Guide to Drought Tolerance of Utah Field Crops

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Overview
Crop variety selection is one of the most important choices on the farm. Crop genetics determine a significant portion of the yield potential and resource use efficiency. Crop types and genetics that use water more efficiently will become increasingly important as water becomes scarcer. Throughout Utah and the Western United States, water availability is decreasing due to various factors, including reduced snowpack and rapid urban growth. Alfalfa, other hay, small grains, and corn are grown on more acres than any other crops in Utah and much of the Intermountain West. These crops all have varieties, hybrids, and cultivars with the potential for more efficient water use while mitigating yield loss. Navigating these options and understanding various mechanisms and effectiveness can be a challenge. This guide will address some of the primary mechanisms, options, and effectiveness of crop genetics for improved water use efficiency.

What Is Water Use Efficiency?
As water is a limitation in crop production, the need for crops to use every applied and natural (i.e., precipitation) unit of water is a high priority. One definition of crop water use efficiency (WUE) is the biomass or grain yield produced per unit of the total water used by the crop. It is calculated as \( WUE = \frac{Y}{ET} \), where \( Y \) is the crop yield, either in total harvestable biomass or marketed yield, and \( ET \) is the combined water evaporation from the soil surface and water transpired by plants (Hatfield et al., 2001).

Water use efficiency is influenced by many factors, including soil and climate conditions. Crop type, management, and genetics also heavily influence

Highlights

- **In four Utah trials**, an alfalfa variety bred for greater drought tolerance (Ladak II) has not consistently yielded better than conventional varieties under full irrigation or drought stress conditions during the first two years of alfalfa production.
- **In five Utah trials**, a corn hybrid genetically modified for drought tolerance has not consistently yielded better or been more profitable than conventional hybrids in full irrigation or drought-stress conditions.
- **Crop genetics for drought tolerance** have shown few water-saving benefits in Utah and should be considered with caution until more research confirms their profitability.
WUE. Although WUE can vary widely, commonly reported values for major grain crops range from about 275 pounds of grain per acre inch of water for corn to 500 pounds of grain per acre inch of water for wheat (Putnam et al., 2001; Sadras & Angus, 2006). Alfalfa is about 300 pounds of biomass per acre inch of water. Silage corn and small grain forages have among the highest reported WUE. Silage corn has WUE of about 910 pounds per acre inch, and wheat forage has a value of about 700 pounds of dry matter per acre inch (Nilahyane & Islam, 2018; Marsalis, 2018).

Another factor to consider when evaluating efficiency is the harvest index. The harvest index is the percentage of the above-ground biomass harvested (Putnam et al., 2001). Because the complete leaf and stem are collected, alfalfa has a harvest index of 100. This is compared to grain corn with a harvest index of 50 or wheat with an index of 45. This increases the efficiency of alfalfa because all water used in the above-ground biomass is harvested compared to grain production, where half the biomass is unharvested. For this reason, silage corn and forage grains also have a higher harvest index and WUE. Several ongoing genetic and management efforts exist to improve the water use efficiencies of these crops.

Alfalfa
Alfalfa is grown and harvested on more acres than any other crop in Utah and other western states. The crop has natural drought-tolerant characteristics due to deep roots and the ability to induce drought dormancy until water returns to adequate levels. There are no genetically modified varieties for drought-tolerant traits currently available on the market, unlike some other crops. Instead, varieties bred or selected for their enhanced drought tolerance are available. Further, some varieties have also been bred for dryland settings with low precipitation (12–18 inches annual precipitation) and no irrigation. Four drought-tolerant traits desired by breeders are the (1) root system's depth and size and (2) the stomata (leaf pores) density per leaf (Quan et al., 2015), as well as (3) plant height and (4) leaf-to-stem ratio (Ray et al., 1999).

Variety Selection
Many alfalfa varieties are rated for drought dormancy, fall dormancy, and/or winter dormancy. When selecting a variety, drought tolerance dormancy should not be confused with fall or winter dormancy ratings. Following is a description of each rating:

- **Drought dormancy** is referred to as summer dormancy in some cases as it is related to dehydration tolerance. During prolonged periods of soil moisture depletion, alfalfa will enter into dormancy. The plant can limit above-ground growth while storing energy reserves in the root system to ensure recovery when water becomes available (Sheaffer et al., 1998; Orloff et al., 2015). This feature allows alfalfa to survive without irrigation for extended periods.

- **Fall dormancy** is a rating of the degree of fall alfalfa growth as a response to temperature and day length. It is determined by clipping alfalfa about 25 to 30 days before a killing frost and measuring the height of regrowth near frost. Lower dormancy ratings exhibit more fall growth,
While higher dormancy ratings indicate less fall growth (Davison et al., 2016). These ratings are indices assigned by comparing the height of fall growth with standard check varieties. They are tested in multiple locations and years to accurately estimate dormancy response across different environments. In some cases, a grower may use a higher dormancy rating to save water but generally, this sacrifices growth and makes a shorter growing season.

- **Winter dormancy** is also referred to as winter hardiness or winter survival. This dormancy is defined as the ability to survive through the winter. It is achieved either by developing a powerful frost tolerance ability or limiting the life cycle to the short summer season.

The two main dormancy ratings, fall and winter, are sometimes used interchangeably. Some varieties with low fall dormancy ratings begin to grow sooner in the spring, resulting in the uptake of early rain and earlier regrowth compared to other varieties with higher dormancy ratings (Undersander, 2015). Because it is hard to determine the differences in drought dormancy in varieties, it is not given in many variety rating reports but can often be obtained from the seed producer. In Utah, fall dormancy ratings of 3 to 5 are used most often.

**Drought Variety Trials**

Three long-term water optimization trials were established in Utah: Logan in 2019, Vernal in 2020, and Cedar City in 2021. Ladak II, a drought-tolerant variety, was compared to conventional varieties common to each of the three areas. Both varieties at each site were tested under differing drought levels. Treatments were replicated three times at each of the three sites. Alfalfa yield and forage quality were measured on the establishment and first-year production at each site.

The conventional varieties used were Nexgrow 6306Q at $4.56 per pound in Logan, WL319HQ at $4.26 per pound in Vernal, and IFA414 at $2.77 in Cedar City. At $3.85 per pound, the Ladak II variety was about $0.40 more per pound than a local brand and approximately $0.40 to $0.71 less per pound than varieties from large seed companies.

In young alfalfa stands at our three trials, Ladak II has not yet shown any evidence of outperforming conventional alfalfa varieties in terms of yield under deficit or full irrigation. In Cedar City and Logan, conventional varieties were superior in yield to drought-tolerant genetics in the seeding year. In Vernal, the yields of the two varieties were the same in the seeding year. The only site with a full production year after establishment was Logan in 2021, with both the conventional and drought-tolerant variety yielding the same (Figure 2). Under deficit irrigation, Ladak II has not yet shown yield advantages over conventional varieties.

Although Ladak II has not shown evidence of improving yield, it has shown improved feed quality. Relative feed value (RFV) was improved in two-thirds of the alfalfa cuttings across sites and maintained the RFV value in the other third of cuttings. The average RFV across all cuttings was increased in both years at the Logan site and was similar to conventional varieties at the other two
sites (Figure 3). Increased RFV has the potential to increase hay values. Ladak II outperformed the conventional varieties in half of the cases for relative feed quality (RFQ), and no differences were observed in the remaining half. Despite elevated feed value and quality in our study, the additional feed value would not have improved the market price of the alfalfa because it was already classified within the supreme category.

Figure 2. Alfalfa Yield of Conventional Varieties Compared to Ladak II, a Variety Bred for Greater Water Use Efficiency or Drought Tolerance
Note. All data was for the seeding year except the second year in 2021 at the Logan site. Averages with different letters within a site and year were statistically different.

Figure 3. Alfalfa Average Relative Feed Value (RFV) of All Cuts of Conventional Varieties Compared to Ladak II, a Variety Bred for Greater Water Use Efficiency or Drought Tolerance
Note. All data was for the seeding year except the second year in 2021 at the Logan site. Averages with different letters within a site and year were statistically different.
Corn

Improved WUE and drought-tolerance efforts for corn have included crop breeding and genetic modifications. Corn has had more genetic modification than most other crops, including improvements for enhanced drought tolerance. Drought-tolerant corn varieties were available on the market beginning in 2013 (McFadden, 2019). Various seed breeding companies have developed different varieties of drought-tolerant corn, making the choice for the producer more complex. Table 1 summarizes a few of the available drought-tolerant traits, the seed company producing them, and their main development pathway.

### Table 1. Some Available Drought-Tolerant Corn Hybrid Types

<table>
<thead>
<tr>
<th>Seed company</th>
<th>Trait name</th>
<th>Conventional/GMO</th>
<th>Modified trait or characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayer</td>
<td>DroughtGard®</td>
<td>GMO</td>
<td>• Inserted stress response gene, allowing for continued protein production during low moisture levels</td>
</tr>
</tbody>
</table>
| Syngenta     | Artesian®   | Conventional     | • Regulated pollen shed and silking  
• Increased volume of harvestable grain  
• Maintained normal growth and development longer during drought stress  
• Optimized growth and health of developing roots, shoots, and floral tissues |
| Corteva      | Optimum®    | Conventional     | • Improved root systems  
• Competitive silk emergence  
• Optimized stomatal closure |
| Corteva      | AQUAmx®     | Conventional     | |

Drought Varieties

The DroughtGard® trait, produced by Bayer, uses biotechnology to offer a defense against the weather as it becomes increasingly unpredictable (Ciampitti et al., 2017). This technology involves inserting a stress response gene into the genetic sequence. This gene allows for continued protein production in the plant that traditionally would have been halted when moisture levels drop below manageable amounts. Protein production is essential for plant growth and DroughtGard technology was designed for growth stability in drought conditions (Bayer, 2017).

Syngenta’s Artesian® is a conventionally bred corn line for drought tolerant vigor. The hybrid has five improved areas to help ensure minimal yield loss during dry periods. The plants better regulate pollen shed and silking resulting in successful fertilization and kernel development. Better resource allocations within the plant have been studied to increase the volume of harvestable grain per ear. The plant can better maintain normal growth and development longer during periods of drought stress, limiting wilting and curling. These hybrids have also optimized the growth and health of developing roots, shoots, and floral tissues (Agrisure Artesian, 2015).
Similar to Artesian, Optimum® AQUAmax® by Corteva is another traditionally bred hybrid line of high-producing drought-tolerant corn. The key trait areas bred for these hybrid lines are improved root systems, competitive silk emergence, and optimized stomal closure. The hybrids are adapted to withstand and maintain yield in drought conditions or remain competitive in nature to other hybrids in a normal environment (Dupont Pioneer, 2013).

**Drought Trials**
Corn water optimization trials were conducted at the same three locations (Logan, Vernal, and Cedar City) as the alfalfa drought-tolerance trials described above from 2019 to 2021. This work has produced five trials of data on the comparison of drought-tolerant and non-drought-tolerant corn hybrids at full and reduced irrigation rates (100%, 75%, and 50%). Comparing a hybrid bred for drought tolerance to a non-drought-tolerant hybrid is difficult because the breeding process usually results in different characteristics of the hybrid (such as day length, pest and disease resistance, etc.). Thus, we elected to use a drought-tolerant hybrid developed with genetic engineering in order to compare two hybrids that were as similar as possible.

In the research trials, we compared two DeKalb hybrids each year at each site. The drought-tolerant hybrid was as similar as possible in all traits (Roundup Ready®, 94 to 96-day length, and pest resistances) to the non-drought-tolerant hybrids, with the exception of the inserted DroughtGard® gene in the drought-tolerant hybrid (Figure 4). The hybrid pairs (non- and drought-tolerant) changed after 2019 because some hybrids were no longer available. This resulted in DKC 51-20 as the drought-tolerant and DKC 50-84 as the non-drought-tolerant in 2019 at Logan. DKC 47-27 was the drought-tolerant hybrid and DKC 46-36 was the non-drought-tolerant hybrid in the other four trials. During 2019 and 2020, the price of the corn seed was about $288 per bag (80,000 seeds) for the non-drought-tolerant and $305 per bag for the drought-tolerant hybrid. Thus, assuming a bag could plant about two acres, the drought-tolerant hybrid cost about $8.50 more per acre than the non-drought-tolerant hybrid.

Figure 5 shows the corn silage yields per site year. Drought-tolerant silage corn yielded on a dry matter basis 5.9 to 16.5 tons per acre while the conventional genetics yielded 7 to 16.3 tons per acre. The lowest yield occurred in Vernal in 2021 due to a water shortage that resulted in an early harvest in August. Despite the variation in yield among sites and years, there was **never a significant difference in corn silage yield between the drought-tolerant genetics and conventional genetics.** This was true at the full irrigation rate and all reduced rates. Thus, all the data shown were averaged across irrigation rates for simplicity.

**Figure 4.** Two DeKalb Hybrids Used in the 2020 Corn Genetics Trial in Logan, Utah, Had Nearly Identical Traits, Except the Drought Tolerant (DT) Hybrid Had the DroughtGard® Trait Inserted
Figure 5. Silage Corn Yields of Drought-Tolerant (DroughtGard® Trait) and Conventional Hybrids Across Irrigation Levels in Five Utah Trials

Figure 6 shows silage corn protein values were affected by corn genetics in three of the five trials where the drought-tolerant hybrid increased protein by 3% to 8%. Values ranged from 20.7% to 24.9% with conventional genetics and 21.3% to 25% with drought-tolerant genetics. Starch values were affected by corn genetics in two of the five trials. At Vernal in 2020, starch was 4% higher with drought-tolerant genetics, and the following year, starch was 2% higher using drought-tolerant genetics (Figure 7). Total digestible nutrients (TDN) had significant differences for three trials, with the conventional genetics producing higher values than the drought-tolerant hybrid (Figure 8). At Logan in 2020, the conventional hybrid had 9% greater TDN than the drought-tolerant hybrid. For Vernal in 2020, there was a 10% advantage with the conventional hybrid, and 2021 had a 19% difference, with the conventional hybrid producing 15.9% and the drought-tolerant at 12.9%.

Figure 6. Silage Corn Crude Protein of Drought-Tolerant (DroughtGard® Trait) and Conventional Hybrids Across Irrigation Levels in Five Utah Trials
Results from these five trials indicate that the genetically modified drought-tolerant hybrids provide little to no consistent advantage in terms of yield and forage quality over similar non-drought-tolerant hybrids. The exception was that the drought-tolerant hybrid improved silage corn protein in 4 of 5 trials (Figure 6). However, this improvement in protein occurred with full and deficit irrigation, so it is not specific to drought conditions.

While our Utah trials did not result in consistent increases in crop yield from the use of drought-tolerant varieties, a Kansas trial indicated different results. Drought-tolerant varieties performed better with environmental stressors and were competitive in yield with non-drought varieties when water was not limiting. Across nearly 350 corn trials, drought-tolerant varieties commonly outyielded non-drought varieties by 5 to 15 bushels.
per acre (Ciampitti et al., 2017). As the yield of the non-drought-tolerant varieties decreased, the yield advantage of drought-tolerant varieties increased. Thus, there is likely situations in Utah and the West were drought-tolerant corn hybrids can increase yield and quality in water-stressed conditions, but we have not been able to detect them yet in our trials. This drought-tolerant hybrid technology does come with a cost. As stated earlier, drought-tolerant corn hybrids increase seed costs by about $8-10 per acre (McFadden, 2019). Thus, ensuring recovery of this added cost when investing in drought-tolerant genetics is a principle question that will drive future Utah research.

Small Grains

Small grains often have higher WUE than other crops due to their shorter and earlier growing season. This can be heavily influenced by the species and harvest type (forage versus grain) of various small grains. The WUE of small grains increases when the crop is harvested as a forage compared to grain because the harvested biomass is greater, and forages generally require less irrigation than grain production. Wheat harvested for grain has a WUE between 452–498 pounds per acre inch (Sadras et al., 2006) compared to an average of 702 pounds of dry matter per acre inch for small grain forage (Marsalis, 2018).

Unlike most crops, small grains are one of the few crops that can withstand dryland growing conditions. Small grains, however, can be highly affected by drought conditions, and historically, irrigation at the right levels and time has drastically improved yield. A study conducted in Western Kansas found that irrigated land yields outperformed dryland wheat by an average of 26%, depending on annual precipitation levels (Norwood, 1995). However, in New Mexico, where the average annual rainfall is much less and more similar to Utah’s rainfall, properly timed irrigation can nearly double small grain yields compared to dryland cropping (Marsalis, 2018). Lower yields in dryland wheat can lead to a higher quality crop than that of irrigated land. Drought-stressed, dryland wheat tends to have a higher protein content than irrigated wheat (Jones & Olson-Rutz, 2020). The water use efficiency of irrigated land is also greater than that of dryland systems. A Texas study found that irrigated wheat averaged twice the WUE of dryland wheat (Musick et al., 1994).

Drought-Tolerant Varieties

Genetically modified drought-tolerant small grain varieties are not currently available on the United States market but may be on the horizon for wheat (Gupta et al., 2017). Instead, drought tolerance has been advanced using conventional breeding techniques. Wheat drought tolerance can be increased by either losing less or taking up more water (Stanfield, 2020). This occurs through managing several traits within wheat and a combination of improvements that allow for the greatest increase in resistance to drought conditions.

Crop breeding efforts for enhanced drought tolerance have included aggressive seedling establishment that decreases evaporation due to greater ground covering early in the season. Breeding for shorter plants increases the harvest index, and improved root systems increase the water uptake. More rapid maturity helps the plant to avoid terminal drought stress and increases its ability to manage evaporative losses, resulting in greater WUE (Mwadzingeni et al., 2016). Enhanced stomatal control and an increase in leaf wax reduce the plant’s water loss (Stanfield, 2020).

For wheat in certain studies, increased yields during times of drought come from the increase in biomass rather than harvest index, which is a key factor in dryland wheat production, and was seen in many newer varieties (Ledbetter, 2013). However, this has also become a problem in irrigated wheat due to tall plants that result in increased lodging. Dryland varieties often do not do well in irrigated settings due to lodging unless irrigation levels are extremely low. Thus, they may only work as a drought-tolerant option where irrigation is severely restricted during drought.
Drought Trials
Utah State University has a long history of testing and developing small grain varieties. Most of these have been dryland varieties, which handle low precipitation well but have limited applicability in irrigated settings. Many studies have examined various small grain irrigation requirements or the performance of several irrigated varieties. However, few have evaluated how several small grain varieties of the same class and type differ in their irrigation requirements. Thus, more local research on this topic is needed and subsequently will be the focus of future research at USU.

Summary
As drought becomes more common and intense in many regions, it is essential that options for drought tolerant crop varieties be explored and considered for growing areas affected by drought. Continued research is being conducted on the performance of drought tolerant varieties and hybrids, specifically in the West. Five Utah studies comparing conventional and drought tolerant varieties of corn and alfalfa have shown little to no consistent increase in crop yield and performance of the drought-tolerant varieties in contrast to conventional varieties. Therefore, drought tolerant options should be considered carefully until further research can locally verify that the agronomic benefits outweigh the added cost.

References


### Other Resources


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