Dairy Forages: What's New in Genetics and Management?

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Introduction

It is clear that both seed genetics and producer management affects forage quality and potential dietary inclusion levels along with impacting daily feed cost and intangible factors such as rumen health and function. However, the relative contribution of genetics versus management (environment) must be considered. In our cow populations, genetics establish the base for milk production potential while environment (feed, housing) dictates the absolute yield. This is also true for forages where growing environment and harvest management often trumps genetics when it comes to yield and quality. High quality forage does not ensure high milk production (cow comfort is equally important) but low quality forage almost certainly will guarantee low milk production (or very expensive rations). Pennsylvania State University research (Buza et al., 2014) refutes the importance of feed cost per cow per day, with data showing that profit margins are affected more by the quality rather than the cost of the feed. That said, once forage genetics are chosen and planted, there are four major areas over which dairy producers have some control in optimizing quality: (1) harvest maturity/moisture, (2) particle size, (3) storage/feedout and (4) nutritional profiling.

The amount of forage in the dairy diet today is primarily dictated by the need to maintain rumen health (and milk components) and the economics of forage production (influenced by yield and cost for harvest, storage and transportation logistics) compared to the availability of other non-forage, co-product fiber sources. It is not unusual today to find diets containing 55-70% forage on a dry matter basis. Much of what has allowed this to happen is improvement in forage genetics, producer management of those genetics and a better understanding of how to analyze and feed high-forage diets.

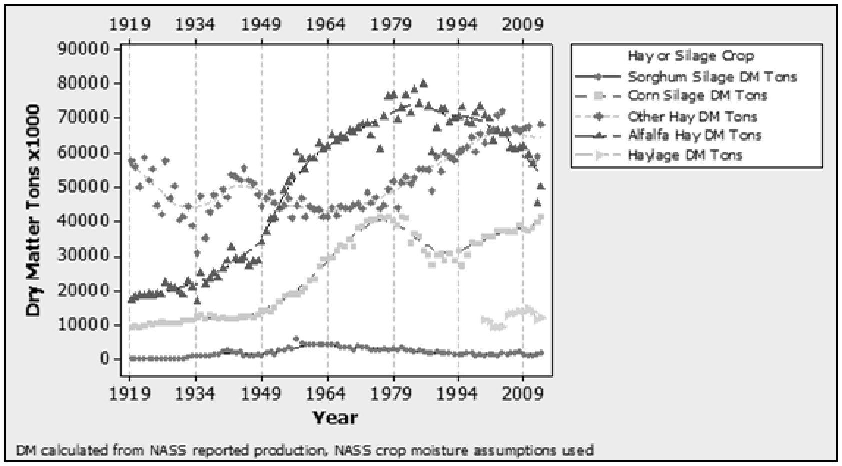
The quantity of forage that can be consumed by a dairy cow depends on the interactions among bodyweight, level of intake, rumen fill, passage rate, specific gravity (buoyancy), neutral detergent fiber (NDF) content, particle size, particle fragility/tensile strength and the pool size and digestion rates of potentially digestible NDF (pdNDF) versus indigestible NDF (iNDF) fractions. Improvements in forage genetics (e.g. BMR corn, reduced-lignin alfalfa, drought-tolerant corn), coupled with improved rumen models (e.g. NDS, CPM) and forage analyses (e.g. Fermentrics™, uNDF240,) are helping provide higher quality forages and the understanding of how to capture their full value in the diet.

High-forage intakes are possible by producing and feeding higher-quality, lower-NDF (and iNDF) forages. The classic multi-forage meta-analysis by Oba and Allen (1999) suggests that a one-percentage point increase in NDF digestibility can increase daily dry matter intake by 0.37 lb., resulting in a daily increase of 0.55 lb. of 4% fat-corrected milk. Chase and Grant (2013) offered these guidelines for herds considering higher forage rations: 1) strive for consistent quality because variations in forage quality will have more effect on milk production as the level of forage in the diet increases, 2) closely monitor forage inventory and considerations for required changes in the cropping (or sourcing) program, 3) allocate the highest-quality forage to appropriate animal groups, 4) frequently analyze forages (including particle size and digestibility) to keep the feeding program on target, 5) monitor rations closely to determine if adjustments are needed based on frequent forage test results (including dry matter), 6) target forage management, including silage face management, aerobic stability and palatability, feed delivery and the need for pushups and 7) track the need for more mixes per day or the need for a larger mixer given that high-forage rations will be bulkier and not as dense (pounds per cubic foot).

Shifts in forage production

It is interesting to note that the top 10 forage production states in 2013 (WI,CA,NY,TX, PA,MN,ID,IA,MI,SD) also represent 8 of the top 10 dairy production states (CA,WI,ID, NY,PA, TX,MN,MI, NM, WA) (Progressive Dairyman, 2014). Forage production in the United States has increased dramatically over the past century (Figure 1) with the major trend of reduced alfalfa production and increased corn silage production. The benefits of high dry matter yields, high starch, consistent fiber digestibility, a single harvest time and the ability to utilize manure has driven higher corn silage inclusion rates responsible for the current corn silage trend.

Figure 1. US Forage Dry Matter Production 1919-2013 (Newell, 2014)



DM calculated from NASS reported production, NASS crop moisture assumptions used

The current alfalfa trend started in the 1990’s, partly due to the corn silage shift, and accelerated downward due to increased corn acres for ethanol production under the Renewable Fuels Standard created under the Energy Policy Act of 2005. Alfalfa production was also affected by the broad regional droughts in 2011 and 2012 which led to declining hay production and shortages that drove up hay prices and increased hauling distances for hay. In response, acres devoted to alfalfa increased in some Western states where corn is less prevalent, but not enough to offset the overall loss of alfalfa acres. The Upper Midwest remained in alfalfa deficit through 2013 due to winter damage and stand loss. 2013 alfalfa production was below trend, and hay market prices continue to remain somewhat elevated. The increase in availability of distillers grains as a mid-protein source replacing alfalfa-protein is also a key factor in alfalfa production and utilization trends. There may be a rebound in alfalfa seedings over the next few years if competing crop prices decline or alfalfa prices stay relatively elevated but total acres could remain stagnant, because average stand age has grown excessively long in some regions where producers delayed new seedings in favor of grain crops. If a higher stand replacement rate unfolds, a younger average stand age could help support a production rebound (Newell, 2014).

Other hay in NASS reports includes warm-season grasses like bahiagrass, bermudagrass, sudangrass and teff, several species of clovers and other legumes, and cool season grasses of many species. Hay species in this large category are often grown for their adaptability in geographies not suitable for row crops and as such, their acres should continue providing substantial hay production (Newell, 2014).

Sorghum and sorghum-sudangrass silages are often more successful than corn under heat and drought stress where rainfall and/or irrigation is limited. Their use is relatively minor from a broad US perspective, but can be locally important, particularly in the semi-arid plains and in the southwest (Newell, 2014).

Corn silage

Since the 1926 commercialization of hybrid corn (*Zea mays*), steady advances in grain yield per acre have occurred. DuPont Pioneer periodically conducts “decade (grain) studies” using saved seed representative of the corn genetics of every decade from the 1930’s to today. In DuPont Pioneer era studies conducted since 1972, corn yields showed no signs of plateauing and it is corn grain that contributes over 60% of the energy in corn silage. In these “decade” studies, genetic gains averaged about 1.5 bu/acre per year since 1963 (the “single-cross” era) in normal growing conditions, and 1.0 bu/acre per year under drought conditions. Genetic gains accounted for about 70-75% of total yield gains. Today’s hybrids have improved stress tolerance, a higher grain-to-stover ratio, less silk delay and barrenness, better stalks and roots, smaller tassels, more upright leaves, better staygreen, and deeper roots than older hybrids. Corn yield gains show no signs of slowing. Growers can expect future gains to continue if corn research is supported at historic or higher levels (Butzen and Smith, 2014).

A corn silage version of DuPont 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 yield of both stover and whole plant have increased. Grain production has been the greatest driver of yields resulting in whole plant yields increasing faster than stover yield. 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 DuPont Pioneer (Owens, 2011) indicates that a summary of published literature and DuPont Pioneer plot data shows that in newer genetics possessing improved late-season plant health, NDFD declined minimally over the maturity range of 30-40% dry matter, while starch increased at the rate of almost 1% unit per day (Owens, 2010).

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 per acre; whereas today, hybrids can routinely withstand the population stress of over 35,000 plants per acre. Improved late-season plant health and kernel weight (grams per kernel) have also increased steadily since the 1950's. When these same modern genetics are exposed to moisture-stress, there is less 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.

Corn Moisture Requirements: Estimates are that about 15% of the U.S. corn acres are irrigated. This means that 80-85% of the acres are at the mercy of Mother Nature. Corn has relatively high water use efficiency (dry matter produced per quantity of water used) compared to alfalfa, but because it produces more total dry matter, it can requires more total moisture. A high-yielding corn crop requires between 20-24 inches of water and upwards of 28-30 inches in the more arid West. One inch of water per acre is about 27,000 gallons. A corn crop requiring 24 inches of moisture would require about 648,000 gallons of water. If that crop yielded a national average of 175 bu, each bushed would require about 3700 gallons of water. 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 semi-arid 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).

Figure 2. Long-term daily average (black line) and individual year (green line) corn water use by growth stage in Nebraska (adapted from Kranz et al., 2008)

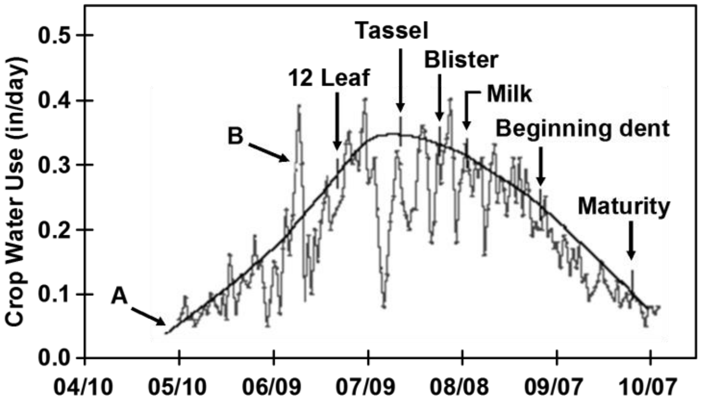
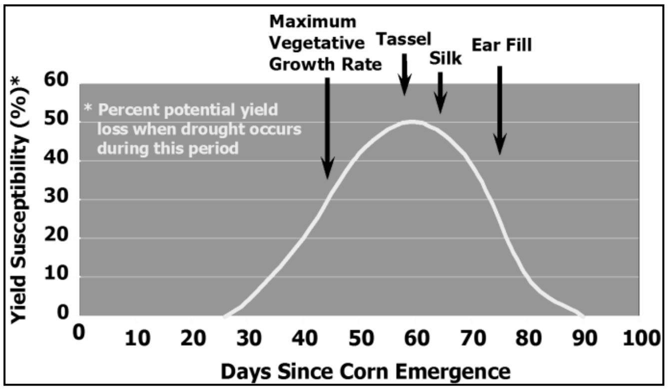


Figure 3. Yield susceptibility to water stress for corn (adapted from Sudar et al., 1981)



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 20-30% and transpiration accounting for the remaining 70-80% 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.

When water supplies do not fully compensate for crop ET, grain yields are reduced compared to 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 depending on growth stage, irrigation timing, crop residue, hybrid genetics and plant populations. The impact of water stress on corn grain yield varies with crop growth stage (Figure 3). During the vegetative growth of the corn plant, it is relatively drought tolerant and can survive on upward of 60% soil water depletion in the root zones without a significant impact on grain yield. However, silage yields will be reduced due to shorter plants when moisture-stressed during vegetative growth stages. The corn plant needs the most moisture from about silking through the blister stage (Figure 2). After blister stage, the plant is again fairly immune to water deficiency and irrigation can be termination when the kernel milk line is at about 50% (Figure 2). 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).

In recent years, the seed industry has been actively engaged in utilizing advanced genetic tools to mine and advance native drought resistance in pursuit of more drought-tolerant hybrids. Several of these products are now on the market and demonstrate upwards of a 5% average grain yield advantage over leading commercial hybrids when water was limited during flowering or grain fill to less than 66% of optimum crop moisture (Warner, 2011). Transgenic approaches to drought tolerance are also being actively pursued by several seed companies but regulatory hurdles must be met before they will reach the marketplace. In general, the tremendous research dollars spent on corn breeding and research compared to any other crop, along with the introduction of biotechnology traits, has been the key driver in the continuous improvement in agronomics and yield of corn.

Climatic Effects: Weather patterns, if trending toward either warmer/colder or wetter/dryer have potential to impact corn yields over time. Increased weather variability within single seasons could also affect yield trend. Using the DuPont Pioneer propriety software, EnClass®, Pioneer breeders were able to evaluate historic weather patterns and model their expected impacts on yield from 1950-2011. This analysis of weather records determined that the effects of weather on yield was minimal, contributing an upward bias of only 0.02 bu/acre per year during the period studied (Butzen and Smith, 2014).

Crop Management Advances: In addition to genetic and technology trait gains, corn yields have benefitted from improvements in cropping practices. Those most beneficial and widely adopted by growers include: 1) earlier planting, which reduces moisture stress during pollination and ear fill, and lengthens the growing season; 2) Use of seed treatments that contain a fungicide and insecticide, and may also include a nematicide, growth promoter, or other active ingredient, 3) increasing use of foliar fungicides to limit leaf diseases, 4) use of improved planters to achieve more consistent depth and coverage of seed, more equal plant-to-plant spacing to reduce competitive effects among plants, more timely planting of a higher percentage of corn acres at higher ground speeds, 5) improvements in irrigation practices and number of acres of irrigated production, 6) improved fertility practices, including higher rates of nitrogen fertilizer, 7) variable-rate technologies that allows growers to plant specific hybrids and place fertilizer where most beneficial, 8) narrower row spacing and 9) increase in systematic tiling (Butzen and Smith, 2014).

BMR: 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 jointly led a 1991-95 UW Corn Silage Consortium that was jointly funded by all the major seed companies. A review of their findings (Coors, 1996) indicates there was genetic variation for nutritive value among adapted U.S. corn hybrids with both silage yield and grain yield potential and that forage quality and agronomic traits were not highly correlated.

The heritability of fiber digestibility in conventional corn silage hybrids is quite high; however, the genetic variation to apply selection pressure against is relatively narrow in high yielding corn genetics. The introduction of brown mid-rib (BMR) corn as a non-GMO, recessive gene trait to improve fiber digestibility in corn silage is testament to the fact that significant improvements in fiber digestibility could not be achieved by traditional selection methods. Corn hybrids with BMR mutants have less lignin and a lower proportion of iNDF than isogenic conventional corn silages. Research conducted at the Miner Institute (Grant and Cotanch, 2011) indicate that, presumably, the more fragile fiber in BMR is what drives higher intakes in early lactation cows who lack the ability to satisfy energy needs from typical dry matter intakes. Rations need to be balanced differently when using BMR corn silage, particularly in terms of starch supplementation, total NDF and physically-effective fiber levels. Despite the lower lignin in BMR resulting in higher fiber digestibility, BMR genetics are also at the mercy of Mother Nature just like conventional silage genetics. Excessively wet growing conditions prior to silking (vegetative stages) typically increases plant height and reduces fiber digestibility, while growing conditions after silking appeared to only exert an effect on grain yield (Mertens, 2002). Bolinger (2010) summarized data from Michigan State University silage plots harvested in a relatively wet growing season (2006) compared to the same hybrids harvested from the same plot in a relatively dry growing season (2007). Hybrids averaged 6.5 points higher in 24-hour NDFD in the drought year. It was interesting to note that, as expected, the highest NDFD in both seasons was a BMR hybrid, but the BMR fiber digestibility was also reduced in the wet growing season (Mahanna, 2010). It has been proposed that with irrigated crops, silage growers might stress the crop for water during pre-tasseling to increase NDFD (without reducing plant height too much) and applying the conserved water more liberally during kernel starch filling periods of plant growth. More research is definitely warranted as to when to irrigate the corn plant to manipulate both silage yield and nutritional value.

Corn silage harvest and feeding advances

High-chopping: High-chopping is a management option to potentially increase fiber digestibility and concentrate more starch in corn silage. In a review of high-chop research by Wu and Roth (2004) at Pennsylvania State University, they found an average increase of 6.7% in NDFD and a 5.9% increase in starch content when comparing 19 inch versus 7 inch chop heights. Leaving the less digestible, lower stalk internodes in the field resulted in an average dry matter loss per acre of 7.4%. There does appear to be a significant genetics-by-growing season interaction suggesting that hybrids need to be analyzed for NDFD at various chop heights just prior to harvest because not all hybrids respond the same to specific growing environments. Several lactation studies with high-chop corn silage indicate higher milk production and but reduced milk fat content. This is likely the result of researchers not reducing the starch level in the high-chop treatments; unlike what field nutritionists would do when recognizing the increased starch level from high-chopped corn silage.

Changing Starch Digestibility: Several research studies have put credence to field experience that starch and protein degradability increase over time in corn silage. However, the effects of fermentation should not be viewed as an acceptable alternative to adequate pericarp damage from proper kernel processing at harvest. Using newly available starch digestibility laboratory methods (e.g. 7-hour starch digestibility or Fermentrics^{TM}) or tracking water-soluble nitrogen levels correlated to increasing starch digestion, can help nutritionists monitor these changes and make appropriate ration adjustments. Understanding these changes can help nutritionists better formulate cost effective rations as well as prevent potential sub-acute acidosis problems caused by longer-fermented silages (Mahanna, 2007).

More Mature Kernel Harvest: As the late-season plant health of the corn plant continues to improve from both genetic advancements and management practices (e.g. foliar fungicides), it allows producers the ability to delay harvest and obtain more starch from advancing kernel maturities without sacrificing significant declines in NDFD. A recent study by Seglar et al., (2014) showed that as kernels matured from the half milk line to black layer, kernel weight increased an average of 24% and starch by 27%, suggesting that premature harvest of corn silage dramatically reduces starch content.

Floury endosperm: There has been recent interest in the endosperm type (e.g. floury versus vitreous) of kernels found in corn silage. Harder texture kernels typically have more vitreous endosperm accompanied by higher levels of zein proteins (prolamin) surrounding the starch granules. Despite some of the marketing claims by some seed companies about the improved ruminal starch digestibility of floury endosperm hybrids, a study (Seglar et al., 2014) of commercial corn hybrids grown in different years at two different locations and harvested at three maturities indicated that neither the kernel density, prolamin content nor prolamin:starch ratio of kernels reliably predicted seven-hour ruminal starch digestibility.

Advocates of floury genetics often show kernel texture data on fully mature dry corn, lacking data on hybrid vitreousness levels at corn silage maturities (half to three quarter milk line). It is further misleading to promote university starch digestibility studies comparing genetic extremes (e.g. 3-66%) in vitreousness (Mahanna, 2013). These comparisons make sense for researchers investigating the mode of action of starch digestion. However, vitreous ranges this wide simply do not exist in commercially viable North American corn hybrids that typically exhibit a range in vitreousness of 50-70% in fully mature kernels and even less of a range in kernels at silage harvest maturity.

University of Wisconsin researchers (Hoffman et al., 2012) have developed an integrated analytical approach to starch digestibility called Feed Grain V2.0 that is available at select laboratories. This approach reinforces the relative importance of: 1) kernel particle size, 2) extent and length of fermentation and finally, 3) endosperm differences (vitreousness or hard kernels). In Feed Grain V2.0, starch digestibility in fermented samples are based on particle size and ammonia content (more ammonia, the longer the fermentation). Starch digestibility in unfermented, dry corn grain is based on particle size and prolamin content. The prolamin content is not considered in high-moisture corn, snaplage or corn silage starch digestibility calculations because of the small variation and minimal effect vitreousness (kernel texture) has on grain harvested at relatively early kernel maturities (pre-black layer).

The inclusion of vitreousness or kernel texture for dry corn grain is consistent with a review by Firkins (2006) indicating that vitreousness of corn grain in silages (fermented grains) was of relatively little value, whereas vitreousness of dry corn grain should be considered, particularly to help users know when to grind corn more finely. At the same particle size, starch digestion is similar for soft and hard corn. More vitreous (hard) corn simply yields larger, more slowly digested particles than softer corn, particularly if it is ground. Research from France (Ramos, 2009) with relatively high-vitreous (flinty) corn compared to North American hybrids showed that grinding removes most of the negative influence of vitreousness in dry corn. The body of research to dates suggests it makes more sense for producers and nutritionists to focus attention on corn yield, agronomic strengths/weaknesses, particle size and fermentation quality rather than the minor effects of kernel texture, especially in silage hybrids (Mahanna, 2013).

Kernel processing advances: Laboratory methods now exist (e.g., corn silage processing scores [CSPS]) which allow nutritionists a better understand of the particle size distribution of kernels in corn silage. Mining laboratory data on how well kernels were processed in submitted corn silage samples indicates upwards of 40% are significantly under-processed. At the same time, producers often desire even longer corn silage fiber particle size in high corn silage diets in an attempt to improve effective fiber and avoid the necessity of adding long fiber such as hay or straw to help establish a rumen mat to stimulate rumination to help buffer the rumen environment. The commercial release of Shredlage® processors in 2010 allowed for excellent kernel damage even when chopping at upwards of 26-30mm (compared to standard 19mm). The design of the teeth on the Shredlage rolls rip and tear rather than smashing kernels apart like conventional rolls. Shredlage rolls also have more grooves on one roll then the other which adds even more differential without changing the speed of the rolls more than the 30% differential set at the factory (Olson, 2013). Two lactation studies by Shaver and co-workers have proven the merits of this alternative approach to processing corn silage (Mahanna, 2014, 2012). It is very encouraging that chopper manufacturers like John Deere and Claas are now also offering unique roller mill designs or modification kits to speed up roll differentials, to finally give dairy producers both effective fiber and kernel damage needed in high corn silage diets.

Choppers with NIRS: It is entirely possible in the near future to “dial-in” desired NDFD or starch content of corn silage with choppers outfitted with on-board Near Infrared Reflectance Spectroscopy (NIRS). As silage is exiting the chopper spout, it could be analyzed for important constituents and the cutter head tied into this information forcing the head up or down to modify either NDFD or starch content of the silage being harvested.

Alfalfa

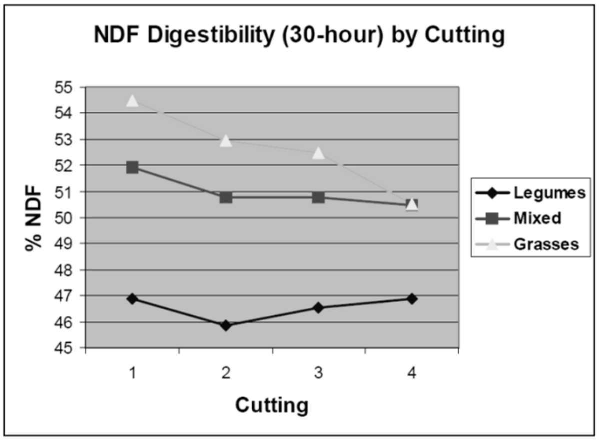
Alfalfa is arguably one of the most variable feeds on many dairies. This is due to field-by-field variations in the age of stand (grass content), harvest maturity/moisture, fiber digestibility affected by the growing environment and issues around fermentation and palatability. It is well documented that environmental factors have a smaller effect on quality than on yield and that most factors that limit plant development (e.g. lack of water, cold weather, plant diseases) tend to promote higher quality because of their effect on altering leaf: stem ratios (Van Soest, 1996). Many nutritionists would rather that producers delay alfalfa silage harvest and deal with lowered digestibility than suffer with feeding rained-on, poorly fermented silages. Field experience has also conditioned producers to target ideal moisture levels at around 60% to reduce protein degradation and the potential for clostridial alfalfa silages. This does bring up a dietary issue regarding need for supplemental soluble protein (SP) in many high corn silage diets due to the fact that less SP is being supplied in the diet from reduced levels of drier (hence less SP) alfalfa silages.

Nothing influences the nutritional quality of alfalfa more than growing environment and harvest maturity. Fiber digestibility is higher under cooler temperatures (Figure 4) with 1st and 4th cuttings having the highest NDFD; and 2nd and 3rd cuttings typically grown under higher heat units, displaying the lowest NDFD. The biggest environmental factors influencing alfalfa quality are temperature, water deficiency, solar radiation and a distant fourth, soil fertility. Growing conditions that promote the highest alfalfa quality exhibit long day lengths, cool nights and moderately dry weather. Warm, wet weather results in the poorest-quality alfalfa. Cool, wet growing conditions produce high-quality alfalfa due to low neutral detergent fiber (NDF) and low lignification (Van Soest, 1996). However, getting a hay crop harvested in these conditions can be problematic, with harvest delays resulting in maturity issues, in addition to potential for higher respiration, leaching or fermentation/spoilage losses from increased exposure to soil-borne fungi and bacteria. Solar radiation (light) is the only environmental factor promoting both yield and quality. Light promotes carbohydrate production with every hour increase in day length increasing digestibility by about 0.2 percentage units (Van Soest, 1996).

The shortening photoperiod in the fall has a negative effect on alfalfa digestibility but is somewhat offset by cooler temperatures. Cloudy weather reduces photosynthesis, causing low sugar and mobilization of nutrients, which results in higher proteins; both of which can be problematic for silage production (Van Soest, 1996). There are also more pentose (5 carbon) sugars in fall-harvested alfalfa, further contributing to fermentation challenges. Drought conditions reduce yield, but the resulting stunted, yet leafy plants, are generally higher in protein and digestibility due to the higher leaf:stem ratio. The digestibility advantages would be greater if they weren't somewhat offset by increased lignification from high temperatures which typically accompany drought conditions. Temperature accelerates plant development and warm weather accelerates NDF development and lignification. Every 1°C increase in temperature will generally decrease the digestibility of forages 0.3-0.7% units (Van Soest, 1996). This is one reason why forages produced in northern latitudes or higher elevations (cooler nights) tend to be higher quality. In the spring, light and temperature are positively correlated until June 21- when maximum day length and light occur - after which light decreases and temperature increases (bad for quality) until the fall, characterized by declining temperatures and decreasing day length and light (good for quality) (Van Soest, 1996).

Alfalfa Silage in a Day: This harvesting approach involves mowing alfalfa into a wide swath to facilitate faster drying followed by merging and chopping all within 24 hours. The most important factors to accelerate the drying of alfalfa are the amount of sunlight hitting the swath (swath density), wind velocity, relative humidity and ground moisture. Being able to harvest more quickly reduces the soluble protein degradation and conserves sugars for use during fermentation or by rumen bacteria. Research from the Northeast has suggested that use of conditioners at cutting time are of no benefit when wide swathing because it interferes with moisture transmission from the leaf stomata. Research from the University of Wisconsin clarified that most of the moisture loss is through stomata openings from fresh cut down to about 70% moisture. For moisture loss to continue beyond that, conditioning of the stem is essential. In that producers are targeting closer to 60% moisture alfalfa silage, most producers continue to condition alfalfa at harvest.

Figure 4. 30-hour NDFD data from legumes (13261 samples), mixed grass/legumes (10158 samples), and grasses (2407 samples) analyzed by NIR at Cumberland Valley Analytical Services (Ward and de Ondarza, 2007).



Seed Coating: Many seed companies sell heavy-coated seed with the most common coating being 33% limestone. Heavy coat is usually less expensive per pound but more expensive on a basis of pure live seed. There is mixed research on the value of limestone-coated alfalfa seed varying from providing a more suitable micro-environment for seed germination to claims that limestone-coated seed has no advantage in cloddy or dry soil conditions and may actually slow water uptake under moderate to dry soils. Despite the research contradictions, alfalfa growers need to understand how heavy-coating affects both the cost and seeding rate in terms of the number of live seed sown per acre. For example, it takes 21 pounds of 33% limestone coated seed, to equal the same number of seeds per square foot as typical 9% coated seed sown at 15 pounds per acre. When a grower purchases heavy-coated seed without increasing seeding rate, they take on a higher risk of thin stands, stand establishment failure, more weeds during the seeding year and risk that yield over the life of the stand will be reduced.

Lodging Resistant Varieties: Lodged alfalfa is more difficult to harvest. Every inch of uncut stem equates to 0.13-0.15 tons per acre of lost hay yield. Uncut stems left in the field can turn ‘woody’ and lower the forage quality of subsequent cuttings. One of the more recent innovations in alfalfa genetics is the commercialization of lodging-resistant varieties. These varieties have much improved standability when exposed to wind and rain events due to a more upright stem and crown architecture. Research also shows that more vertical plant architecture has no effect on lowering fiber digestibility.

Alfalfa Fungicides: There is a definite lack of consistent and statistically significant results from small-plot university research on the use of fungicides on alfalfa, yet farmer testimonials seem to suggest a positive response to fungicide application. General recommendations are to apply fungicides prior to first cutting when alfalfa is 6-8-inches tall. It only requires about 0.1- 0.2 tons per acre of added yield to justify the price of fungicide and application when the crop is selling for upwards of $200 to $250 per ton. Producer testimonials and company literature suggest early application to prevent fungal growth rather than assuming later maturity applications will eliminate disease problems after they have become established. The required yield improvement necessary to justify fungicide use is also less if growers are adding it to tank mixes of insecticide that they are already applying to control leafhoppers.

Positive grower observations may be the result of greater variability in their production-sized fields compared to smaller, replicated research plot studies in terms of canopy humidity levels, fungal loads, trash content and less than optimum soil environments (low pH, low fertility, poorly drained soils) across their larger acreages. More research is certainly needed on the effectiveness of other chemistries given the potential concern of resistant fungal populations. The good news is that, as growers continue to drive this market, more fungicides will likely add alfalfa to their approval list. As more research and producer experience is accumulated, there will likely be improved diagnostics as to when fungicides make the most sense such as in wet springs or on older stands. From a scientific, published literature perspective, the jury is leaning against the economics of alfalfa fungicides. However, fungicides would be expected to be most beneficial in growing conditions conducive to the development of stem and leaf diseases. Wet growing conditions coupled with a heavy crop should theoretically respond to a greater degree to fungicide application. Application in the fall may improve plant health to help stands weather the winter. Fungicides should also be more beneficial in stands which are harvested at later stages of maturity (e.g. lower lignin varieties) which are more susceptible to increased leaf drop (Mahanna and Thomas, 2014).

RFV versus RFQ: Relative Feed Value (RFV) was developed over a quarter century ago as a standard for comparing alfalfa quality based on voluntary animal intake of digestible dry matter. A RFV of 100 describes full bloom alfalfa hay containing 41% ADF, 54% NDF and digestible dry matter of 1.29% of body weight. Relative Forage Quality (RFQ) is an improvement on RFV in that it includes NDF digestibility in the calculation. If sellers and buyers of alfalfa would agree on the same reputable lab and base value on RFQ, there would likely be fewer situations where two lots of hay have the same fiber levels but considerably different results in lactating rations. Producers should remember that when using a RFQ target to stage harvest, it is not uncommon to lose 20 RFQ points during harvest and ensiling.

Cutting Height: Lowering the cutter bar obviously results in higher yields of alfalfa. Research shows that alfalfa can be cut as short as 1.5 in. and that each inch above this will result in a half-ton-per-acre reduction in annual yields (Undersander, 2009). However, increased yields must be balanced against the tendency for disc mowers to vacuum soil (which contributes to ash values) into the crop, resulting in lowered digestibility and the potential for increased soil-borne clostridia.

AM versus PM Cutting: The time of day to harvest alfalfa (morning versus afternoon) has research results that fall on both sides of the debate. The basic idea is that cutting later in the day allows the crop to lay down more sugars to improve palatability or aid in silage fermentation. Much of the positive research has been conducted on alfalfa hay harvested in western states. Although morning versus afternoon forages differ in initial composition, these differences don't always exist after drying and/or fermentation because cell respiration reduces sugar levels at night and in sections of the windrow not receiving sunlight.

Research in Wisconsin (Undersander, 2003) showed that 11 of 14 Wisconsin farm samplings had higher sugars with afternoon-cut alfalfa, yet only one of the 14 had higher sugar levels in stored forage. There also appear to be adequate sugars to support fermentation when alfalfa is harvested at typical North American moistures/maturities compared to wetter European forages (Nasser et al., 2006). A Miner Institute study (Thomas, 2001, 2007) showed no statistical difference in plant sugars, starch, NDF or *in vitro* digestibility between am and pm harvested alfalfa. While afternoon-harvested alfalfa was numerically higher in sugar and starch, the small differences either decreased or disappeared entirely by the time the forage was 40% dry matter. Alfalfa mowed in the morning was ready for silage harvest in about nine hours, while alfalfa mowed in the late afternoon was not harvestable until after noon on the following day. Many researchers in the Midwest or East believe it makes more sense to cut early in the day to maximize the hours of drying from solar radiation rather than expose the crop to delayed drying or increased weather risk.

Reduced Lignin Alfalfa: The October 2014 World Dairy Expo in Madison Wisconsin was the launch site of two new alfalfa technologies; a genetically-modified reduced lignin alfalfa (HarvXtra™) by Forage Genetics International (FGI) that will be licensed to a number of seed brands and the other being lower-lignin alfalfa from Alforex Seeds developed through conventional plant breeding. The Alforex Seed products (Hi-Gest 360 and Hi-Gest 660) are reported by the company to have 7-10% less lignin and will be available in 34%-coated, non-Glyphosate-tolerant varieties on a limited basis for spring 2015 planting season (Jaynes, 2014).

HarvXtra was developed through a strategic partnership between FGI, The Samuel Roberts Noble Foundation and the U.S. Dairy Forage Research Center in conjunction with Monsanto. There are several steps in the process of lignin synthesis in alfalfa with the lignin biosynthetic pathway involving twelve different enzymes. Each is required for a specific step in the pathway. Noble Foundation scientists identified and suppressed several "lignin genes" that code for specific pathway enzymes. FGI scientists generated and evaluated biotechnology-derived plants with suppression of a specific lignin gene resulting in 10-15% decrease in lignin content, 10-15% increase in NDFD and RFQ when compared to related lines without the HarvXtra™ trait. HarvXtra™ alfalfa also displays a slower change in quality with advancing maturity compared with conventional varieties yet maintains alfalfa's important agronomic characteristics, including lodging potential equal to most commercial varieties harvested at the same time. HarvXtra™ alfalfa will be sold in a trait stack with Genuity® Roundup Ready® alfalfa. A petition to deregulate is currently under review by the USDA with anticipated limited commercial introduction in 2016 to allow growers the opportunity to realize the benefits of the technology, with 2017 as the first year of a wide-scale commercial launch (Fanta, 2014).

These technologies should provide alfalfa producers with greater harvest flexibility when either adhering to current harvest schedules and harvesting higher RFQ alfalfa or by delaying harvest to capture more yield yet maintaining desirable forage quality. In geographies that typically take four harvests, there is opportunity to improve yields upwards of 15-20% by harvesting only three times, and obtaining the same or better quality compared to lower-yielding late-bud harvest. The improved fiber digestibility of these varieties will likely provide the most benefits in transition and early-lactation diets where dry matter intake is of most concern. Research will be needed to determine desirable physically-effective fiber levels in rations containing low-lignin alfalfa, especially if it is coupled with BMR corn silage (Mahanna and Thomas, 2013b).

Condensed Tannin Alfalfa: Researchers at the U.S. Dairy Forage Research Center are conducting studies with condensed tannins (CT) which are compounds found in forages such as birdsfoot trefoil that have the ability to bind proteins to reduce protein degradation during the ensiling process. Researchers are investigating new methods of assaying CT in forages and characterizing alfalfa bioengineered to produce CT. The practical utility of this technology will depend on the need for reducing protein degradation in alfalfa silage, which may not be desirable in high corn silage diets (Zeller et al., 2014).

Grass

Interest in cool-season forage grasses exists because not all soils are suited to growing alfalfa. In the Northeast, it is not uncommon for producers to plant alfalfa with a cool-season grass such as timothy, orchardgrass, or tall fescue in proportions of alfalfa: grass of 2:1 to 3:1 (depending on the grass species), with a total seeding rate of about 20 pounds per acre. The best alfalfa-growing soils are deep, well-drained loams that permit alfalfa taproots to penetrate far into the soil profile. Some soils have fertile topsoil with much less desirable subsoil, including high acidity and/or a fragipan that limits good drainage. Grasses have dense, fibrous root systems that don’t penetrate nearly as deep into the soil making them more suitable for tough soils (Thomas and Mahanna, 2012).

Alfalfa tap roots store nutrients needed for the next crop and do not regrow from the cut stems but rather from crown buds. Grasses do not have tap roots and regrow from the cut stems. Nutrients for the following crop are stored in the bottom few inches of grasses, so cutting height can impact both regrowth and stand life. The trend toward disc mowers (versus sickle bar mowers) has resulted in lower stubble heights because disc knives are less apt to be damaged from scalping the soil surface or hitting rocks. Reduced grass stand life can be caused by short stubble height due to grass not having enough nutrients in the remaining stubble for normal regrowth. While it may be acceptable to mow alfalfa to a 2-inch stubble height, many agronomists now recommend a 4-inch stubble height for cool-season forage grasses (Thomas and Mahanna, 2011).

Grass species differ in their tolerance to soil drainage and seasonal growing conditions. Reed canarygrass will tolerate very wet soils, while orchardgrass will not. Orchardgrass and tall fescue will produce well under typical summer growing conditions, while timothy grow well in the spring but will become somewhat dormant during the heat of the summer. Orchardgrass is high-yielding but requires aggressive management and is more susceptible to winter damage, particularly ice sheets.

Forage quality also differs among grass species. Cornell University research reported somewhat higher forage quality for tall fescue versus reed canarygrass when both were harvested at the boot stage. If establishing a pure stand of grass it is best to use one species because there are considerable differences in heading date among cool-season grasses and also between varieties. In recent years, the cool-season grass species generating the most interest is endophyte-free tall fescue. There are dozens of tall fescue varieties on the market, most which head at about the same calendar date as do the latest-maturing orchardgrass varieties (Thomas and Mahanna, 2015). There can also be large differences in maturity within the species. For example, early maturity varieties of timothy and orchardgrass head out at least 10 days earlier than late-maturity varieties of the same species. There is somewhat less varietal difference in the heading dates of reed canarygrass, tall fescue, and bromegrass. Within a species, there is little difference in forage quality when the varieties are harvested at the same stage of maturity. However, there are significant differences in varietal yield within a species, so variety selection is important (Thomas and Mahanna, 2011).

Research at the University of Minnesota found that tall fescue and orchardgrass had higher yield and quality than did alfalfa, and forage analyses predicted that both milk per acre and milk per ton would be higher for the two grasses. However, even though the neutral detergent fiber (NDF) in grass is more highly digestible than alfalfa NDF, the digestion rate is slower which may limit the amount of grass that can be fed to high-producing dairy cows. The farms that have the most success feeding grass put a high priority on harvesting any grass that will be fed to high-producing cows when it’s still in the boot stage (Thomas and Mahanna, 2015).

Sorghum

There has been renewed interest in forage sorghum and sorghum-sudangrass attributable to the 2012 drought and declining water in the Ogallala Aquifer (South Dakota to Texas). The advantage of these forages is their adaptability to high temperatures and requiring about 33% less water than corn. Sorghums are diverse cultivars ranging from shorter (3-5 feet) grain (milo) sorghums to taller (8-13 feet), higher-tonnage forage sorghums that have stems and leaves similar to corn. Forage sorghums have varying grain-to-stover ratios, ranging from no grain with male sterile to upwards of 40% grain depending upon variety. Sudangrass grows 4-7 feet, has much smaller leaves and stem diameter and can be harvested as early as 45 days after planting. The smaller stems allow for faster drying than other sorghums for those interested in harvesting as hay. Sorghum-sudangrass hybrids are intermediate between forage sorghum and sudangrass, with leaf-to-stem ratios driving their nutritive value and regrowth contributing to total yield potential. There are also brown midrib (BMR) versions of forage sorghums, sudangrass and sorghum-sudangrass hybrids which have reduced lignin in both the stem and leaves, resulting in higher fiber digestibility. However, similar to corn, there is a slight yield drag (10%) in BMR genetics compared to conventional genetics (Mahanna and Thomas, 2013).

Forage sorghums are typically harvested for silage when grain is about mid-dough maturity to optimize yield, quality, berry starch digestibility and adequate plant dry matter for ensiling. Non-heading varieties usually require a killing frost for the plant to reach adequate dry matter to prevent excessive levels of effluent. Post-frost harvesting can result in lower yield and quality due to leaf loss and lodging. Sudangrass and sorghum-sudangrass are harvested before reaching 3 feet tall, allowing for two to three cuttings per year. These crops must be field wilted to achieve proper ensiling moisture.

There are several published research studies with sorghum silages claiming similar milk production when dairy cows are fed a ration containing BMR sorghum silage versus a ration containing corn silage. However, the cows in these studies are typically late-lactation and/or low-producing cows (57-75 pounds per day). In one short-term study, cows fed the BMR forage sorghum silage consumed 2 pounds more dry matter per day than those fed corn silage, yet the cows on the corn silage treatment gained 7.5 pounds more body weight. This would indicate more energy among the corn silage treatment despite similar milk production. The other issue is that the corn silage in these trials didn’t represent typical fiber and starch content levels. In one study, the corn silage contained 55% NDF, which was similar to the level of NDF in the BMR forage sorghum. Obviously, there was little starch in the corn silage to dilute the NDF. Similarly, another trial comparing BMR forage sorghum to corn silage used corn silage containing 46% NDF and only 20% starch. These trial details may help put in perspective the claims that BMR forage sorghum has 85-100% the feeding value of corn silage. Perhaps this is true for the poorest corn silage, but certainly not compared to typical corn silage. Research has yet to be conducted comparing BMR sorghum to BMR corn silage. In the end, it is not just who wins in milk production, but which forage yields the most starch and digestible fiber resulting in the highest income over feed cost which, unfortunately, is not reported in most studies. Despite advances in sorghum breeding, the variability in plant height (yield), dry matter, standability, starch content and starch digestibility has held back wider adoption of sorghum silage. However, for producers dealing with dwindling water supplies, BMR forage sorghum may have a place, especially for heifers, dry and late-lactation cows which have lower nutrient requirements (Mahanna and Thomas, 2013).

Cereal forages

Small grain silages, such as wheat, oat, rye, barley or triticale (wheat-rye hybrid), used in double cropping programs are becoming increasingly popular as a forage source, especially for young stock. In general, cereals should be harvested in the milk-to-soft dough stage if the goal is to maximize the yield of energy per acre. As small grains mature from flag to boot to head to flower to milk to dough stages, the protein level drops while yield and energy value typically increase. Dairy producers can maximize protein content by harvesting small grains in the late flag leaf to early boot stage. While the boot stage of maturity produces the highest "bite for bite" nutrient value, dry matter yields are considerably reduced. Producers desiring the highest quality forage are cutting at this stage of maturity. The milk stage is less desirable than the early dough stage as it is less palatable and studies indicate animal performance may be reduced. The early dough stage of maturity produces maximum energy per acre and is the most common maturity for harvest.

If considerable acres of small grain are to be harvested, it is recommended to begin harvest at milk stage to avoid harvesting past the dough stage of maturity. The following guidelines are commonly used as to when to harvest specific cereals: 1) wheat and barley - soft dough stage (direct chop), 2) oats - boot to early heading (wilted), 3) rye - boot stage (wilted) and 4) triticale - flag leaf fully emerged but no head (wilted) (Kilcer, 2010). Moisture levels in the range of 60-70% are best for ensiling small grain silage. Small grain silages with less than 60% moisture are difficult to pack, and excessive heating and nutrient losses can occur. Recommended length of cut is ¼-3/8 inch to facilitate packing and reduce oxygen being carried in with hollow stems in later harvested cereals.

Forage environmental implications

One potential concern with high-forage diets is an increase in methane emissions. There is little that can be done to changes this biological fact and methane may simply be the price for balancing “starch for humans” versus “fiber for ruminants”. Manure accounts for about 25% of dairy farm methane emissions, with the remaining 75% from enteric emissions, representing between 6% and 10% of the total gross energy intake of lactating cows (Chase 2010). In December 2009, the U.S. Department of Agriculture and the Innovation Center for U.S. Dairy signed a memorandum of understanding to work jointly in support of the goal to reduce dairy industry greenhouse gas emissions 25% over the next decade (Bauman and Capper, 2011). The areas they have identified that directly affect methane emissions are: (1) rumen function (including microbial genomics/ecology) and modifiers, (2) enhancing feed quality and ingredient usage to improve feed efficiency, (3) genetic approaches to increase individual cow productivity, (4) management practices to increase individual cow productivity and (5) management of the herd structure to reduce the number of non-productive cow-days (Tricarico, 2012).

The U.S. dairy industry has had a remarkable record of advances in productive efficiency and environmental stewardship over the last half-century, with annual milk production per cow increasing by more than 400% with a corresponding two-thirds reduction in the carbon footprint per unit of milk (Bauman and Capper, 2011). It is also important to maintain a global perspective on the goal of reducing methane emissions. The U.S. provides about 16% of the world's total milk production but only about 8% of total greenhouse gas emissions (Chase, 2010). North America and Europe currently have the lowest greenhouse gas emissions per unit of fat-protein-corrected milk. The highest level is in sub-Saharan Africa and the majority of the increase in global livestock production over the next 35 years will occur in the developing world (Mitloehner, 2010).

Research from Wageningen University (Dijkstra, 2013) suggests that improving feed efficiency and reducing methane output required an interdisciplinary, fundamental approach and that direct methane inhibition through the use of dietary lipids, nitrates or tannins typically does not improve feed efficiency. They advised approach to improve feed efficiency and reduce methane emission intensity is to increase milk production levels and improve forage quality

Conclusion

As concluding "food for thought", listed below are field comments the author has solicited from DuPont Pioneer colleagues and interactions with consulting nutritionists when they were asked about the important forage-related areas dairy producers should keep in mind: 1) reduce fermentation and feed-out losses as a way to improve water utilization, 2) have someone in the operation who makes a priority of managing the agronomics and harvesting of forage crops, 3) optimize locally grown energy sources – anchor the diet with corn silage and reasonable levels of alfalfa, 4) consider all factors if switching from corn to sorghum due to water limitations - shorter maturity hybrids planted a lower populations may provide more energy per acre than sorghum, 5) focus on ration consistency and reducing variation in forage inventories, 6) be mindful of the huge varietal differences in sorghums and decide at what production level sorghum in the diet makes economic sense, 7) focus on economics of growing versus purchasing forages, 8) establish legal contracts for purchased forages with clear incentives around quality parameters (starch, kernel processing), 9) investigate ways to feed cows with less alfalfa by using alternative forage sources, 10) look closely at new silage technologies to improve forage feeding such as enzyme-producing inoculants, oxygen-barrier film, facers, rumination monitors and on-farm NIRS, 11) remember that forage quality cannot drive economical production without consistency and cow comfort, 12) consult with trusted academic and industry specialists to help separate "fact from fiction" when it comes to new forage technologies, 13) utilize new forage analysis methods to proactively predict the associative effects of combining various forage and supplements into a lactating diet and 14) keep abreast of agronomic advances allowing for prediction of yield, quality and harvest timing of forages as the growing season advances.

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Notes: