Water in Dryland Cropping Systems

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Availability of water is the single most limiting factor to dryland crop production in the Central Great Plains. Precipitation varies widely in timing and amount across the region and from year to year, resulting in highly variable crop productivity. Using the climate record from Akron, CO as an example, we find annual precipitation varying from a high of 26.8 inches to a low of 9.9 inches, averaging 16.5 inches. Seasonal distribution of precipitation in this region follows a summer rainfall pattern, with nearly 80% of the annual total falling in the months of April through September, suggesting that production of annual summer crops is suited to this region. However, average conditions rarely occur, and it is common for there to be lengthy periods (2 to 6 weeks) with no effective precipitation during the months of April through September.

Having just experienced the very significant drought year of 2002, we might take a closer look at the April through September rainfall record to see what has happened in the past during very dry periods. During the period of 1908 to 2001, April through September rainfall has been below 9 inches 11 times. In the years following those dry years, April through September has been above normal (greater than 13.2 inches) 6 times. All 11 dry years were followed by years with greater April through September precipitation.

Because of the highly variable nature of the limited precipitation in the Central Great Plains, a production strategy of diversified crop production employing several crops with varying growing seasons and sensitivities to water deficit amount and timing could be employed to lower risk of complete crop failure. For example, winter wheat generally completes its growing season by July 1, with a critical water use period of May 21 to July 1. Corn has a different growing season, generally running from May through September, with a critical water use period of July 15 to August 25. We have found no consistent relationship in the Akron climate record between amount of precipitation falling in the wheat critical growth period and amount of precipitation falling in the corn critical growth period. 22% of the years were high wheat years, 27% were high corn years. Of those years that were high precipitation years for wheat or corn, 1/3 were low precipitation years for the other crop. Only 16% of the years were classed the same for both crops in the same year (high precipitation years for both wheat and corn, or low precipitation years for both wheat and corn).

Precipitation during the growing season is only one part of the water that is used for crop production. Crops use water stored in the soil during the non-crop period prior to planting. Reducing tillage during the non-crop period increases the amount of soil water stored through increased precipitation storage efficiency (PSE=[change in soil water/precipitation]*100). This increase in PSE is a result of several factors, including:

- residue interception of raindrop impact, which maintains a high infiltration rate
- reduction in evaporation from the soil surface due to cooler temperature and lower windspeeed
- less opportunity for stimulated evaporation due to fewer tillage events and less soil stirring
- better, more timely weed control due to better equipment, better chemicals

In the wheat-fallow production system, weed control methods during the fallow period have changed over time. In the 1920's and 1930's weeds were not controlled in the summer and fall after wheat harvest. Farmers used intensive tillage (plow and disk) for weed control during the following summer. Precipitation storage efficiency (percentage of precipitation stored in the soil profile) averaged 24% with this method using a one-way disk, which left a dust mulch on the soil surface, but virtually no crop residue. In the 1940's , the rod weeder replaced some disking operations, and storage efficiency reached 27%. During the 1950's and 1960's, stubble mulching was developed, in which the sweep plow controlled after-harvest weeds as well as the following-summer weeds. This method improved storage efficiency to 33%.

Herbicide availability led to the development of new weed control methods during fallow: reduced-till and no-till. The reduced till method consisted of application of residual herbicides after wheat harvest, followed by tillage for weed control during the second summer, resulting in a storage efficiency of 40%. The no-till method is similar to reduced-till, except that foliarly-active herbicides replace tillage operations in the second summer. The increase in storage efficiency (shown by Smika in Colorado to be 49%, but lower values reported by others) is largely due to no soil stirring during the second summer. Both methods store more precipitation than stubble mulch because residual herbicides control fall weeds without disturbing the position of wheat stubble. Upright stubble catches snow over winter and reduces water evaporation from the soil surface during the summer.

Studies conducted in Sidney, MT, Akron, CO, and North Platte, NE demonstrated the effect of increasing amount of wheat residue on the precipitation storage efficiency over the 14-month fallow period between wheat crops. As wheat residue on the soil surface increase from 0 to 9000 lb/a, precipitation storage efficiency increased from 15% to 35%.

Snowfall is an important fraction of the total precipitation falling in the central Great Plains, and residue needs to be managed in order to harvest this valuable resource. Snowfall amounts range from about 16 inches per season in southwest Kansas to 42 inches per season in the Nebraska panhandle. Akron, CO averages 12 snow events per season, with three of those being blizzards. Those 12 snow storms deposit 32 inches of snow with an average water content of 12%, amounting to 3.82 inches of water. Snowfall in this area is extremely efficient at recharging the soil water profile due in large part to the fact that 73% of the water received as snow falls during non-frozen soil conditions.

Standing crop residues increase snow deposition during the overwinter period. Reduction in wind speed within the standing crop residue allows snow to drop out of the moving air stream. The greater silhouette area index (SAI) through which the wind must pass, the greater the snow deposition (SAI = height*diameter*number of stalks per unit ground area). Data from sunflower plots at Akron, CO showed a linear increase in soil water from snow as SAI increased in years with average or above average snowfall and number of blizzards. Typical values of SAI for sunflower stalks (0.03 to 0.05) result in an overwinter soil water increase of about 4 to 5 inches.

An examination of the average precipitation distribution and crop water use in the wheat-fallow system demonstrates the inefficiency of water use in that system. Precipitation falling during the first summerfallow period is 10.3 inches and during the second summerfallow period is 10.8 inches. 11.6 inches falls during the wheat growing season, for a total of 32.7 inches of precipitation to grow the crop. But actual measured water use for wheat in the wheat-fallow system is only 14.0 inches, meaning that 18.7 inches of precipitation is wasted in non-productive evaporation during times when no crop is growing.

Precipitation storage efficiency varies with time of year. Farahani et al. (1998) showed that precipitation storage efficiency during the 2 ½ months (July 1 to Sept 15) following wheat harvest averaged 9%, and increased to 66% over the fall, winter, and spring period (Sept 16 to April 30). But from May 1 to Sept 15, the second summerfallow period, precipitation storage efficiency averaged -13% as water was actually lost from the soil that had been previously stored. So a strategy for making more efficient use of precipitation is to reduce the amount of time in fallow when precipitation storage efficiencies are low or negative.

By growing two crops in three years (e.g., W-C-F), the percent of the total system time that is without a crop growing is not decreased when compared with W-F: both have slightly more than 60% of the total system time without a crop. With the continuously cropped system of W-C-M, only 53% of the total system time is without a crop growing. But a more important change to note is the change in when non-crop time is occurring in the systems. For the W-F system, 31% of the non-crop system time is in the May 1 to Sept 15 period when no precipitation storage occurs. That value decreases to 21% for the W-C-F system, and further decreases to 8% for the W-C-M system. This results in an increasing percentage of non-crop system time in the higher precipitation storage period of Sept 16 to April 20.

Let's examine how this change in cropping system affects the amount of available soil water at wheat planting time. Soil water contents measured at wheat planting at Akron, CO (1993-2002) averaged 9.1 inches for W-F (NT), 8.4 inches for W-C-F (NT), 6.2 inches for W-F (CT), and 5.1 inches for W-C-M. Most of the 0.7 inches difference between W-F (NT) and W-C-F (NT) occurs in the bottom three feet of the six foot profile, probably due to deep water extraction by the corn crop that is not recharged before wheat planting. As we shall see later, that 0.7 inches of water will result in 3.7 to 4.6 bu/a. So for the price of about 4 bu/a (in water usage), we can get a corn crop by intensifying our rotation system. Because of the lower residue amounts and frequent soil stirring with tillage, the W-F (CT) system averages 2.2 inches less available soil water at planting than the W-C-F system. With the W-C-M system there is very little time to recharge the soil profile following millet harvest before wheat is planted, so water content averages 3.3 inches lower than in the W-C-F system. But that system has the advantage of production of three crops in three years.

We can assess the value of stored soil water in several ways. The first is to look at the water use-yield relationship for a crop. Different crops have different relationships with regard to the amount of yield produced for a given amount of water used. Corn is a tropical species with the C4 photosynthetic pathway. It is a very efficient producer of grain, producing more than 10 bu/a per inch of water used (about 580 lb/a per inch). On the other hand, as typical of many oilseed crops, sunflower has a response about 1/4 the response of corn, with about 150 lb/a of seed produced for every inch of water used. With this approach we have found that wheat responds to water at a rate of about 6.5 bu/a per inch.

Another way to assess the value of stored soil water is to look at the yield response to available water at planting. For wheat we have found two responses, based on the type of water year. For years with slightly below normal to above normal precipitation conditions during April, May, and June (about 87% of the years) wheat produces about 5.3 bu/a more yield for each additional inch of water in the soil at planting time. During the other 13% of the years, when very dry conditions occur, wheat has a lower yield response of about 1.7 bu/a more yield for each additional inch of water in the soil at planting. The plant does not get enough support from growing season precipitation to take advantage of higher amounts of stored soil water.

From a somewhat limited data set we have found that sunflower yield increases with starting soil water. Within a given year, corn yields are higher in areas with higher water contents at planting, but the relationship of yield to starting soil water is so variable from year to year that no useful predictive relationships can be defined. This is due to the very strong dependence that corn yield has on rain that falls in the critical six-week period that begins just prior to tasseling and silking. That relationship indicates that corn yield increases 7.5 bu/a per inch of water received between July 15 and August 25.

In summary, the key to effective and efficient use of the variable and limited water supplies in dryland cropping systems in the central Great Plains is to get more water to be used for plant transpiration and less for evaporation. This can be accomplished by the use of systems that:

1) increase precipitation storage efficiency (get more precipitation into the soil reservoir), and
2) grow crops in place of fallow.

References

Greb, B.W. 1980. Snowfall and its potential management in the semiarid central Great Plains. USDA-SEA Agric. Rev. and Man. ARM-W-18. U.S. Gov. Print. Office, Washington, DC.

Farahani, H.J., G.A. Peterson, and D.G. Westfall. 1998. Dryland cropping intensification: A fundamental solution to efficient use of precipitation. Adv. Agron. 64:197-223.

Farahani, H.J., G.A. Peterson, D.G. Westfall, L.A. Sherrod, and L.R. Ahuja. 1998. Soil water storage in dryland cropping systems: The significance of cropping intensification. Soil Sci. Soc. Am. J. 62:984-991.

Nielsen, D.C. 1995. Water use/yield relationships for central Great Plains crops. Conservation Tillage Fact Sheet #2-95.

Nielsen, D.C. 1998. Snow catch and soil water recharge in standing sunflower residue. J. Prod. Agric. 11:476-480.

Nielsen, D.C. 1998. Sunflower water use relationships. Conservation Tillage Facts #1-98. Central Great Plains Research Station, Akron, CO.

Nielsen, D.C. 2002. Crop rotation, soil water content and wheat yields. Conservation Tillage Facts #1-02. Central Great Plains Research Station, Akron, CO.

Nielsen, D.C. 2002. Water use efficiency, enhancing. p. 1399-1402. In R. Lal and L. Ahuja (ed.) Encyclopedia of Soil Science, Marcel Dekker, New York.

Nielsen, D.C., and R.L. Anderson.1993. Managing residue and storing precipitation. Conservation Tillage Fact Sheet #2-93.

Nielsen, D., G. Peterson, R. Anderson, V. Ferriera, W. Shawcroft, and K. Remington. 1996. Estimating corn yields from precipitation records. Conservation Tillage Facts #2-96. Central Great Plains Research Station, Akron, CO.

Nielsen, D.C. M.F. Vigil, R.L. Anderson, R.A. Bowman, and A.D. Halvorson. Cropping system influence on planting water content and yield of winter wheat. Agron. J. 94:962-967. 2002.

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