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WATER USE EFFICIENCY, ENHANCING

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INTRODUCTION

In semiarid regions of the world, water is generally the most limiting factor to crop production. Therefore, a primary objective of cropping systems in these regions is to improve water use efficiency, i.e., get the most production of marketable yield for each unit of water used by the cropping system. There are many definitions of water use efficiency (1, 2), but this discussion uses the following: water use efficiency is the ratio of crop grain yield to the evapotranspiration used to produce that yield. The following discussion will deal mostly with enhancements to water use efficiency that are a result of altering and improving the cropping environment in semiarid regions.

An extremely important method for enhancing water use efficiency is to get more water to be used for plant transpiration and less for evaporation. This can take two forms in a dryland cropping system: increasing precipitation storage efficiency, and growing a crop in place of a fallow period.

REDUCING TILLAGE/MAINTAINING CROP RESIDUES

Increasing precipitation storage efficiency through soil-surface water evaporation reduction during the noncrop period of a crop rotation can be accomplished by: 1) reducing tillage to minimize the number of times moist soil is brought to the surface, and 2) maintaining residues to shade the soil surface, reduce convective exchange of water vapor at the soil–atmosphere interface, reduce runoff by preventing surface crusting, and catch snow.

Precipitation storage efficiency increases as tillage is reduced during the summer fallow period (3, 4) (Fig. 1a). The increased soil water storage is a result of both maintaining crop residues on the soil-surface and reducing the number of times that moist soil is brought to the surface. Data from western Kansas showed water use efficiency increasing by 28% for corn, 17% for sunflower, 10% for soybean, and 7% for grain sorghum. This efficiency was found when a no till production system was used in place of a conventional tillage system, (5) using three or four sweep plow tillage operations to control weeds in the fallow period prior to crop establishment.

The effect of residue amount on precipitation storage efficiency using data from three Great Plains sites is demonstrated in Fig. 1b (6). Increased precipitation storage efficiency during the 14-month fallow period of a winter wheat–fallow system resulted from increasing amount of surface wheat residue. Crop residues reduce soil water evaporation by shading the soil-surface and reducing convective exchange of water vapor at the soil–atmosphere interface (7, 8). Additionally, reducing tillage and maintaining surface residues reduce precipitation runoff and increase infiltration, thereby increasing precipitation storage efficiency (9).

The reduction in convective exchange of water vapor is more effective in standing crop residues (compared to flat residues) because wind speed is reduced near the soil-surface by the standing residue (10–13). Reductions of up to 50% in potential surface soil water evaporation have been demonstrated when wheat stubble height after harvest was increased from 0.1 to 0.5 m, or when stem populations of short (0.1 m) standing wheat stems were increased from 100 to 600 stems m^{-2} (14).

Standing crop residues also increase the soil water available for crop production in the central and northern Great Plains by increasing snow deposition during the overwinter period (15–19). Reduction in wind speed within the standing crop residue allows snow to drop out of the moving air stream. The greater the silhouette area index (SAI = height × diameter × number of stalks per unit ground area) through which the wind must pass, the greater the snow deposition. Typical populations and heights of standing sunflower stalks after harvest (SAI = $0.03–0.05\,m^2\,m^{-2}$) can result in an overwinter soil water increase of about 10–12 cm when winter precipitation is near normal in amount and number of blizzards in northeast Colorado (20) (Fig. 2). Overwinter soil water storage in North Dakota increased 0.24 cm for each cm increase in wheat stubble height because of greater snow trapping (21). Because of the drifting and packing of snow that occurs in standing crop residues, precipitation storage efficiencies can be very high. Overwinter precipitation

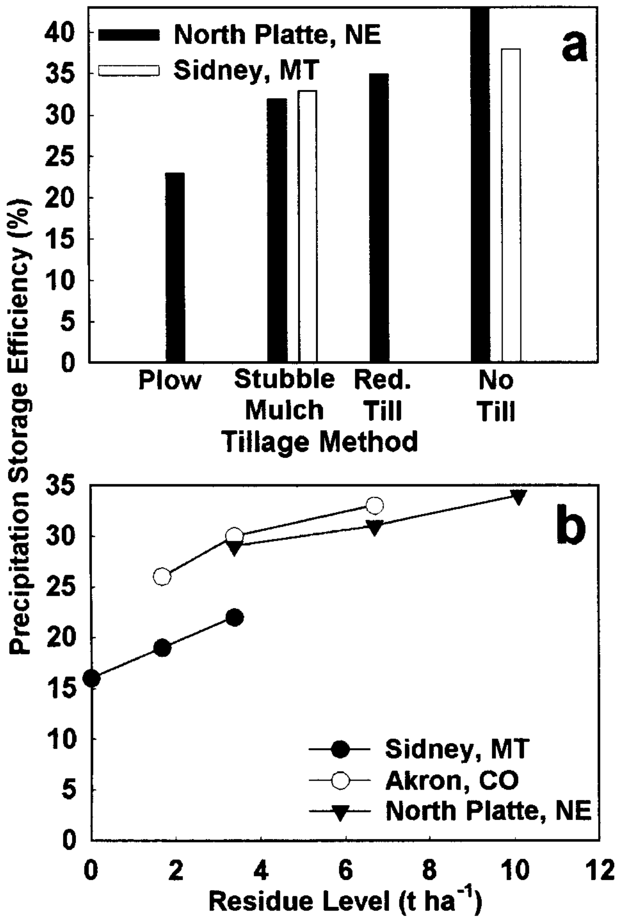

Fig. 1 Precipitation storage efficiency as influenced by a) tillage method during the 14-month fallow period in a winter wheat–fallow production system (data from North Platte, NE, from Ref. 3; data from Sidney, MT, from Ref. 4, and b) crop residue level on the soil surface. (From Ref. 6.)

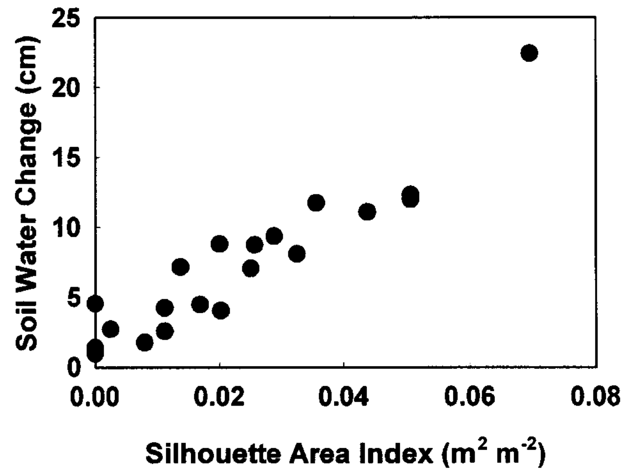

Fig. 2 Influence of sunflower silhouette area index on overwinter soil water change at Akron, CO. (From Ref. 20.)

storage efficiencies in excess of 100% in standing sunflower stalks have been reported in some years (20) as stalks collect snow blown in from adjacent areas without standing residues. Average overwinter precipitation storage efficiency of 55% has been reported for wheat stubble in northeast Colorado (22).

The increased precipitation storage efficiency from maintaining residues on the soil-surface will result in greater amounts of stored soil water. These higher soil water contents at planting have been shown to lead to higher crop yields for winter wheat and proso millet (23). The water use efficiency also increases with increased available soil water at planting, but only in years with normal or below normal growing season precipitation. In above-average precipitation years, when growing season precipitation makes up a higher percentage of total water use, there is no increase in water use efficiency with increasing water content at planting.

SHIFTING WATER USE TO CRITICAL GROWTH STAGES

Another method for enhancing water use efficiency is to shift growing season water use so that a greater proportion of the total is occurring during the more critical growth stages of flowering and grain filling, and less in the not-so-sensitive vegetative growth stage. When a growth retardant was applied to restrict vegetative development and leaf area in corn, water use during the vegetative stage was reduced, increasing the amount of water available for use during reproductive stages, resulting in a 16% increase in water use efficiency (24). Dryland winter wheat water use efficiency in the southern High Plains ranged widely from 0 to 36 $kg\,ha^{-1}\,cm^{-1}$ due to the wide range in amount and seasonal distribution of precipitation (25). Winter wheat water use efficiency at Akron, CO increased linearly as the amount of precipitation falling between 15 May and 25 June (jointing through grain-filling) became a higher percentage of the total growing season precipitation.

Similar results are reported for experiments with limited irrigation in which water is withheld during vegetative growth and applied during flowering and grain-filling. When a set amount of limited irrigation was applied to corn, sorghum, and wheat during flowering and grain-filling, as opposed to applications throughout the entire growing season, water use efficiency increased by 19, 42, and 29%, respectively (26). Similarly, water applied to

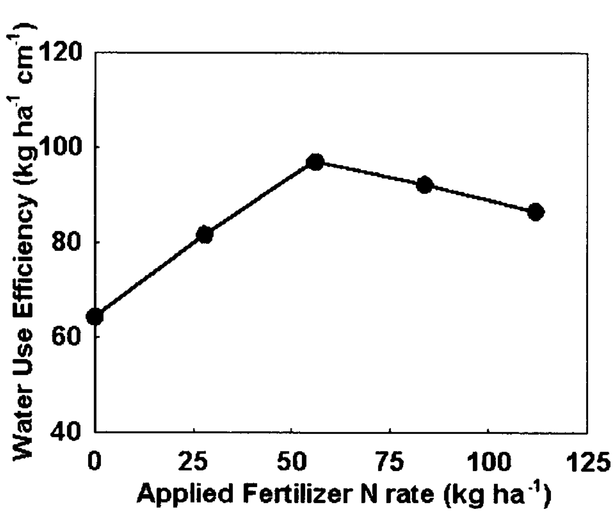

Fig. 3 Influence of nitrogen fertilizer application rate on winter wheat water use efficiency at Akron, Colorado. (From Ref. 28.)

winter wheat during the boot to anthesis stages averaged twice the yield response of water applied during tillering through jointing, without substantially increasing seasonal evapotranspiration (25).

APPROPRIATE FERTILIZER APPLICATION

In most cases when water supply is fixed, any management factor that increases yield will increase water use efficiency because evapotranspiration is little affected by the management (2, 27). For example, dryland winter wheat in northeast Colorado had increased water use efficiency with increased level of applied nitrogen fertilizer (Fig. 3) (28). However, water use efficiency can decline when high levels of nitrogen fertilization produce excessive vegetative growth which uses up the limited soil water supply early in the growing season (29). When water availability is low, plants grown under extremely high nitrogen fertility conditions may undergo more water stress during the more critical flowering and grain-filling stages than plants grown under lower fertility. Consequently, grain yield was reduced at the two highest fertilizer application rates while water use remained nearly the same for the highest N application levels.

REDUCING OR ELIMINATING FALLOW

One of the most productive ways of improving cropping system water use efficiency is to eliminate fallow periods. Cropping systems in the Great Plains have traditionally relied on the practice of summer fallowing in which one crop of winter wheat is grown every other year. The purpose of this was primarily to reduce the erratic yields (and sometimes total crop failure) associated with annual cropping. However, this practice is extremely inefficient in its storage and use of precipitation (30). Most of the precipitation received during the summer of fallow just preceding wheat planting in the wheat–fallow system is lost to evaporation. Intensifying cropping systems by reducing or eliminating fallow periods increases water use efficiency of the system.

Data averaged over 6 years at Akron, CO, show an 18% increase in water use efficiency through reduction of tillage in the wheat–fallow system, going from conventional tillage (35.5 kg ha^{-1} cm^{-1}) to no tillage (41.9 kg ha^{-1} cm^{-1}). When corn is added to the system such that two crops are produced in 3 years (wheat–corn–fallow), the water use efficiency increased by 55% (to 54.9 kg ha^{-1} cm^{-1}). With the continuous wheat–corn–millet system, the water use efficiency increased by 82% (to 64.4 kg ha^{-1} cm^{-1}). An even higher system water use efficiency (87.3 kg ha^{-1} cm^{-1}) was reported in a continuous dryland cropping experiment (8 years) with barley, corn, and winter wheat, also at Akron, CO (31).

CONCLUSION

In semiarid regions where lack of water is limiting to crop yield, water use efficiency needs to be maximized to get the most from this scarce resource. This can be accomplished through several management techniques to improve the cropping environment, including: reducing tillage to maintain surface crop residues, minimize evaporation, and trap snow; applying irrigations only during critical growth stages; matching fertilizer application rates to the expected available water condition; and employing crop rotations that reduce or eliminate fallow periods.

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