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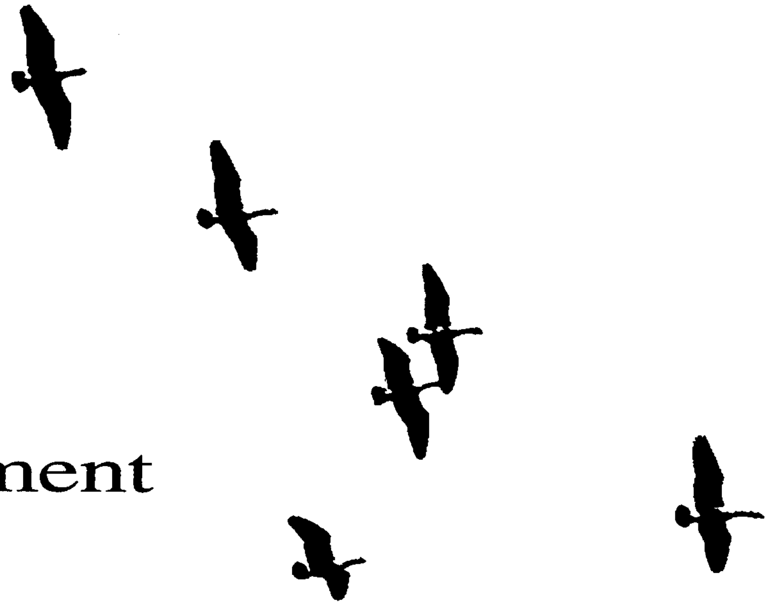
A White Paper



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Impacts of tillage practices on water-use efficiency

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As competition for water increases among various sectors of the society (agricultural, municipal, industrial, and recreational), it is imperative that all sectors use available water supplies responsibly and efficiently. Crop production agriculture can act responsibly and achieve more efficient water use by adopting practices that improve crop water-use efficiency (WUE). A small amount of additional water available at a critical growth stage generally can greatly influence crop yields. For example, additional water stored in soil having a low storage capacity can help crops in humid areas withstand potential adverse effects of short-duration droughts. While improvements in WUE are desirable in all climatic regions, the emphasis often is greater in precipitation-deficient areas where dryland or irrigated rather than rainfed agriculture is practiced.

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Dryland agriculture involves crop production without irrigation in semiarid regions where precipitation usually is less than 30 inches annually. In contrast, rainfed agriculture involves crop production without irrigation in subhumid and humid regions where annual precipitation usually is greater than 30 inches (Stewart and Burnett 1987). The annual precipitation amounts, however, are not absolute because precipitation distribution relative to crop water needs and other prevailing climatic conditions affect crop water requirements. Successful dryland crop production usually depends on water conservation (water storage in soil) whereas removal of excess water often is important for rainfed agriculture. Dryland crop yields generally increase with increases in soil water storage.

The term WUE has been used to describe processes ranging from gas exchange within individual plant leaves for a few minutes to crop grain yield response to different irrigation treatments for an entire season (Stewart and Steiner 1990). For this report, WUEp-h denotes crop yield (grain) per unit volume of water used during the growing season (planting to harvest) and WUEh-h denotes that from harvest to harvest of successive crops. In equation form, WUEp-h (or WUEh-h) = Crop Yield/ET, where ET is evapotranspiration (evaporation and transpiration). For the period considered (planting to harvest or harvest to harvest), ET = precipitation + net irrigation - net soil water change (+ for extraction, - for storage), with appropriate adjustments made for runoff or drainage beyond plant rooting depth.

Many management factors such as the crop selected and cultivar grown, and use of appropriate planting and harvesting dates, plant populations and row spacings, fertilizers and soil amendments, pest control measures (weeds, insects, diseases, etc.), irrigation practices (timing and amount), tillage and related practices, crop residues, and cropping systems affect WUE. Stewart and Burnett (1987) and several authors in books edited by Dregne and Willis (1983), Taylor et al. (1983), and Singh et al. (1990) discussed most of these management factors in considerable detail. Therefore, this report emphasizes effects of tillage and related practices, crop residues, and cropping systems that influence soil water infiltration, storage, and evaporation; crop growth and yield; and, hence, crop WUE.

Tillage systems and related practices, crop residues, and cropping systems affect crop yields and WUE through their effects, among other things, on soil water storage and evaporation. Where water conservation is important, a successful system must 1) retain precipitation on the land, 2) reduce evaporation, and 3) involve crops that have drought tolerance and that best fit the precipitation patterns (Stewart and Burnett, 1987).

Tillage may enhance or hinder soil water storage. Tillage enhances storage when it increases infiltration due to loosening of surface crusts or other slowly permeable soil layers, increases detention storage on the surface to provide more time for infiltration, or retains crop residues on the surface to protect the soil against raindrop impact, thus reducing soil aggregate dispersion and surface sealing, which increase runoff. Residues retained on the surface by using conservation tillage systems, especially no-tillage, are highly effective for protecting soil surfaces and maintaining favorable infiltration rates. In addition, use of no-tillage maintains soil pore continuity, which not only results in more rapid infiltration, but generally also results in storage deeper in soil where water is less subject to evaporative losses. Decreasing evaporation potentially increases water available for transpiration, thus improving WUE. Tillage hinders water storage if it results in a smooth, unstable soil surface that readily seals due to raindrop impact, thus increasing runoff. Tillage also hinders storage when it exposes moist soil to the atmosphere, thus increasing evaporative losses.

Practices related to tillage include contouring, terracing, furrow diking, strip cropping, deep plowing, chiseling, subsoiling, and land leveling. Use of these practices improves water conservation mainly by providing more time for infiltration or by loosening dense soil layers (deep plowing, chiseling, subsoiling). With respect to WUE, effectiveness of these practices increases if they result in water storage deeper in soil, which reduces the potential for evaporative losses.

A major reason for using crop residues is to reduce evaporation, which is achieved by insulating and cooling the soil surface, reflecting solar energy, decreasing wind speed near the soil surface, or providing a barrier against water vapor movement. Crop residues also absorb the energy of raindrops and may increase water infiltration if they are porous. Many types of crop residues can be used, but crop residues are most common and practical for large-scale farming conditions, as practiced in the United States. Future technological advances could lead to using waste materials (municipal, industrial, agricultural) as crop residues, which could help alleviate current waste disposal problems.

Limited residue production by dryland crops severely limits the use of crop-residue crop residues in semiarid regions. Unger (1978) showed the potential of a crop-residue crop residue for increasing precipitation storage efficiency (PSE, defined as percent of fallow- or noncrop-period precipitation stored as soil water), sorghum grain yield, and WUE when increasing amounts of wheat straw were placed on the soil surface. Straw at rates ranging from 0 to 10,700 pounds/acre was placed on Pullman clay loam (Torrertic Paleustoll) at the time of wheat harvest (start of fallow) and grain sorghum was planted after 10 to 11 months of fallow. For the above two treatments, PSE averaged 23 and 46 percent, yield averaged 1590 to 3560 pounds/acre, WUEp-h averaged 127 and 260 pounds/acre-inch, and WUEh-h averaged 73 and 175 pounds/acre-inch, respectively. Greb (1983) also reported major increases in PSE during fallow when increasing amounts of straw crop residue were on the soil surface.

For an irrigated winter wheat-dryland grain sorghum study with 10 to 11 months of fallow between crops, PSE during fallow after wheat averaged 15, 23, and 35 percent; sorghum grain yield averaged 1720, 2230, and 2800 pounds/acre; and WUEp-h averaged 150, 175, and 202 pounds/acre-inch for disk-, sweep-, and no-tillage treatments, respectively (Unger and Wiese 1979). Wheat residue amounts at the start of fallow averaged 6200 pounds/acre during the 4-year study. For another irrigated winter wheat-dryland grain sorghum study that provided similar wheat residues amounts at the start of fallow, PSE during fallow after wheat averaged 29, 34, 27, 36, and 45 percent; sorghum grain yield averaged 2290, 2120, 1960, 2470, and 2980 pounds/acre; WUEp-h averaged 161, 147, 138, 163, and 188 pounds/acre-inch; and WUEh-h averaged 100, 95, 84, 107, and 132 pounds/acre-inch with moldboard-, disk-, rotary-, sweep-, and no-tillage treatments, respectively (Unger, 1984). In both studies, WUE was greater with treatments that retained residues on the soil surface (sweep- and no-tillage) than those that resulted in residue incorporation with soil, with the greatest increase resulting from the no-tillage treatment.

Cropping systems affect WUE primarily through their effect on water storage during the interval between crops. Storage generally increases, but PSE generally decreases as interval lengths between crops increase, mainly because of greater evaporative losses during longer intervals. Intervals are about 4 months for continuous wheat (CW), 10 to 11 months for wheat-sorghum-fallow (WSF), and 16 months for wheat-fallow (WF) cropping systems in the southern Great Plains. Whereas grain yields generally are greater due to more water storage during the longer fallow periods, use of long fallow periods reduces WUEh-h. One potential means of improving WUEh-h is to grow forage crops that have less critical growth stages than those for grain crops.

Summary

Many factors influence crop WUE, including tillage systems and related practices, crop residues, and cropping systems that affect WUE mainly through their effect on soil water storage and evaporation. Storage is increased when they increase infiltration and result in water storage at a soil depth that reduces evaporation. Surface crop residues help reduce evaporation. In general, water storage and WUEp-h are greater for cropping systems with long rather than short intervals between crops. However, systems with long intervals between crops have lower WUEh-h, showing that they result in less efficient use of water resources. The examples given show that adoption of improved tillage and related practices can lead to improved crop WUE. Such improvements are essential because agriculture must act responsibly and use available water supplies efficiently, thus helping to assure that all sectors of society will have adequate water.

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