The Effect of Growing Environment and Harvest Management On Yield and Nutritional Quality of Corn Silage and Grain

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INTRODUCTION

The final feeding quality of corn silage or grain is a function of plant genetics, growing environment, harvest timing/management, extent of processing/grinding, and length of time ensiled for fermented feeds. The influence of growing conditions (especially moisture) is a major source of the yield and nutritional variability seen within hybrids across years and locations. University of Illinois research (Below, 2009) attributes only 19 % of grain yield performance to hybrid genetics, with the remaining influence the result of weather (27 %), nitrogen (26 %), previous crop (10 %), plant population (8 %), tillage (6 %) and growth regulators (4 %). The purpose of this paper is to review the influence of environmental factors (over which we have little control) versus harvest maturity and processing factors where producers and nutritionist can exert significant influence.

GENETICS AND ENVIRONMENT

The influence of growing conditions (especially moisture) seems a major source of the nutritional variability seen within hybrids across years and locations. Corn breeders are very interested in the interaction between genetics and environment (**GxE**). If GxE (in a statistical sense) is significant, then it means hybrids grown in different environments could rank differently for any particular trait. Contrast this to environmental influence on genetics indicating they will rank similar across environments, but the relative magnitude of difference will be smaller or larger depending upon the particular environment. It could also mean the absolute values will change with no change in the relative hybrid differences between environments. While GxE is a very real effect experienced by hybrids and explains why seed companies do so much testing to determine the area of adaptation of hybrids, there is no indication that nutritional characteristics are any more susceptible to environmental interactions than either grain or whole plant yield (Coors, 1996).

The impact of growing environment on the lower-than-expected grain yield in the 2010 Iowa corn crop was recently modeled by Iowa State researchers (Elmore, 2010) to test the hypothesis that warmer 2010 minimum temperatures between silking and dent reduced grain yield potential. Two sets of simulations were performed using the University of Nebraska-Lincoln computer model, Hybrid-Maize. This crop model aids the understanding of the interactions between management, genetics, and weather by allowing users to fix practices such as planting, emergence date, plant population, water regime, and crop heat unit requirements. Simulations were run comparing the 8 degrees warmer maximum temperatures in 2011 against temperatures actually recorded in 2010. The Hybrid-Maize model predicted grain yield reductions during seed fill due to either fewer kernels per ear (tipping back), decreased kernel weights or both. USDA-NASS yield forecasts earlier in the 2011 growing season are not able to predict either of these variables with precision (Elmore, 2010).

The tremendous influence of growing environment on corn silage yield and nutritional value is depicted in Figure 1 which shows the relative silage yield, starch content, and 24-hr neutral detergent fiber digestibility (**NDFD**) of the same hybrid grown in 14 locations in Michigan in 2009 (Bolinger, 2010). This clearly demonstrates why it is not valid for nutritionists to attribute hybrid genetics as the primary cause of nutritional differences when comparing hybrids grown on different farms. This is also why seed companies and universities prefer to compare hybrids grown in the same location (side-by-side's) within the same maturity, seed treatments, technology segment, and planting populations.

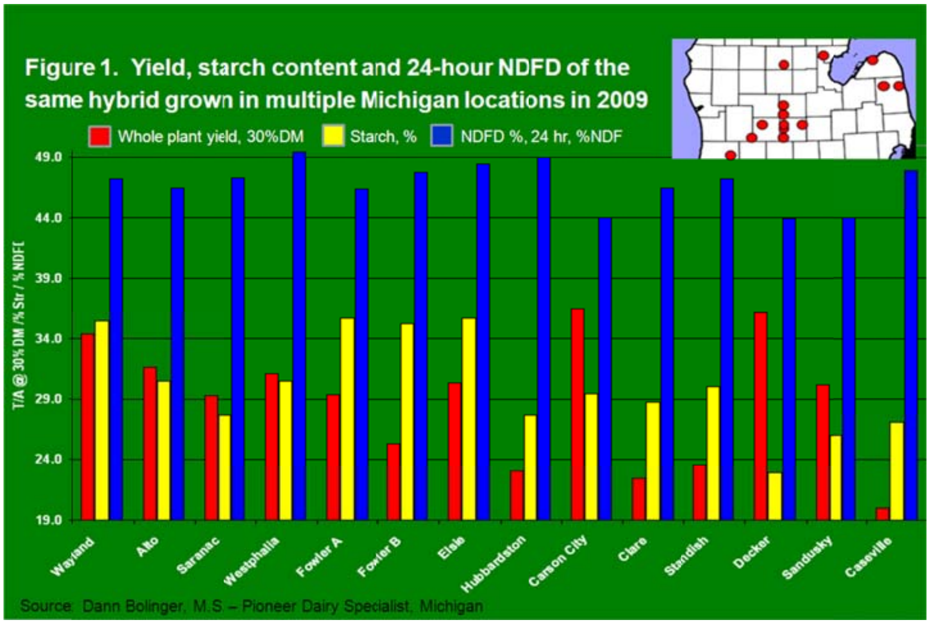


Figure 1. Yield, starch content and 24-hour NDFD of the same hybrid grown in multiple Michigan locations in 2009

Source: Dann Bolinger, M.S – Pioneer Dairy Specialist, Michigan

MOISTURE STRESS

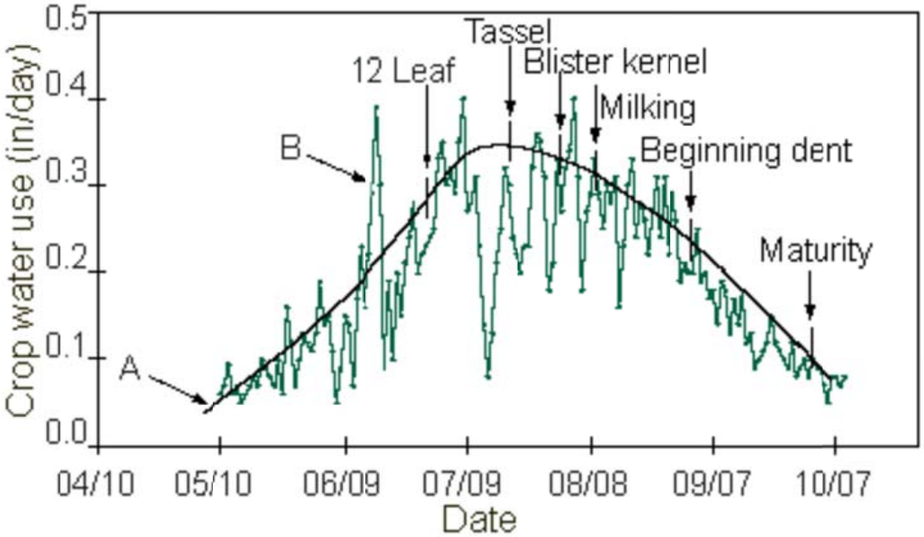
At some point during the growing season, 85 % of all corn acres will experience some level of water deficit (Warner, 2011). Knowledge of the relationships between plants and their environment is vital to successful irrigation management (Kranz et al., 2008). Soil characteristics important to irrigation management include water holding capacity, water intake rate, and restrictive soil layers that might limit root penetration and/or water movement. Plant factors include crop development characteristics, rooting depth, and daily and total seasonal crop water use. Atmospheric factors are solar radiation, air temperature, relative humidity, and wind. Total available seasonal water supply is also important (Shanahan and Groeteke, 2011).

Irrigated corn grain yields are about 30 % higher than non-irrigated yields, attributing to irrigated corn accounting for nearly 20 % of total U.S. corn production while occupying only 15 % of acres (USDA, 2007). Much of the irrigated corn is cultivated in the semiarid Great Plains region (Musick and Dusek, 1980) of the U.S., with corn occupying more irrigated acres in this area than any other crop (Norwood, 2000). However, recent concerns have been raised regarding declining surface and groundwater supplies (Clark et al., 2002) and increased pumping costs (Norwood and Dumler, 2002) in this region. For this reason, improving management practices under declining water supplies is critical for sustaining irrigation water resources (Shanahan and Groeteke, 2011).

Corn production uses water through evapotranspiration (**ET**). In this process, water is removed directly from the soil surface to the atmosphere by evaporation and through the plant by transpiration. Plant transpiration is evaporation of water from leaf and other plant surfaces. For corn, evaporation often accounts for 20 to 30 % and transpiration 70 to 80 % of total ET over the course of a growing season. Transpiration involves a continuous flow of water from the soil profile, into the plant roots, through plant stems and leaves, and into the atmosphere. This serves to cool the crop canopy and prevent leaf tissues from reaching lethal temperatures. Additionally, water from transpiration provides positive pressure inside cells that gives plants much of their structure and ability to stand. Finally, the transpiration stream carries water-soluble nutrients like nitrate and potassium from the soil into the plant, providing essential nourishment for plant growth (Shanahan and Groeteke, 2011).

Both evaporation and transpiration are driven by a tremendous drying force the atmosphere exerts on soil or plant surfaces. Hence the magnitude of daily ET will vary with atmospheric conditions. For example, high solar radiation and air temperatures, low humidity, clear skies, and high wind increase ET; while cloudy, cool, and calm days reduce ET. Seasonal water use is also affected by growth stage, length of growing season, soil fertility, water availability, and the interaction of these factors. Although the amount of daily water use by the crop will vary from season-to-season and location-to-location, it will generally follow the pattern shown in Figure 2.

Figure 2. Long-term daily average (smooth line) and individual year (jagged line) corn water use by growth stage as per Kranz et al. (2008).



When water supplies cannot fully compensate for crop ET, grain yields are reduced versus fully irrigated corn. To maximize yields and returns under limited water supplies growers must understand how corn responds to water, and how changes in irrigation and agronomic practices can influence water needs as affected by growth stage, irrigation timing, crop residue, and hybrid and plant population selected. The impact of water stress on corn grain yields varies with crop growth stage (Figure 2). Corn is relativity insensitive to water deficits during early vegetative growth because water demand is relatively low (Figure 2). Plants can adapt to water stress throughout most of the vegetative period to reduce its impact on grain yield (Shaw, 1977). The fact that corn grain yield is much more sensitive to water stress from flowering though grain fill (Shaw, 1977; Doerge, 2008) with the vegetative stage less sensitive, judiciously delaying of the first irrigation may offer an opportunity to conserve water and maintain profitability. Growers may be able to delay the first irrigation as late as tasseling in years of lower evaporative demand provided soil water reserves are ample at planting and irrigation systems have the capacity to rapidly correct soil water deficits (Shanahan and Groeteke, 2011).

FIBER

Van Soest (1996) and Van Soest and Hall (1998) suggest that cool, dry years are best for corn silage quality and that slight moisture stress might also stimulate seed (grain) production. Cool temperatures (especially at night) appear to inhibit secondary cell wall development. These studies suggest that accumulated growing degree days after silking may be most important in affecting corn silage nutritive value because of the nutritional value derived from improved grain yield.

The specific timing of environmental stress during the development of the corn plant also appears important to fiber digestibility. Research by Mertens (2002) indicates the weather before and after silking may interact to affect final corn silage nutritive value. In a cooperative research study with Pioneer, Mertens analyzed unfermented whole plant corn samples from various genetics grown in multiple locations, with each location geo-referenced to allow for weather station data to be included in the analysis. Moisture stress prior to silking (vegetative growth stages) reduces corn plant height (and stover yield) yet improves fiber digestibility. Moisture stress after silking reduces corn grain yield and total dry matter (**DM**) digestibility without exerting much effect on fiber digestibility (Mertens, 2002).

It has been proposed that with irrigated crops, silage growers might slightly stress the crop for water during pre-tasseling to increase NDFD; applying the conserved water more liberally during kernel starch filling periods of plant growth. However, excessive moisture stress during vegetative growth can reduce stover yields by reducing stalk internode length and possibly reduce grain yield during 6th leaf and tasseling growth stages when the plant is determining the number of kernels around the ear (ear girth) and number of kernels per row (ear length), respectively. Silage growers may have to decide what to optimize in limited water situations. Grain (starch) content will certainly maximize energy density of the plant and a shorter plant with excellent grain fill will provide even less dilution to the energy-rich ear. Perhaps irrigation strategy needs to be different depending upon the intended end-use of the silage crop targeting more stover yield for heifers, dry cows, and tail-enders; while optimizing starch yield for high production animals. It is clear that much more research is warranted as to when to irrigate the corn plant to manipulate both silage yield and nutritional value.

GENETIC PROGRESS

Since the 1926 commercialization of hybrid corn (Zea mays), steady advances in grain yield per acre have occurred. Pioneer has conducted *decade (grain) studies* using saved seed representative of the corn genetics of every decade from the 1930's to today. Much of what has contributed to corn yield improvements has been improved stress tolerance, allowing plants to respond better to higher planting populations (Wikner, 1996; Paszkiewicz and Butzen, 2001). Hybrid corn in the 1930's was typically planted at densities of 4-5,000 plants/ acre; whereas today, hybrids can routinely withstand the population stress of over 35,000 plants/acre. Improved late-season plant health and kernel weight (grams/kernel) have also increased steadily since the 1950's. When these same genetics are exposed to moisture-stress, there is less observed improvement in yield, kernel weight, and staygreen. This fact, along with depleting agricultural water supplies, is driving seed companies to actively research mechanisms and genes controlling drought tolerance. The introduction of biotechnology traits has also been an important instrument in maintaining the historical legacy of continuous improvement in the agronomics and yield of corn. United States corn and soybean growers lead in global seed biotechnology adoption.

The corn silage version of Pioneer *decade (grain) studies* has been conducted at the University of Wisconsin (Coors et al., 2001; Lauer et al., 2001). This UW corn silage *era research* shows that as corn genetics have advanced, dry matter (**DM**) yield of both stover and whole plant have increased. Grain production has been the greatest driver of yields; so whole plant yields have increased faster than yields of stover. Over time, cell walls (neutral detergent fiber, **NDF**) have comprised less and less of the whole plant, because of the dilution effect of higher grain yields. Stover, per se, has not changed significantly in percentage of NDF or in *in vitro* digestibility. In fact, unpublished work by Fred Owens (personal communication, 2011) indicates that a summary of published literature and Pioneer plot data shows that in newer genetics possessing improved late-season plant health, NDFD declines minimally over the maturity range of 30-40 % DM, while starch increases at the rate of almost 1 % unit per day (Owens, personal communication, 2010).

Some nutritionists question if breeding for improved agronomic traits, such as standability, has negatively impacted corn stover (cell wall) nutritional composition and digestibility. In conventional corn hybrids, there is no obvious association between either fiber or lignin concentration and stalk lodging. Distribution of structural material may be as important, or more important, than concentration of structural components, per se (Allen et al., 2003). The University of Wisconsin Departments of Agronomy and Dairy Science led a 1991-95 UW Corn Silage Consortium that was jointly funded by all the major seed industry companies. A review of their findings (Coors, 1996) indicates there was genetic variation for nutritive value among adapted US corn hybrids with both silage yield and grain yield potential and that forage quality and agronomic traits were not highly correlated.

In recent years, Pioneer has been actively engaged in utilizing advanced genetic tools to mine and advance native drought resistance in pursuit of more drought-tolerant hybrids. Products developed from this program will be introduced in 2011 and will be marketed as Optimum® Aquamax™ hybrids. These hybrids demonstrate a 5 % average grain yield advantage over leading commercial hybrids when water was limited during flowering or grain fill to < 66 % of optimum crop moisture (Warner, 2011). Transgenic approaches to drought tolerance are also being actively pursued by Pioneer and several other seed companies.

GRAIN (STARCH)

As corn genetics improve, and given that about 91 % of corn is grown for grain, it is not surprising that silages may be increasing in quantity of starch. The Pioneer Livestock Nutrition Center analyzed corn forage (not yet fermented) samples from 3414 customer plots in 1993, with the average starch content of 22.7 %. Today, it is not uncommon to find upwards of 35 % starch in Midwestern corn silage samples. If the crop is high-cut (e.g. 18 in vs. traditional 6-8 in), it is not uncommon to find starch in the low-to-mid 40 % range. Given the variability in grain yield from both genetics and subsequent growing conditions and management, it is critical corn silage be analyzed for starch content.

There are some that suggest corn silage can have too much grain (starch). Their logic is that grain can always be added to corn silage and one should not sacrifice fiber digestibility to obtain high grain yields. This assumes that high grain yield and high fiber digestibility are mutually exclusive traits. This assumption conflicts with university research showing no relationship between grain content and stover digestibility (Vattikonda and Hunter, 1983) and other research reporting no correlation between ear content and stover digestibility (Deinum and Baker, 1981). Coors (1996) concluded from the 4-yr UW corn silage consortium that while evaluating forage potential of hybrids might require separate testing programs, grain yield need not be sacrificed when developing hybrids with high DMI yields and improved nutritive value.

Harvest maturity is a key driver of silage quality. Advancing maturity usually results in increased starch content without significant reductions in NDFD (in healthy plants). This is allowing many silage growers to delay harvest in healthy plants until closer to ¾ milk line to capture more starch without compromising NDFD or moisture needed to facilitate silage compaction or fermentation. Determining proper harvest timing by monitoring kernel milk line is increasingly less reliable as one moves east of the Mississippi River. This is because improved late season plant health (e.g. improved insect and foliar disease resistance) is allowing moisture to be retained in the stover, while the kernel continues to mature. The improvement in late season plant health has tremendous benefits especially in a growing season like 2009, which lagged in heat units but yielded a warmer-than-normal September. The fact that plants were still healthy and actively photosynthesizing in September allowed for the harvest of a record crop. What these changes in the plant require is that all parties involved, including the dairy producer, nutritionist, and chopper-operator; need to agree on the acceptable timing of silage harvest to satisfy everyone’s needs and expectations.

FEEDING MANAGEMENT CONSIDERATIONS

Vitreous Starch

Some nutritionists have also expressed concern about the texture or vitreousness of corn kernels in silage and grain. North American corn genetics consists primarily of dent rather than flint background. Dent corn contains more soft, floury endosperm (hence the *dent* at the top of the kernel when it dries), which is more *open* in structure and opaque in appearance. Dent corn has about equal proportions of soft, floury starch to hard, vitreous endosperm. Flint corn is similar to popcorn with much more vitreous starch. European, shorter-season (< 90 day comparative relative maturity) corn still contains considerable flint influence because of the agronomic advantages, such as early growth vigor, provided in flint lines. Recent Wisconsin work showed vitreousness of flinty hybrids averaging 73 %, while mature dent hybrids averaged 48 % hard vitreous starch (Correa, 2002).

Care is needed to assure that sample handling and ranges being tested in research studies are realistic. For example, extrapolating results from well-designed and executed studies on kernel maturity (Correa et al., 2002; Ngonyamo-Majee et al., 2008) to the feeding of fermented HMC or corn silage is open to question when kernels are assayed as unfermented grain and not exposed to the modifying effects the fermentation process can have on both the pericarp and the endosperm protein:starch matrix. Other studies have investigated starch digestibility using extremes in vitreousness ranging from 3 to 66 % (Taylor and Allen, 2005a,b,c) or from 25 to 66 % (Allen et al., 2008) of the starch being vitreous. Although such wide extremes in vitreousness (and presumably prolamin content) may aid in the understanding of how one specific mechanism can limit starch digestion, caution should be exercised when applying these findings (or production expectations) to field situations where rations are built around commercial hybrids with a much narrower range in vitreousness (typically 55 - 65 %) (Mahanna, 2009a,b).

Wisconsin research (Correa, 2002) also supports that silage, harvested wetter than about 35 % DM, exhibits very little differences in starch digestibility attributable to kernel texture or vitreousness. Specifically, that ruminal starch availability showed a decline only after the blacklayer stage of maturity. This agrees with published (Andrighetto, 1998) and unpublished work at Pioneer (Owens, personal communication, 2007) that shows high test-weight, high-vitreous grain (versus low test weigh, softer-texture grain) does not have a negative effect on ruminal starch disappearance when fed as corn silage or even high moisture corn (> 24 % kernel moisture). The published negative effect on feed efficiency and decline in ruminal starch digestion of high, test weight grain appears to only occur when this grain is fed as dry (14 - 18 % moisture), coarsely rolled corn (Jaeger et al., 2004).

With corn grain fed in the form of dry rolled grain, starch digestibility is generally lower for larger particles from more vitreous kernels, however, the majority of the decline in starch digestibility in vitreous corn can be overcome by fine-grinding (e.g. 800-1000 microns). Vitreousness has little, if any, impact on the digestibility of starch from corn that is moist, well-fermented/processed (silage or grain) or adequately steam flaked (Owens and Soderlund, 2007; Firkins, 2006). Much attention of late has focused on testing for prolamins (zein) proteins in corn grain. While these proteins which encase starch granules and are more prevalent in the vitreous starch may interfere with digestion, especially in non-fermented, coarsely-ground or rolled corn, attention on most dairies would be better focused on monitoring the kernel processing score of silages and assuring consistency in the kernel particle size of HMC or snaplage.

Processing Corn Silage

Kernel processing of corn silage has long been popular in Europe but did not gain much attention in the US until the late 1990's with the invasion of European chopper manufacturers who sold machines with the roller mill as standard equipment. Given the energy demand of high-producing cows, the trend towards higher corn silage inclusion rates, and the cost of supplemental corn grain, the adequate processing of corn silage is increasingly important.

Some research has shown processing not to be beneficial in terms of fat-correct milk yield. This is because the processing typically increases the rate of ruminal starch digestibility (Andrae et al.,1999; Johnson, et al., 2002). The difficulty in evaluating this research is because the trial design often results in cows being fed the same amount of concentrate, even if one of the treatments alters starch content or availability. This means that the processed silage-fed cows (with the increased rate of starch availability) could be receiving excess ruminal available starch, causing acidosis, likely reducing intake and/or milk components. This leads the researcher to interpret processing or high-chopping as not beneficial (example: Quellet et al., 2003). This trial design is contrary to how field-nutritionists would balance rations. If analysis showed reduced kernel particle size leading to an increased rate of ruminal starch digestion, field nutritionists would simply reduce the level of concentrate feeding accordingly.

Many factors which contribute to the degree of kernel damage including chop length, roller mill wear, differential, teeth design, and gap. Producers should evaluate silage processing as silage is coming to the bunker (Pioneer 32-oz cup method available from Pioneer sales professionals) and post-harvest by the use of the Ro-Tap lab method available from most laboratories. This will aid nutritionist in fine-tuning the amount and availability of starch in the ration. It can also be a useful measurement to discuss with the chopper-operator should more aggressive processing be desired.

High Chopping

Some producers have opted to high-chop (e.g. 18 in vs. traditional 6-8 in) to achieve NDF digestibility values approximating BMR genetics (Lauer, 1998). A recent Penn State summary of corn silage cutting height trials indicates high-cut silage starch content was increased by 6 %, NDF content reduced by 7.4 %, NDFD improved by 6.7 % (3.4 percentage units) while reducing DM silage yield an average of 7.3 % (Wu and Roth, 2004). Unpublished research by Pioneer indicates about a 1-1.5 t (30 % DM) yield reduction for every 6-in increase in plant cutting height. Caution should be exercised when interpreting data from high-cut research. One year worth of data is not adequate to claim high-chopping does not improve silage NDFD because hybrids will respond differently depending upon the growing season and in some years, the lower internodes do maintain quite high levels of NDFD.

Starch Digestibility in Ensiled Storage

Research findings (Benton et al., 2004; Newbold et al., 2006) are starting to put credence to field experiences suggesting starch and protein degradability increase over time in both high-moisture corn (**HMC**) and corn silage.
Owens (personal communication, 2007) has proposed that length of fermentation exerts influence primarily from ethanol solublizing zein protein along with acid hydrolysis of other kernel proteins that may interfere with starch granule degradation. The author has personally experienced field situations where 12-hr, *in vitro* ruminal starch digestibility analysis showed an increased from 68 to 85 % for 27 % moisture HMC ensiled for 60 versus 240 d, respectfully. Increases of this magnitude could explain some of the *spring acidosis* observations given that most nutritionists do not adjust the energy density of fermented feeds based on length of time in storage.

Using newly available starch digestibility laboratory methods or perhaps tracking water-soluble nitrogen levels may help nutritionists monitor these changes. Ensiling higher-moisture corn grain can improve corn grain feeding value, but must be managed more carefully from both an ensiling and feeding perspective. It may be helpful to collect and freeze samples that have fermented for 30 - 40 d to benchmark against samples fermented for a longer time (e.g. 200 d). Understanding these changes can help nutritionists better formulate cost-effective rations as well as prevent potential acidosis problems caused by longer-fermented feeds (Mahanna, 2007).

CONCLUSIONS

It is difficult to offer generic agronomic advice at nationally-attended conferences because of the tremendous influence of local growing conditions and/or water availability. For the sake of brevity, nutritionists should be aware that fertility primarily impacts yield and crude protein of the corn plant. Variation in planting row spacing and populations are hybrid-specific and can significantly impact yield and grain (starch) content. Moisture stress is a critical issue due to corn grain yield being highly sensitive to water stress from flowering though grain fill.

Agronomic and hybrid issues should be discussed with locally-savvy crop advisors and/or your seed company representatives. To ensure adequate supply of quality forages, large commercial livestock producers should partner with (or hire) successful growers and work to develop strong working relationships with clearly defined goals. Every dairy producer serious about growing and feeding corn grain or silage should also consider having these websites bookmarked on their computer:

- University of Wisconsin Extension: http://www.uwex.edu/ces/crops/uwforage/uwforage.htm
- Pioneer Hi-Bred website: http://www.pioneer.com/home/site/us
- Purdue University King Corn website: http://www.agry.purdue.edu/ext/corn/
- UW Corn Agronomy: http://corn.agronomy.wisc.edu/
- Iowa State University Agronomy Extension http://www.agronext.iastate.edu/corn/

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