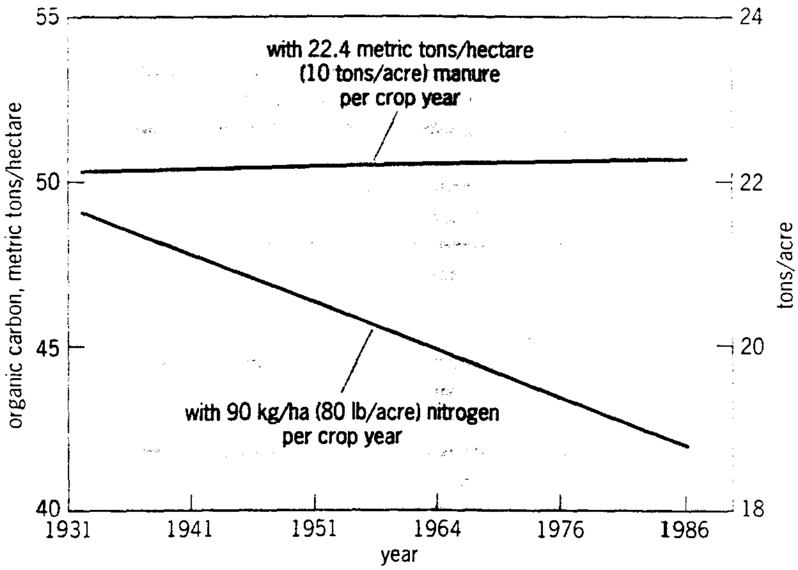
Variants. Conventional tillage consists of primary and secondary tillage. Primary tillage is often done with tools that invert the soil (that is, moldboard plows or disk plows); secondary tillage is generally performed with disks, subsurface sweeps, or harrows. Weed control is accomplished with herbicides incorporated into the soil, cultivation, or postemergence spray herbicides. Variants of conservation tillage practices include ridge tillage, stubble mulch tillage, and no-tillage.

In ridge tillage, seedbeds are prepared on ridges that are produced with tillage implements. Crop residue is left on the soil surface between ridges. Generally, only one seed row is planted on each ridge. Weed control is accomplished with herbicides or cultivation.

In stubble mulch tillage, or simply mulch tillage, plant residues are minimally disturbed during tillage and seedbed preparation so as to leave a protective cover on the soil surface. Subsurface sweeps are the general tillage implements used. Weed control can be chemical or mechanical.

In the no-tillage variation, the soil is left undisturbed, except for the opening of the soil with the seed drill to place the seed at the intended depth. Previous crop residue remains undisturbed by tillage, and weed control is accomplished with herbicides.

Conservation tillage practices are gaining some acceptance among farmers but are far from being the most popular practices. For example, of approximately 1.6 million hectares (4 million acres) of wheat grown in Montana, nearly 30% receives some form of conservation tillage, but only 7% is no-tillage.



Soil organic carbon at 0–30-cm (0–1-ft) depth in a fallow-winter-wheat cropping system in the Pacific Northwest. ***(After P. E. Rasmussen and W. J. Parton, Long-term effects of residue management in wheat-fallow: I. Inputs, yield, and soil organic matter, Soil Sci. Soc. Amer. J., 58:523–530, 1994)***

Various tillage practices have profoundly different influences on the physical and chemical properties of soils because of variations in soils and climate. A given tillage practice employed in different locales may cause different soil responses. Certain soil and crop response factors are particularly important in the semiarid agriculture of North America.

Organic matter. Organic matter is an important constituent of mineral soils. Its influence on physical and chemical properties of soils far outweighs its proportionate presence in soils. Long-term tillage causes large decreases in organic matter content of soils. As compared with virgin equivalent grassland soils, cultivated soils lose 30–50% of their original organic matter during the first 40–50 years of cultivation. To maintain in cultivated soils the levels of the original virgin organic matter, or to revert to them, is impossible and unnecessary; but a certain level of organic matter must be maintained for productive agriculture.

Maintaining productive soils is a function of soil and crop management. The fallow-wheat production system in semiarid agriculture is particularly prone to organic matter loss. Few crop residues are returned to the soil, soil erosion is common, and microbes readily oxidize organic matter. Organic matter can be maintained in semiarid agriculture by heavy application of manures where available (see **illus.**), or by soil and crop management practices that allow annual cropping, which returns proportionally more crop residue to the soil as compared with alternate fallow-crop production.

Bulk density. Soil bulk density, the dry weight of a unit volume of soil, includes both solids and pores, so loose and fluffy soils have lower bulk densities than more compact soils. Depending on soil types and soil conditions, bulk densities range from about 1.0 to 1.8 g/cm^3 (0.6 to 1.0 oz/in.^{3}) in surface soils. The higher bulk densities are found in sandy loams and sands. Crop and soil management practices influence bulk density. Additions of large amounts of manure or organic residues lower bulk densities, whereas intensive cultivation, which includes heavy-machinery traffic, increases bulk densities.

Results from recent comparative tillage studies in the United States have been inconsistent with respect to bulk-density effects. Some studies found that bulk densities increased under no-tillage as compared to conventional (plow) tillage. Results from other studies show a decrease in bulk densities under no-tillage. Data from a 10-year study on the northern semiarid Great Plains showed a decrease under no-tillage. On the southern Great Plains, results were mixed: some studies showed a decrease in bulk densities following a period of no-tillage, others an increase. When tillage practices are changed, it takes several years for significant permanent changes to take place in soil properties such as bulk density.

Soil penetration resistance. Resistance of a soil to penetration can be measured with a cylindrical rod that has a blunt or tapered probe tip. Penetrometer resistance is an integrated index of soil density, soil water content, soil texture, and type of clay minerals present in the soil. The most important factor influencing penetrometer readings appears to be soil-water content. Therefore it is important when comparing penetration resistance among tillage treatments that soil-water content and bulk density also be determined. Soil penetrometer measurements are more sensitive to small changes in soil strength and density than bulk density. Soil bulk density is generally measured by taking relatively large soil volume samples.

Penetration resistance generally followed the same trends as bulk density in studies conducted on the northern semiarid Great Plains. Resolution of differences among tillage treatments was generally higher with penetrometer measurements. Annually cropped no-tillage wheat lowered penetration resistance as compared with conventional fallow-wheat crop sequence. Results from the southern Great Plains were again mixed, with no difference between no-tillage and tilled treatments in some cases, and increased penetration resistance under no-tillage in other cases.

Infiltration. Water infiltration refers to the downward movement or entry of water into the soil. Infiltration can be estimated in various ways, from ponding water on the soil surface to using rainfall simulators. Data from a study of rainfall simulator infiltration on the northern Plains showed that there was little difference in infiltration between no-tillage and tilled treatments. On the southern Plains, rainfall simulator infiltration was highest on tilled treatments. Surface crusting is a serious problem on many soils, hindering infiltration. The low infiltration on no-tillage treatments was ascribed to this soil crust formation. Tillage loosens the soil surface and creates small basins for water to accumulate, thereby increasing infiltration. In no-tillage, the residue is left undisturbed and, along with other factors associated with no-tillage and tillage treatments, reduces soil-water evaporation from the soil surfaces. Thus, overall soil-water conservation was greater for no-tillage treatments.

Crop response. Crop yields across the United States are generally favorable for conservation tillage practices, including no-tillage. On the southern Plains, no-tillage practices are viable for conserving soil water, they have no adverse effects on soil properties, and wheat yields have been similar on conventional and no-tillage fields. On the northern Plains, a 10-year study shows that no-tillage management of annually cropped wheat was the most profitable practice when compared to other management practices, including traditional fallow-crop rotation. The study included five low-yielding years (as low as 2 bushels/acre or 135 kg/ha), and five high-yielding years (as high as 51.5 bushels/acre or 3465 kg/ha).

Fallow practices may have their place, particularly during drought years; and infrequently, it is necessary to incorporate into the soil fertilizers that do not readily move in the soil solution, for example, phosphorus. Large applications of phosphorus will satisfy plant requirements for many years. Nitrogen, however, must be applied every year; and depending on the type of nitrogen fertilizer, it must be either broadcast or injected into the soil. Injection causes soil disturbance. Weed control can usually be accomplished with herbicides, regardless of the tillage method used. There may be occasions when a particularly noxious weed infestation must be mechanically controlled. With modern, improved farming techniques, including appropriate use of herbicides, conservation of soil water, and protection of soil from erosion, the general conclusion is that no-tillage and reduced-tillage farming are viable practices and that successful farming on the semiarid Great Plains need not include a season of summer fallow.

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Tillage and Root Development

A soil–root association is extremely complex and delicate, and can be altered in countless ways by tillage-induced disturbance. In considering the vastly different soil types, climates, and crop plant species that are found in modern agriculture, it is obvious that the type and magnitude of crop root responses to tillage systems are extremely variable. Differences among soil tillage systems influence root growth and development in a variety of ways that may also impact plant performance and, ultimately, crop yield.

As farming becomes more specialized and sophisticated, and as costs continue to rise, a greater understanding of plant–soil interactions within modern cropping systems is essential. The urgent need to reduce soil erosion and runoff of agricultural chemicals while reducing costly inputs, such as fuel and labor, has led to the recent development of a variety of alternative agricultural tillage systems. The response of particular crop plants specifically in terms of their root systems has not often been considered

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