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The water conundrum of planting cover crops in the Great Plains:

When is an inch not an inch?

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Cover crop use is being widely promoted throughout the entire United States because of the potential benefits related to protecting and improving the soil. However, in semiarid environments such as the western and central Great Plains (where water is the single most limiting factor to crop production), cover crop water use may result in significant yield loss in following crops such as winter wheat. This article explores why many of the benefits associated with cover crop use may not be seen in this water-limited environment. Earn 1.5 CEUs in Crop Management by reading this article and completing the quiz at www.certifiedcropadviser.org/certifications/self-study/699.

Seasoned travelers often check the forecast to decide whether they need short sleeves and shorts, a parka and gloves, or an umbrella and waterproof shoes. Such travelers know the most notable changes from the Prairie Provinces of Canada to the South Texas savannah are the temperature and presence or absence of four distinct seasons. Likewise, the most notable change from the Front Range of the Rockies to the Mississippi River is the amount precipitation. While the north–south temperature gradient extends somewhat uniformly across the breadth of the continental U.S. (Fig. 1), the east–west precipitation gradient is most distinct across the Great Plains region from Texas to North Dakota (Fig. 2, next page).

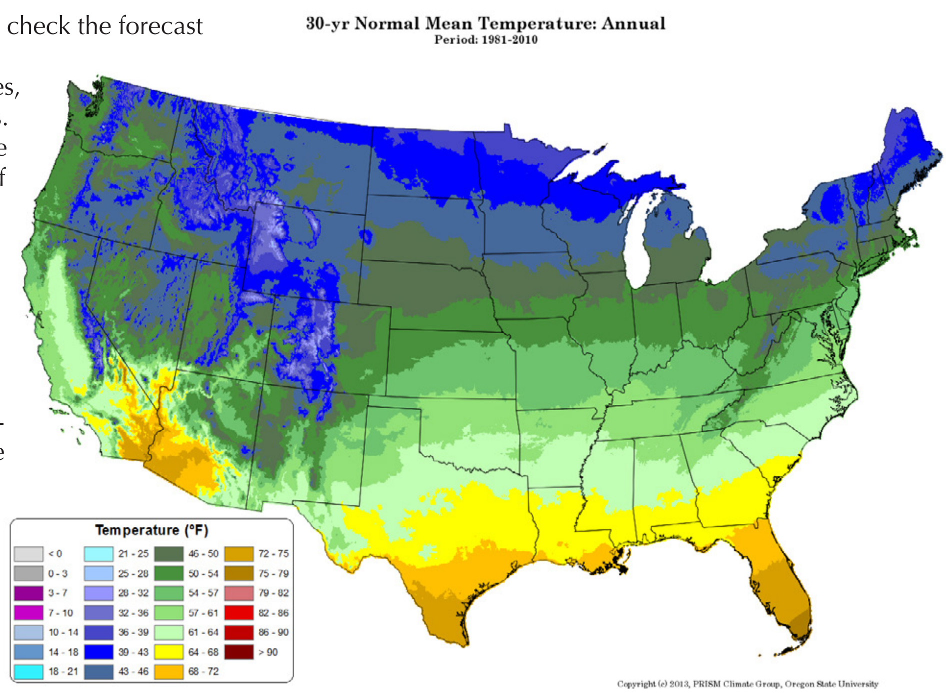

Fig. 1. Contiguous 48 United States mean annual air temperature.

Driving on I-40 across the Texas Panhandle from New Mexico to Oklahoma, the traveler observes the vegetation changing from short grasses to mixed grasses and some trees, as the mean annual precipitation increases about an inch every 25 miles. The temperature differences along that transect control both the length of the growing season and the growing degree days available to grow a crop, and thus limit potential crop selections. But once the crop selections are made, the potential success or failure of a crop is a story of water.

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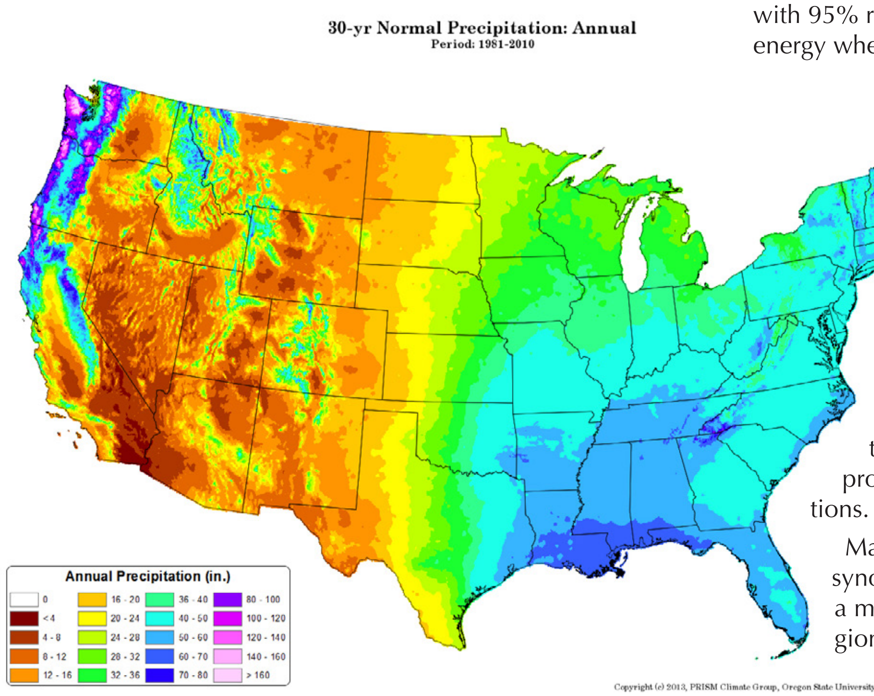
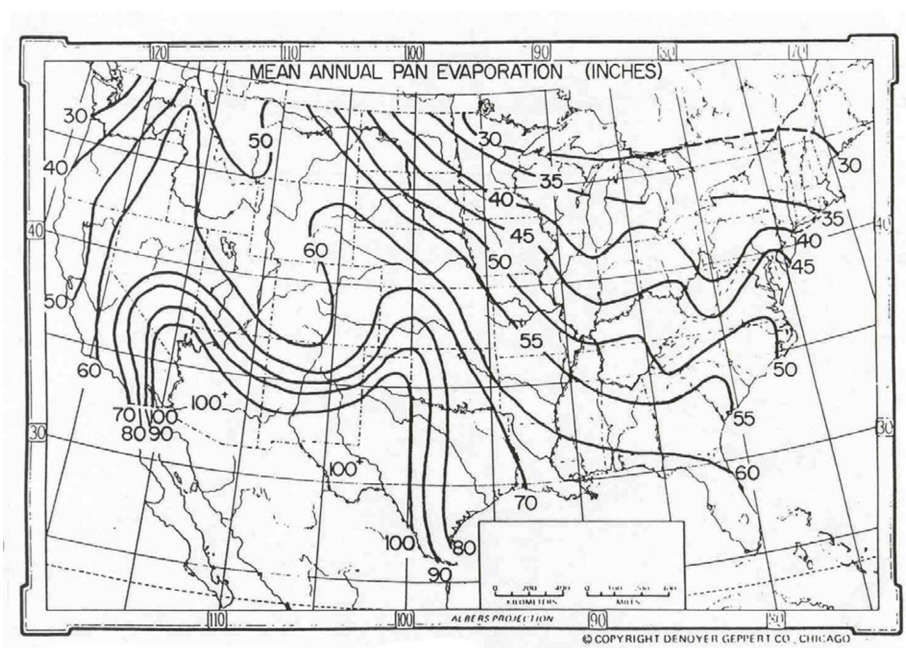
Image on opposite page courtesy of USDA-NRCS South Dakota



| **Fig. 2.** Contiguous 48 United States mean annual precipitation (inches).



| **Fig. 3.** Contiguous 48 United States mean annual pan evaporation (inches).

The story of water is not only about precipitation quantity, distribution, and intensity, but also includes the atmospheric thirst for water. Most travelers notice that 95°F in Denver with 15% relative humidity and a slight breeze is much more comfortable than 95°F in St. Louis with 95% relative humidity. Water consumes a lot of energy when it changes phases from liquid to vapor and has the potential to lower the temperature to the dew point. Greater differences between the air temperature and the dew point result in greater evaporation. The evaporation from a water surface can be measured from an open pan and varies greatly from south (warmer) to north (cooler) and west (dry air) to east (moist air) (Fig. 3). This phenomenon explains why evaporative air conditioners are used in the western U.S. but not in the Midwest.

So how can these simple observations be translated into the climatic constraints for crop production in the Great Plains? First, some definitions. Then, the journey.

Many people use “dryland” production as a synonym for “non-irrigated” production, but this is a misnomer. Dryland agriculture is practiced in regions where producing an annual crop on growing season precipitation alone is not possible. When annual crop production is possible solely with growing season precipitation, as in the Midwest, the correct term for non-irrigated production is rainfed, not dryland.

For dryland agriculture in the Great Plains and the Pacific Northwest, fallow is the practice of leaving land idle during a growing season *for the purpose of* storing precipitation in the soil for the subsequent crop. In the northern Great Plains and the Pacific Northwest, the production system was typically wheat–fallow (one crop in two years). In the southern Great Plains, the system was typically wheat–fallow–sorghum–fallow (two crops in three years). Using fallow, it is usually possible to successfully grow a crop on growing season precipitation *plus* the water stored in the soil during the fallow period.

Precipitation storage efficiency during the fallow period is diminished by evaporation. Evaporation is enhanced by tillage and bare soil surfaces. Historically, weed control during fallow was accomplished with tillage. More recent studies suggest more water often was lost to evaporation following tillage than from modest weed populations in the fallowed field. As tillage systems progressed from clean-till to sweep-till to no-till, average precipitation storage efficiency during the fallow period in the central Great Plains increased by more than 75% (Nielsen and

Vigil, 2010). The yields of the following crop increased with the additional water available to the crop.

How much water does it take to produce a crop?

So how much water does it take to produce a crop? It depends. Five things can happen to agricultural water: runoff, evaporation, percolation below the root zone, transpiration, or storage in soil. Transpiration is the only one that benefits a plant. Why? During photosynthesis, the plant uses carbon dioxide and water to produce carbohydrates and oxygen. Most of the water comes from the soil via uptake by plant roots. Carbon dioxide is obtained from the air through stomata in the plant leaves. When the stomata are open to take in carbon dioxide, oxygen and water vapor escape. The amount of water that escapes depends on the evaporative demand of the atmosphere—how dry the air is. And so, if the air is drier, as it is in the southern Plains compared with the northern Plains, more water escapes, and it takes more water moving through the plant to produce a unit of dry matter. This difference in crop productivity response associated with evaporative demand across the Great Plains region has long been known and was first reported for many different crops in 1917. For example, the water requirement data for alfalfa from that report (Fig. 4) indicates twice as much water is needed to produce a unit of alfalfa in Texas as is required in North Dakota.

Plants must produce a certain amount of biomass before they begin producing grain (Fig. 5). In a perfect world, all the water used in crop production would be transpired through the plant, but evaporation is inevitable and difficult to separate from transpiration. Without evaporation, biomass accumulation would begin with transpiration, but as the figure shows, it does not. Evapotranspiration (ET) is the sum of the water used by the plant in transpiration and lost from soil and plant surfaces through evaporation. The difference between zero cumulative ET and the point where biomass accumulation begins is evaporation.

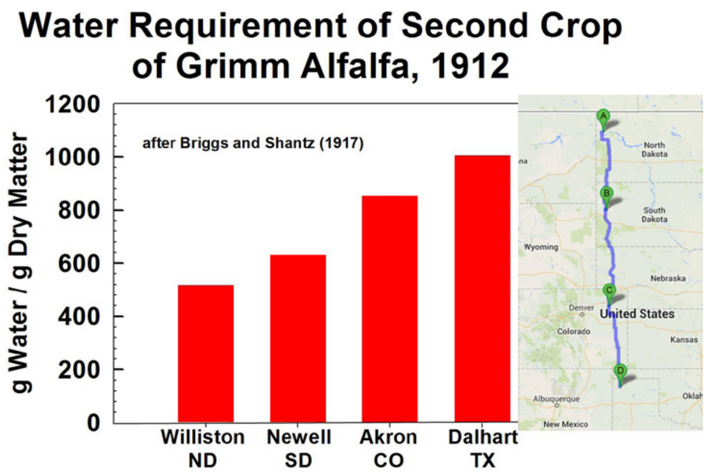


Fig. 4. Water requirement of second crop of Grimm alfalfa, 1912.

Crops vary in the amount of water they take to produce a unit of biomass or grain. Proso millet is considered a short-season, drought-tolerant crop, and when grown in Akron, CO, it will begin producing grain with less than 5 inches of water use (Fig. 6). On the other hand, corn needs almost 10 inches before it will produce grain. But once corn and millet start producing grain, as C4 plants, they use water much more efficiently than the C3 plants (wheat, safflower, and sunflower). The yield increase per inch of water used is least for the oilseed crops (safflower

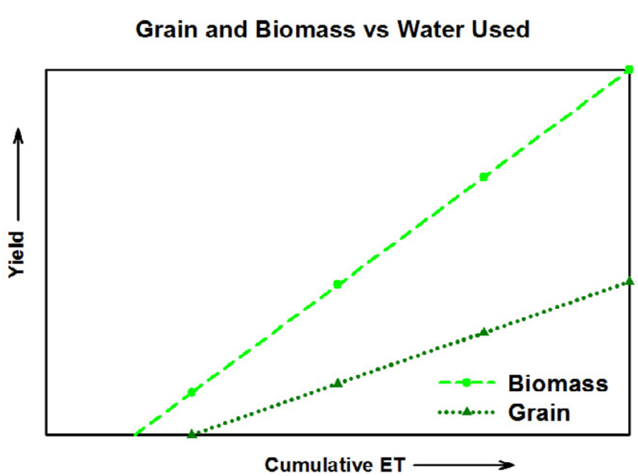


Fig. 5. General relation of grain and biomass to cumulative evapotranspiration (ET).

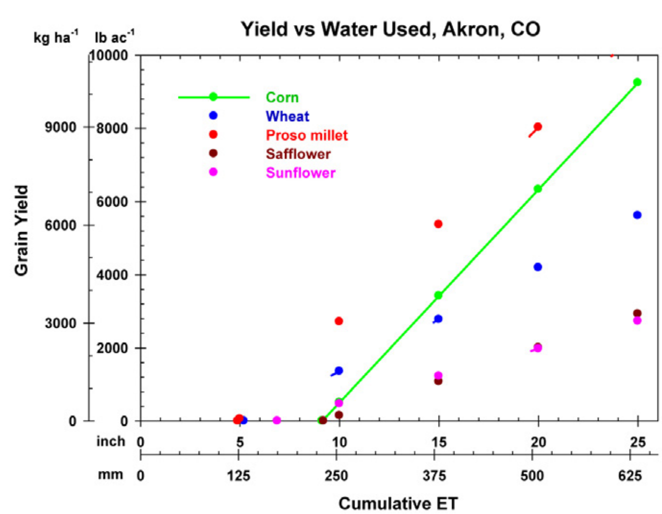


Fig. 6. Cumulative evapotranspiration (ET) and grain yield of several crops at Akron, CO

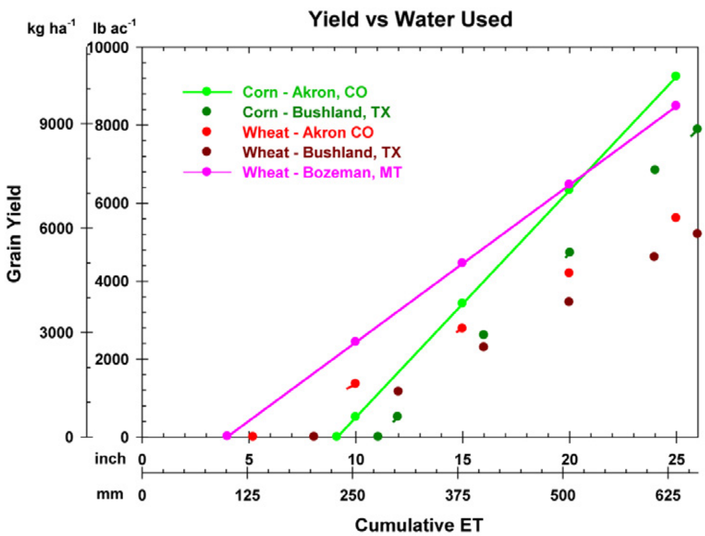


Fig. 7. Cumulative evapotranspiration (ET) and grain yield at Akron, CO; Bozeman, MT; and Bushland, TX.

and sunflower) because of the extra energy required by the plant to form oil compared with starch.

Bushland, TX gets a bit more precipitation than Akron but is warmer and drier and has greater evaporation rates (see previous figure). As a result, for both corn and wheat, less water is required to produce the first unit of grain in Akron than Bushland (Fig. 7). Even less water is required to produce the first unit of wheat at Bozeman, MT, and the water use efficiency (slope of line) is greater than at Akron or Bushland.

In order to understand and predict climate effects on crop production, agronomic climatologists and engineers developed methods to determine the potential evapotranspiration (PET). The PET is defined as the amount of water that would be lost from a 2-inch cool-season grass surface that is never limited for water. Lysimeters were used to measure these values, and mathematical models were developed to predict PET from weather parameters. The PET integrates how hot, dry, sunny, and windy the environment is. The PET at Akron and Bushland is about 70% of the Class A pan evaporation. The May-to-October Class A pan evaporation at Bushland is about 12 inches more than at Akron (Fig. 8) or about 8 inches of PET. The actual water use of a crop varies depending upon available water, plant growth stage (leaf area), and time of year. The actual ET increases with leaf area and eventually exceeds PET after canopy closure for most crops when adequate water is available to maintain non-water-stressed conditions.

The PET explains a great deal about the potential success or failure of a cropping system, and when considered with the precipitation, explains why fallowing was necessary to produce a dryland crop in the Great Plains. Some

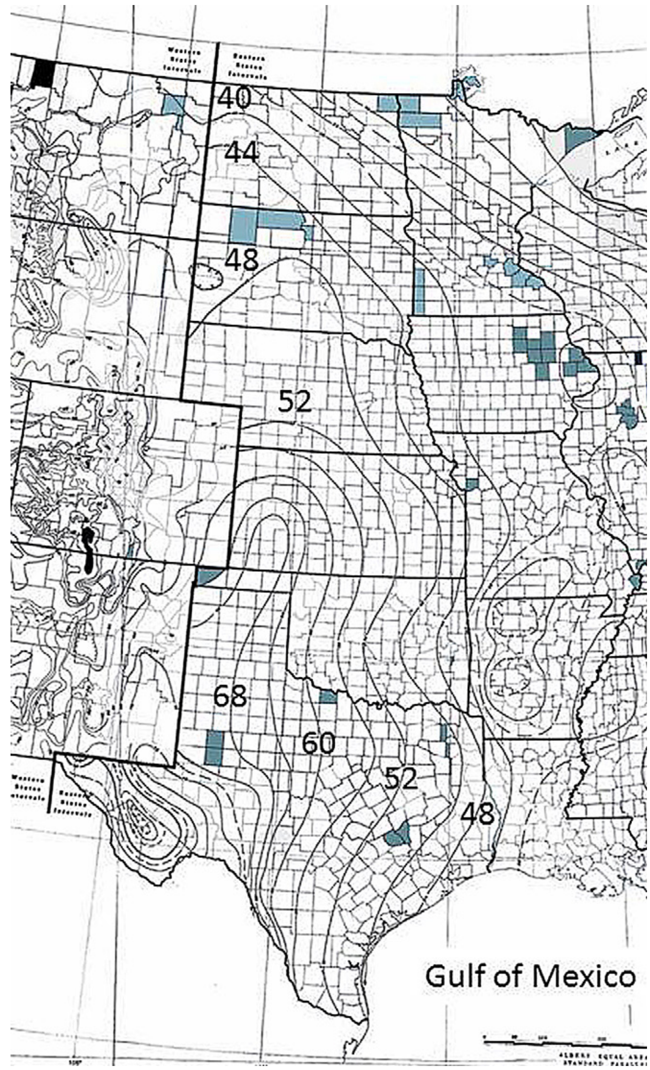


Fig. 8. May to October Class A pan evaporation, adapted from NOAA Technical Report NWS 33.

individuals use the ratio of the precipitation to the PET as a planning and classification tool (Fig. 9). Where precipitation exceeds about 35 to 40% of PET, rainfed farming is common. Where precipitation accounts for about 20 to 35% of PET, dryland farming is possible, if measures (such as reducing tillage and maintaining crop residues on the soil surface) are taken to store water in the soil during a fallow period. Irrigated agriculture is also common in these drier regions when adequate sources of irrigation water are available. When precipitation is less than about 20% of PET, irrigation is required to produce a crop. Using these guidelines, Bismarck, ND and Temple, TX are in the rainfed farming region while Big Spring, TX is on the marginal end of dryland farming.

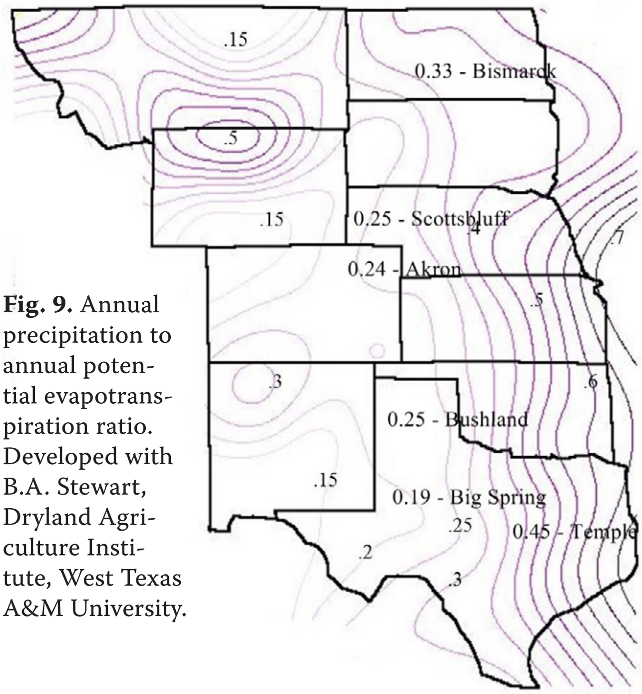


Fig. 9. Annual precipitation to annual potential evapotranspiration ratio. Developed with B.A. Stewart, Dryland Agriculture Institute, West Texas A&M University.

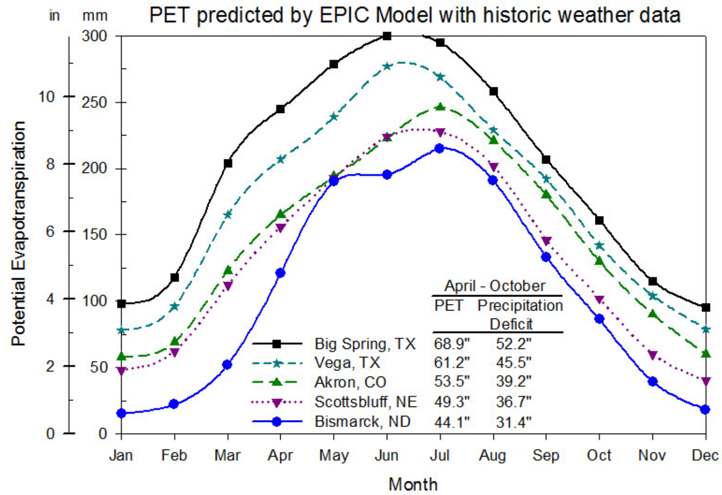


Fig. 10. Predicted potential evapotranspiration (PET) at five locations in the western Great Plains.

Journey from Ames, IA to Temple, TX

Now it is time to get back to that journey.

Become the traveler and embark on a journey from Ames, IA to Bismarck, ND; south along the western margin of the Great Plains to Big Spring, TX; then east to Temple, TX. Along the way, make observations about the potential for rainfed or dryland farming and the likely success or failure of integrating a cover crop into a cropping system as water becomes more and more limiting.

Ames lies in a humid region, in the heart of the Corn Belt, on the tallgrass prairie though hardly any area of native prairie remains. The annual PET is about 43 inches, but the precipitation is about 35 inches, for a deficit of about 8 inches for the year. The soil is black. Rainfed, annual cropping is the norm, and water is seldom the limiting factor for crop growth. Fall precipitation is usually sufficient to establish a cover crop, and the soil profile recharges every winter. The NRCS recommendation to terminate a cover crop at or within five days of planting (NRCS, 2014) but before germination generally results in no negative effect on the yield of the following crop.

Traveling northwest from Ames to Bismarck, the annual precipitation decreases more than half to about 16 inches, and the tall prairie grasses give way to mixed grasses. The soil is a little lighter but still almost black. The PET increases slightly to about 49 inches though 44 inches of that occurs in the growing season, from April 1 to October 31 (Fig. 10). The growing season precipitation deficit is the difference between PET and precipitation in that period. Conditions are less favorable than Ames, but annual, rainfed cropping is common, and cover crops are still possible, with enough fall moisture to establish the crop, and little ET throughout the winter as the crops are dormant and/or covered with snow. The NRCS recommends cover crops be terminated at least 15 days before planting (NRCS, 2014). Cover crops contribute to increases in soil organic carbon and biological activity. Yields of the following crops are seldom affected, and there often is a nitrogen benefit when legumes are included.

Traveling south to Scottsbluff, NE, the mixed grass prairie transitions to the shortgrass prairie, which continues all the way south to Big Spring. The annual precipitation decreases another inch while the annual PET increases to 62 inches. The soils are still dark but lighter than in Bismarck. The growing season PET and precipitation deficit both increase about 5 inches. The amount of water to produce one unit of plant biomass has increased by about 50% compared with North Dakota. Dryland cropping systems with a fallow period have become the norm, so as many as half the dryland fields lie idle during the growing season. Irrigation is common when an adequate water source is available. Some producers use cover crops but only as forage when incorporating livestock into their system (Watson, 2014). This usage does not fit the traditional cover crop concept in which the crop is not harvested and only provides cover during a period when cash crops would leave the ground bare (Nielsen, 2014). If planted after the cash crop to provide groundcover before planting the next cash crop, yields of following crops generally decrease. Increased costs and decreased yields necessitate an alternative income stream to remain economically viable, and so producers interested in forage crops typically integrate livestock into their management systems.

At least half the biomass should remain on the surface after grazing to provide cover until planting the next cash crop. The benefits to biological diversity and biomass are much less apparent in this central Great Plains location than in North Dakota (Watson, 2014). The NRCS recommendation for this region to terminate a cover crop 15 days or more before planting will often not allow sufficient time for the soil water to recharge enough to establish the economic crop. If the economic crop fails, surface residue cover may decrease to the point that it takes several years of fallow and no-till management to recover. It may require as much as 5 inches of irrigation water to establish a cover crop, increasing production costs even more. Therefore, without an additional income stream, most producers will not irrigate a cover crop following the harvest of a cash crop. The most valuable cover available are surface residues from the cash crops, optimized through no-till management systems and inclusion of high-residue crops such as wheat every two to three years.

Continuing south on the journey to Akron, the precipitation increases about an inch, the PET by about 4 inches, and the precipitation deficit about 2 inches. The soil color is similar to Scottsbluff and changes little until approaching Lubbock, TX. The amount of water to produce one unit of plant biomass has increased by about 80% compared with North Dakota. The historic dryland crop production system was wheat–fallow, one crop in two years, with the fallow period used to enhance soil water storage to limit the risk of crop failure. With the development of reduced-tillage and no-till systems that promoted residue cover that increased soil water storage, wheat–summer crop–fallow systems, two crops in three years, are now common in dryland production systems, so about 30 to 40% of the cropland lies fallow each year. Irrigation is practiced when water is available.

The most valuable cover available is the residue from cash crops. Producers have little interest in cover crops due to the increased costs to establish the crops, but mostly due to the increased risk of a crop failure in the following cash crop. Within a wheat–fallow conventional-tillage production system, replacing 2.5 months of the 14-month fallow period with a legume cover crop can decrease average soil water available for the next wheat crop in this region by 20% and subsequent wheat yield by 25% (Nielsen and Vigil, 2005). If the legume cover crop is allowed to grow for another 30 days (75 days prior to wheat planting), an additional 2 inches of water is used and the subsequent wheat yield is reduced another 12 bu/ac (a 45% reduction in yield compared with the wheat-on-fallow yield). Mixed-species cover crops can use even more water and to greater soil depths than some single species used as cover crops, resulting in greater cash crop yield decreases.

Water is the most limiting factor for all biological activity, whether crop growth or soil organisms. While increases in soil microbiological activity or microbial populations are observed in this region with cover crops compared with fallow periods, increases in wheat yields due to that biological activity have not been observed. Wheat yields following no-till fallow are often 20 to 50% greater than if following a cover crop. In Garden City, KS, wheat yields following fallow may be two to seven times those following a cover crop (Nielsen, 2014). Though the NRCS recommends terminating a cover crop 35 days or more before planting the cash crop in this region (NRCS, 2014), this is insufficient time to allow soil water recharge, as illustrated by these wheat yields.

Traveling south from Akron, the short grasses get shorter, the annual PET increases about 12 inches from Akron to Vega, and another 12 inches from Vega to Big Spring, and the growing season precipitation deficit grows by about 6 inches more with each leg of the journey. The amount of water required to produce one unit of biomass is about double that in North Dakota. Irrigation is the dominant crop production system when water is available though dryland production acreage increases as the water supply diminishes. Dryland acres in the western Texas Panhandle are dominated by wheat–sorghum–fallow cropping systems, and native prairies are common, as are CRP (Conservation Reserve Program) fields. Dryland crop production is a risky venture, and CRP offers a reliable income. Incorporating no-till management into wheat–sorghum–fallow production increased the stored soil water at planting and average wheat yield from about 15 bu/ac with conventional tillage to 30 to 45 bu/ac. This increased stored soil water availability still is not sufficient to incorporate cover crops without risking crop failure in the following wheat or sorghum crop.

Wheat and sorghum residues are resistant to decomposition and degradation over time and provide good surface cover. Since water is the most limiting factor to biological activity, decomposition and earthworm activity are minimal. Residues persist on the surface for months. It is not uncommon to find some sorghum or wheat residue at the surface more than two years after harvest when that crop is planted in the next cycle of the rotation. Limiting tillage is the most effective way to increase soil organic matter and improve soil health. Some irrigated producers might consider cover crops, but it is a hard sell to ask a producer to spend the money to pump 2 to 5 inches of water to establish a crop they will not harvest. Some producers might use the cover crop for grazing to improve the income stream, but without careful grazing management, remaining residues may be minimal, subjecting the valuable soil resource to damage from erosion.

Going south towards Lubbock, the dominant crop shifts to cotton and the soil color begins to lighten with an ob-

Webinar

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Last year, the American Society of Agronomy (ASA) broadcast a webinar series titled “Cover Crops 2.0.” This webinar can be viewed at **http://agronomy.peachnewmedia.com**. The series examines the reasons many of the benefits associated with cover crop use may not be seen in water-limited environments such as those found in parts of the Great Plains. These reasons have to do with the differences in both the atmospheric forces driving crop evapotranspiration (water use) and the available precipitation that occurs in different regions of the country. Data from both long- and short-term experiments conducted under dryland conditions are presented that document cover crop water use (both from single-species and mixed-species plantings) and the effects of that water use on subsequent winter wheat yield. Costs associated with cover crop use are also documented. Major concerns for dryland crop production in this region are reduction of soil erosion potential and effective storage of precipitation. These two concerns may best be dealt with by good no-till management of existing crop residues rather than incorporation of cover crops into the cropping system. *CEUs available.*

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servable reddish tint that becomes dominant on the way to Big Spring. Wheat and other cool-season crops drop out of the rotation because the spring temperature and precipitation patterns do not match. The growing season precipitation deficit exceeds 50 inches, and the amount of water to produce a unit of biomass is about 250% of that in North Dakota. Only drought-resistant crops such as cotton are reasonable choices. Crop–livestock systems are left behind, so there is little need to grow forage crops. Cover crops use water that could be used to grow a cash crop. The bimodal precipitation pattern here might provide enough precipitation to establish a cover crop in some years, but the cover crop depletes the soil water, decreasing the yield of the following cotton crop and increasing the likelihood of a total crop failure. Irrigated producers are reluctant to sacrifice their limited water to a cover crop that will not bring in any income.

Turning east from Big Spring, the annual precipitation increases about 1 inch every 25 miles. The precipitation almost doubles by the time we arrive at Temple, TX, and the precipitation deficit is down to about 33 inches although the PET is about the same as Akron. The vegetation has changed from short-grass, to mixed-grass prairies, to oak savannah and mixed grasses. Cover crops are again a possibility because of the amount and timing of the precipitation.

Now our journey is done, and we’ve seen the reasons for why it takes 2.5 inches of water to do the same kind of crop production in Big Spring as it does for what an inch of water can produce in Bismarck (or perhaps less than three-fourths of an inch in Ames). This climatological difference, more than any other factor, determines the potential for successfully incorporating cover crops into a cropping system and maintaining economic viability. &

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