# Soil Management:

## Building a Stable Base for Agriculture

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# Fallow Effects on Soil

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Fallow has been defined as a farming practice wherein no crop is grown and all plant growth is controlled by cultivation or chemicals during a season when a crop might normally be grown. (Haas et al., 1974). Fallow as a practice, associated with crop rotation, had its origins in Mediterranean agriculture (Karlen et al., 1994) and continues to be used throughout the semiarid and arid regions of West Asia and North Africa (Ryan et al., 2008). Additionally, summer fallow has been practiced widely across the 15 western states of the United States and the farmed areas of the prairie provinces of Canada in response to widely varying precipitation from year to year. For example, precipitation in any given year for a specific site in the central Great Plains region of the United States may range from double to less than half of the long-term average (Greb et al., 1974).

The primary reason for summer fallow is to stabilize crop production by forfeiting production in one season in anticipation that there will be at least partial compensation by increased crop production the next season. Summer fallow was almost universally adopted in the semiarid U.S. Great Plains in response to the 1930s dust bowl, higher wartime prices, and much improved tractor power systems and implements needed to control weeds during fallow (Greb, 1979). Other objectives of fallowing are to maximize soil water storage through improved water intake, snow trapping, and decreased evaporation; maximize plant nutrient availability; minimize soil erosion hazards; and minimize energy and economic inputs (Greb, 1979). Soil texture determines water holding capacity, thereby influencing how well fallow can buffer the influence of variable growing season precipitation on crop yield.

Fallow systems in semiarid regions can vary in fallow frequency (one crop in 2 yr, two crops in 3 yr, three crops in 4 yr, etc.), with the more frequently cropped systems generally producing more surface crop residues (Cantero-Martinez et al., 2006). Crop residue produced degrades over the fallow period at varying rates depending on the weed control methods used and climatic conditions. Fallow systems vary in intensity of tillage needed to control weeds during the noncrop period, and include maximum tillage (plowing and harrowing), conventional bare fallow (shallow disking and rod-weeding), stubble mulch (undercutting), minimum tillage (combinations of residual and contact herbicides with subsequent tillage), and no-tillage (use of only herbicides to control fallow weed growth). Tillage knocks down, cuts up, and incorporates standing and flat crop residue, facilitating organic matter mineralization by bringing together substrates, microbes, water, and oxygen. The various combinations of fallow frequency, tillage, and chemical weed control have effects on surface soil residue quantity, orientation, and duration, which subsequently affect surface soil organic matter content, soil physical structure, precipitation storage, nutrient availability, microorganisms,

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crop and fallow management; and (iv) erosion loss from and deposition on surface soil. Losses of surface soil C and N are generally greatest during the first 8 to 10 yr after sod is cultivated, although losses continue to occur at a slower rate thereafter (Peterson and Vetter, 1971; Campbell et al., 1976). The generally moist, warm late spring and early summer periods in the central Great Plains create favorable conditions to decompose soil OM (Bowman et al., 1999), and those favorable conditions are enhanced by tillage operations (Doran et al., 1998).

## Effects on Soil Physical Structure

Tillage for weed control during the fallow period is reported to have varying effects on the soil bulk density in the surface layer. The lack of a consistent response of bulk density to tillage in fallow systems may be attributable to amount of time and precipitation between tillage and sampling, type of tillage (disk vs. sweep vs. plow), depth of tillage, and soil type (Mikha et al., 2006). Results also vary with sampling depth. Generally, tillage will decrease bulk density in the tilled soil layer. However, tilled soil may eventually reconsolidate due to gravity, precipitation, and traffic. Mielke and Wilhelm (1998) found a bulk density of 1.19 Mg $m^{-3}$ in the 0- to 7.6-cm layer of a silt loam soil in western Nebraska that had been plowed during the fallow period of a wheat–fallow system compared with a bulk density of 1.27 Mg $m^{-3}$ for the system under no-till management. Halvorson et al. (1997) reported greater bulk densities in no-till vs. conventional till wheat–fallow after a 15-yr study comparing the two systems in northeastern Colorado. Those differences were seen at all sampling depths from 0 to 20 cm, with the greatest difference (17% higher bulk density in no-till) occurring in the 2.5- to 5.0-cm depth interval. Mielke et al. (1986) reported no difference in bulk density in the 0- to 7.5-cm layer of an Alliance silt loam (Aridic Argiustolls) in western Nebraska due to tillage in a wheat–fallow system 8 mo after the tillage occurred. On the other hand, they reported lower bulk density under no-till for a Duroc loam (Pachic Haplustolls). Mielke et al. (1984) and Unger (1991) reported no effect of tillage treatments on bulk density, while Unger and Fulton (1990) found greater bulk density under conventional stubble mulch tillage than under no-till in the 4- to 7-cm depth. Pikul and Aase (1995) analyzed the combined effects of tillage and cropping intensity on bulk density in northeastern Montana. They found that after 9 yr of cropping, the spring wheat–fallow conventional till system had higher bulk density in the surface to 12-cm layer than in either the annual spring wheat no-till system or the annual spring wheat system with fall and spring tillage. Pikul et al. (1997) found no difference in bulk density in the 0- to 0.08-cm, 0.08- to 0.15-cm, and 0.15- to 0.30-cm surface soil layers of a Williams loam (fine-loamy, mixed Typic Agriboroll) in eastern Montana when comparing wheat–fallow no-till and conventional till systems and continuously cropped systems over a 5-yr period.

Pikul et al. (2006) reported greater water-filled pore space for systems employing fallow compared with continuously cropped systems at two northern Great Plains locations, but mixed results regarding the effects of tillage on water-filled pore space. The mixed results are likely to be a result of variations that occur with time of sampling and the large seasonal fluctuations that occur in water-filled pore space during different rotational phases. Mielke et al. (1986) found greater water-filled pore space in both the Duroc loam and Alliance silt loam mentioned above under no-till management, and lower air permeability and hydraulic conductivity under no-till.

Tillage for weed control during fallow periods can also create soil conditions that can restrict root growth and development. Results of a study conducted at Tribune, Kansas, where a sweep plow was used in a conventional till wheat–fallow system, showed increased bulk densities (compared with sod and no-till) at 30 to 40 cm (McVay et al., 2006). Many tillage operations at a consistent depth can lead to destruction of plant roots, and without plant roots to reinforce the soil, machine-induced compaction can occur (Ess et al., 1998). Pikul and Aase (1995) also identified a bulk density maximum occurring at about 10 cm in a wheat–fallow conventional tillage system, coinciding with the depth of the shallow sweep tillage operation conducted during the fallow periods.

Changes to the soil physical condition by reducing the frequency of fallow in a were less effective for reducing runoff than for reducing soil loss. In the semiarid area of north-central Oregon, runoff was reduced during fallow periods of a conventional till winter wheat–fallow system receiving 145 kg N ha$^{-1}$ per crop as manure for the previous 67 yr compared with the same system receiving 90 kg N ha$^{-1}$ per crop as commercial fertilizer (Williams, 2004). Williams (2004) concluded that using manure amendments and not burning residue from the previous crop maintained soil organic C levels that reduced or retarded runoff. That same data set provided evidence of reduced soil erosion with the use of manure and maintenance of wheat residue on the soil surface (Williams, 2008).

Small grain harvest methods can greatly influence residue amount and orientation, and subsequently soil water evaporation during the fallow period. McMaster et al. (2000) showed that soil water evaporation could be reduced by 20 to 50% as wheat harvest cutting height increased from 0.1 m to 0.5 m, with the amount of evaporation reduction during the fallow period being dependent on standing residue stem population. Under very low stem population conditions (a result of poor seedling emergence and/or poor growing season rainfall), the use of a stripper-header (Fig. 19|1) (Henry et al., 2008) was advised to increase standing residue mass and height to minimize soil water evaporation over the fallow period.

The combined effects of decreased runoff and evaporation through reduced tillage and increased surface residues during the fallow period lead to increased infiltration. Baumhardt and Lascano (1996) measured cumulative infiltration in winter wheat residue increasing from 29 mm with 0 Mg ha$^{-1}$ of residue to 47 mm with 2.5 Mg ha$^{-1}$ of residue in response to 65 mm of simulated rainfall applied over an hour. They noted the ability of surface residues to absorb raindrop impact and retard runoff. In a study on a sandy clay loam in southwestern Queensland, Thomas et al. (2008) reported increased surface residue resulted in increases in time to runoff, final infiltration rate, and cumulative infiltration following 100 mm of simulated rainfall to wheat residues at the end of a 6-mo fallow period. Pikul and Aase (1995) reported greater infiltration in an annual wheat no-till system than in a wheat–fallow conventional till system during the first hour of the first day in which measurements were taken, but that this difference disappeared over the course of the infiltration run. They concluded that the sandy loam soil of the experimental area settled firmly following rainfall, with textural size components that effectively filled the available void spaces of the soil with solids causing surface sealing. Pikul et al. (2006) found no significant cropping system effects on infiltration for locations that had the same tillage system but differing cropping intensity or crop species in the cropping system. However, where no tillage was compared with tillage, infiltration was greater following tillage and declined over time in tilled systems. They cautioned that conclusions regarding cropping system effects on infiltration should be made carefully due to the significant temporal variation in infiltration rate measurements.

No-tillage, however, does not always result in the most infiltration from a given precipitation event (Unger, 1992; Jones and Popham, 1997). Infiltration may be greater into a tillage-loosened than a no-tillage soil when precipitation amounts do not exceed the temporary storage capacity of the loosened soil layer. Also, infiltration into a tillage-loosened soil may be greater when

Fig. 19|1. Fallow wheat stubble following harvest with a stripper-header.

water can move below the active root zone, taking with it N and potentially affecting groundwater quality. O'Connell et al. (2003) measured increased drainage below the root zone in a fallow system (fallow–wheat–pea [*Pisum sativum* L.]) compared with a system without fallow (mustard [*Brassica juncea* (L.) Czern.]–wheat–pea) in southeastern Australia. Introduction of fallow production methods in the semiarid areas of the Great Plains has sometimes led to the formation of saline seeps (Halvorson and Black, 1974) as water percolated below the root zone. This problem can be alleviated with the use of flexible crop rotations involving small grains, grasses, deep-rooted crops, and a minimum amount of summer fallow as crops are grown when sufficient soil water is present at planting to indicate likely successful crop production.

## Effects on Nutrient Availability

Fallow enhances accumulation of nitrate through mineralization of organic matter (Smika, 1983a; Campbell et al., 1990). Cochran et al. (2006) stated that during the early years of crop production in the northern Great Plains, relatively high levels of organic matter supplied adequate nutrition as N mineralization was enhanced by aeration with tillage in conjunction with high soil moisture content during the fallow period. Prolonged cropping of these prairie soils depleted soil N such that fertilizer N is now required. Unger (1991) reported a nonsignificant tendency for a no-till wheat–sorghum–fallow system in Texas to have higher levels of N, $NO_3$-N, P, and K at the soil surface than the stubble mulch tillage system 6 to 8 yr after the systems were established. Mikha et al. (2006) found total soil N was significantly increased in the 0- to 7.5-cm depth by decreasing tillage and fallow frequency at several central and northern Great Plains locations. The effect of fallow tillage intensity on total N in the 0- to 7.6-cm depth in a wheat–fallow system in Texas was reported by Unger (1968). After 24 yr of management, 36% higher total N was found in the system where six to ten sweep tillage operations were delayed until the spring and summer following wheat harvest compared with the system where up to ten fallow-period one-way disk operations were used to control weeds throughout the entire fallow period.

Fallow no-till systems can also increase P and other micronutrients in the upper layers of soil. Unger (1991) also reported approximately 60% higher extractable P in the 0- to 4-cm soil layer from a wheat–sorghum–fallow system under no-till management compared with stubble mulch management in Texas. Follett and Peterson (1988) showed tillage intensity effects on several nutrients from a loam soil in western Nebraska that had been in wheat–fallow production for 16 yr. They found that total P, organic P, K, Zn, and Fe in the 0- to 5-cm layer declined with increasing tillage intensity (no-till > stubble mulch > moldboard plow). They attributed these results mainly to cycling of nutrients to the soil surface in plant parts and subsequent residue that was then mixed and diluted with soil from lower depths as tillage intensity increased.

Bowman and Halvorson (1997) conducted a detailed study of the effect of fallow frequency on P in the 0- to 5-cm soil layer in northeastern Colorado. As fallow frequency was reduced from one crop in 2 yr to two crops in 3 yr to three crops in 4 yr to continuous cropping, water-soluble P, anion-exchange resin P, total soil organic P, phosphatase activity, soil bicarbonate-extractable organic P, and total P all increased. They attributed the increase primarily to greater residue production in systems with less fallow. The P uptake from deeper in the soil profile was deposited at the soil surface through greater residue and litter production and subsequent leaching of P from the residue and decomposition of the residue in contact with soil. Additionally, there was probably enhanced P protection from wind erosion as summer fallow was eliminated. Decreasing fallow frequency similarly increased levels of Zn, Mn, and Fe in the 0- to 5-cm layer but did not affect Cu or $SO_4$-S levels (Bowman and Vigil, 2000).

Because crop water use generally exceeds precipitation in the semiarid regions that employ fallow systems, leaching of N beyond the root zone through downward water movement is rarely a loss mechanism for N (Ryan and Monem, 1998). In comparing fallow tillage systems in Queensland, Australia, Standley et al. (1990) found greater losses of N, P, S, and K in the surface 10 cm fatty acid analysis indicated that microbial community structure diverged from that of the adjacent grassland sites, partly due to increased abundance of Gram-negative bacterial markers.

Exceptions do occur, showing that not all microbial functions are equally sensitive to fallow. Enwall et al. (2005) showed that bare-fallow soils had similar genetic fingerprints as unfertilized cropped plots, indicating that fertilizer addition and pH may be more important drivers of microbial diversity than the presence or absence of plants in the soils studied.

The reduced C inputs in bare fallow can have negative effects on soil function through the reduction of microbial enzymes. Pankhurst et al. (2005) compared three crop break treatments—pasture, alternate crops, and bare fallow—as alternatives to continuous sugarcane in Queensland, Australia. The microbial biomass C decreased up to 43% and total free-living nematodes decreased up to 14% under bare fallow relative to continuous sugarcane. Interestingly, the soil microbial community of the bare-fallow break had a reduced capacity to utilize different C substrates than the soil microbial community under sugarcane, indicating a clear effect on soil microbial function in the absence of plant cover.

Weigand et al. (1995) investigated microbial C, catalase activity, and earthworm abundance in soils from different sites in Bavaria maintained under bare fallow for 6 yr. Microbial C was strongly correlated with soil organic C and with soil catalase (an important enzyme for aerobic metabolism). The soils under bare fallow, with no rhizodeposition or residue input, had less microbial biomass and lowered efficiency of microbial C metabolism as measured by substrate induced respiration.

Acosta-Martinez et al. (2007) showed that cropping intensity affected soil microbial composition and enzyme activity in long-term plots in northeastern Colorado. The study aimed to find more efficient alternatives to the traditional wheat–fallow common in the region. Increased fallow frequency coupled with conventional tillage was associated with reduced soil microbial biomass and soil enzymatic activity. Fatty acid methyl ester analysis indicated that the plots under the more intense rotations also had a different soil microbial community structure than the wheat–fallow plots, as well as reduced fungal abundance in the wheat–fallow treatment.

Bare fallow can have a direct effect on obligately symbiotic organisms such as arbuscular mycorrhizal fungi that depend entirely on certain plant roots for their energy. The long-fallow disorder occurs when mycorrhizal fungal inoculum declines during a bare-fallow period because of the absence of active crop roots (Thompson, 1987; Hulugalle et al., 1998; Pankhurst et al., 2005). Mycorrhizae can benefit row crops by increasing P and water uptake, so the bare fallow can potentially result in reduced performance in subsequent crops. However, P and Zn fertilizer help alleviate the long-fallow effect by reducing nutrient deficiency and promoting mycorrhiza formation. Oliveira and Sanders (1999) observed the long-fallow effect on low-P soils in Leeds, England. As expected, fallow soils had lower mycorrhizal infectivity than recently cropped soils. Interestingly, prior cropping with a strongly mycorrhizal plant (*Zea mays* L.) increased infectivity relative to a wheat pre-crop, suggesting a strategy to minimize the negative effect of the fallow on mycorrhizal infection.

Bare fallow can also affect soil pathogenic microorganisms by removing the host crops, reducing crop residues, and changing the soil physical environment in such a way that the pathogen life cycles are disrupted. Hulugalle et al. (1998) compared long-fallow cotton (*Gossypium* L.) with continuous cotton in New South Wales, Australia. The long-fallow cotton affected the soil physical properties by reducing soil strength and plastic limit, and black root rot was lower during the cotton phase after long fallow. *Fusarium* fungi can cause important economic losses in crops because *Fusaria* can infect the xylem of the plant and cause head blight, root rot, crown rot, and seedling blight in several crop species. Contaminated crop residues are an important source of *Fusarium* propagules (Dill-Macky and Jones, 2000), so crop rotations and residue management are important options to control disease. Sturz and Johnston (1985) found that pathogenic *Fusaria* are found on stubble in soil, and tend to be in higher amounts in soils under continuous cropping than in bare-fallow soils due to the differences in crop residue. Because of this, they suggest result is more protection of the soil from wind erosion and greater precipitation storage efficiency during fallow periods.

Sharratt et al. (2007) quantified soil loss from conventionally tilled silt loam fallow fields (winter wheat–fallow system) in the Columbia Plateau of eastern Washington. Six high wind events occurred over a 2-yr period resulting in soil loss ranging from 43 to 2320 kg $ha^{-1}$ per wind event and PM10 loss ranging from 5 to 210 kg $ha^{-1}$ per wind event. The PM10 loss comprised 9 to 12 per cent of the total soil loss. They concluded that alternative tillage practices or cropping systems were needed for minimizing PM10 emissions and improving air quality in that region. Similar magnitudes of soil losses through wind erosion have been reported for silt loam soils in Colorado (Van Donk and Skidmore, 2003) and in Washington (Zobeck et al., 2001), but much higher losses (12,000 to 56,000 kg $ha^{-1}$) have been reported for sand and sandy loam soils in other locations (Zobeck et al., 2001; Larney et al., 1995). The higher soil losses may also be related to differences in wind event speed and duration, surface roughness, or surface cover. Using the wind erosion prediction system (WEPS; Hagen, 1991), Feng and Sharratt (2007) estimated an annual soil loss of 14,250 kg $ha^{-1}$ from summer fallow fields in eastern Washington.

Soil loss under fallow management due to water erosion can also be significant. Boellstorff and Benito (2005) described the increase in bare (unseeded) fallow area in Europe that occurred following the adoption of the 1992 MacSharry reforms to the European Union's Common Agricultural Policy that included a set-aside program requiring farmers to take certain percentages of arable land out of production. In central Spain, even areas with sufficient precipitation to support seeded fallow with a cover crop were being put into traditional unseeded fallow with tillage. A study involving the use of the revised universal soil loss equation (RUSLE; Renard et al., 1991) indicated the use of seeded fallow in central Spain would cut the area estimated to have greater than 6 t $ha^{-1}$ soil loss to one-third the area under that risk when in unseeded fallow (Boellstorff and Benito, 2005). In central Croatia, Basic et al. (2004) measured a 5-yr average soil loss of 87 t $ha^{-1}$ from standard bare fallow USLE protocol plots (Wischmeier and Smith, 1978) on a 9% slope.

Fig. 19|3. Anemometers in fallow sunflower stalks.

## Summary

Fallow production systems continue to be used throughout various regions of the world, but particularly in semiarid regions where precipitation is highly variable in timing and amount. Systems that reduce or limit fallow frequency and tillage intensity generally result in greater amounts of surface crop residues remaining during fallow periods. Those residue increases generally produce positive effects on soil quality for crop production, including increases in soil OM, nutrients, physical structure, water content, and microorganisms, as well as reductions in soil loss by wind and water erosion.

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