Corn Silage: Managing the Manageable

Bill Mahanna

Pioneer Global Nutritional Sciences, 7100 NW 62nd Ave, Johnston, IA 50131
E-mail: bill.mahanna@pioneer.com

Take Home Messages

- Corn hybrid genetics set the potential for silage yield and nutritional value, but crop management, growing environment, ensiling efficiency and feed-out management determine the outcome.
- Agronomic strengths and weaknesses, dry matter yield and starch content are the primary traits to consider when selecting hybrid genetics for silage production. The best non-brown midrib (non-BMR) silage hybrid is typically a tall, high-yielding grain hybrid.
- Dry matter yield is influenced by hybrid genetics, hybrid maturity, planting population, growing season, plant height at the ear (biomass yield), and kernel maturity at harvest.
- While both fibre and starch digestibility are important when balancing diets, they should not be a focus when choosing non-BMR silage hybrid genetics because of limited genetic variation among hybrids harvested at typical silage maturities.
- High fibre digestibility can be achieved by planting BMR hybrids, harvesting healthy, disease-free plants and potentially by high-chopping plants.
- Starch digestibility can be optimized by aggressive kernel processing and allowing four to six months in fermented storage before feeding.
- Silage growers have little control over growing environment (other than fertility and irrigation) but once genetics are selected, they can exert influence over silage yield and dietary impact by harvest maturity, chop length, degree of kernel processing, and ensiling and feed-out management.
- Producers must pay attention to potential for conjugated linoleic acid production induced by low ruminal pH from changing corn silage starch digestion in high corn silage dairy diets to avoid butterfat depression problems.

Introduction

There has been a trend in recent years for dairy producers to feed higher inclusion rates of corn silage in their lactating cow diets. Martin et al. (2017) reported that between 1982 and 2017, alfalfa hay, hay crop silage and green chop acreage in the U.S. decreased by 32%. At the same time, corn silage acres remained unchanged (with declining cow numbers) but because of improved genetics and crop management, corn silage production increased by 33%. The primary reasons why corn silage is becoming the preferred fermented forage for many producers include: 1) high yields compared with other forage options, 2) easily fermented and palatable feed, 3) high starch content, 4) desirable and more consistent fibre digestibility than multiple-harvest forages,5) lower labour-intensity because of one harvest period, and 6) efficient utilization of manure.

Once hybrid genetics are selected and planted, there are six main areas over which silage producers have some control in optimizing silage yield and quality: 1) harvest maturity and moisture, 2) chop length, 3) degree of kernel processing, 4) inoculation, 5) bunker and pile management, and 6) feed-out rate and management.

Hybrid Genetic Selection

Before the late 1980s, many nutritionists used book values for the nutritional value of corn silage because little research had been conducted to understand how hybrids differed in terms of nutrient content. Early work by Pioneer, in conjunction with the University of Idaho (Hunt et al., 1992) was the first published research showing significant differences between six hybrids grown at two locations in Idaho and California and harvested at three maturity points. Further research (Hunt et al., 1993) from the University of Idaho showed significant differences in animal growth performance between two commercially available hybrids commonly used in the Northwest at that time.

Agronomics

Important genetic agronomic traits that deserve selection consideration for a silage hybrid include 1) heat units (crop heat units [CDU] or growing degree units [GDU]) to both silk and physiological maturity (kernel black layer), 2) plant height, 3) stress emergence, 4) drought tolerance, 5) fungicide response, 6) suitability to high populations, and 7) resistance ratings to important local diseases (e.g. foliar diseases, ear moulds). Some of these traits are delivered via genetic modifications and some by natural genetic adaptability or resistance. Other traits commonly reported by seed companies such as stalk/root strength, grain dry down and test weight are of little importance to silage growers. Silage producers should never rely solely on seed company catalog ratings; they should seek the advice and knowledge of local seed sales professionals who have local experience and the opportunity to observe hybrids over multiple years in experimental plots before commercialization.

Producers should select silage hybrids that are five to ten relative maturity days longer than would be typically be grown for grain in their geography because the heat units are not needed to mature the crop to dry grain (combining) maturity. This approach will help maximize silage yield and starch content. If maturity is too long for the growing zone, starch levels and total yield may be compromised by planting a hybrid whose heat unit requirements exceeds the average killing frost date.

Silage growers will often reduce risk by spreading the pollination period between hybrids. However, planting hybrids with differing kernel physiological maturity ratings may not always provide the desired effect because the hybrids could have similar CHU or GDU to silk. Growers should consult CHU or GDU to silk ratings to see the relative difference in timing of pollen shed and silk emergence. It is difficult to compare CHU or GDU to silk across companies because industry standards are lacking for how heat unit and maturity ratings are determined.

Earlier silking hybrids generally move north of their adapted zone and more readily adapt to higher elevations. If moved too far north or in elevation, late silking hybrids may not reach physiological maturity before the first killing frost or may have reduced grain yield potential if abnormally late silking exposes the crop to cooler temperatures during starch fill.

Dry Matter Yield

Once proper maturity and agronomic traits are decided, the next trait that should be considered is dry matter (DM) yield. In silage, this is primarily determined by the amount of starch and height of the plant at the point of ear attachment (biomass). Longer-season hybrids generally have more yield potential than do shorter season hybrids. However, it is important to select hybrid maturities that allow healthy plants to mature to at least ½ milk line before silage harvest given that starch content is highly correlated with DM yield. Corn grain typically contributes 45–50% of silage DM yield. The corn kernels in silage, because of their starch and oil content, are responsible for 60–70% of the plant's energy content, with the remaining 25% of the energy coming from cell walls (neutral detergent fibre [NDF]) and 10% from cell contents of the vegetative parts of the plant.

Concurrent with the continual 1–2 bushels/acre/year increase in North American corn yield is a parallel

tonnage increase in corn silage yields. This is not surprising given the relationship between starch content and silage yield. Much of the increase in grain and silage yield in the last 15 years can be attributed to plant breeding efforts that produced hybrids which tolerate the stress of high plant populations. In the early 1980s plant populations were about 24,000 plants per acre. Today, we see most silage growers successfully planting and harvesting high quality corn silage at plant populations between 32,000–40,000 plants per acre depending upon geography and growing conditions. A summary of University of Wisconsin silage hybrid plot results from 1995 to 2007 (Lauer, 2014) showed that the top three drivers of silage DM yield were: 1) kernel maturity at harvest, 2) hybrid genetics, and 3) planting date (longer season hybrids typically yield more total DM).

Starch Content

Kernel maturity at the time corn silage is harvested is a significant driver of silage DM yields. A healthy corn crop can deposit as much as 1.0 percentage unit additional starch every two days from 1/3 milk line to physiological maturity (black layer). Harvesting when kernels are immature (e.g., ⅓ milk line) will result in lower DM yield compared with harvesting at later kernel maturities (e.g., ¾ milk line). Research conducted by Pioneer in conjunction with the University of Illinois reported kernels could increase in starch content by over 25% from ½ milk line to black layer maturity (Walker et al., 2010). Kezar (1989) reported starch increase of 22% between ⅓ and ⅔ milk line. Delaying harvest to allow kernels to more fully mature requires a plant that maintains good late-season plant health. This is a constant goal of all corn breeders and is aided by fungicide use in those geographies prone to foliar diseases (Mahanna and Thomas, 2012).

Corn silage DM content of 30–32% is often referenced as being the goal for silage stored in bunkers or drive-over piles. This traditional DM recommendation comes from two perspectives: 1) ensuring enough moisture for adequate silage compaction, and 2) fearing that delaying harvest will result in significant reductions in fibre digestibility. However, technologies have advanced in bunker and pile management (improved compaction capacity, oxygen-barrier file, inoculation), and plant genetics now allows for targeting ¾ milk line (approximately 36–38% whole plant DM) in healthy plants to capture more starch. A review by Pioneer of all published corn silage literature in the Journal of Animal Science and the Journal of Dairy Science (Owens, 2018) found that in healthy plants, fibre digestibility declined only minimally (2–3 percentage points) from ⅓ milk line (~30–32% DM) to ¾ milk line (36–38% DM). Corn is a “modified grass”, but generations of corn breeding efforts for improved late-season plant health has allowed corn plants to retain high fibre digestibility, even in later maturities, while the kernel is still depositing valuable starch.

When selecting silage maturities, it is often advantageous to select a slightly shorter-season hybrid and let it mature to ¾ milk line rather than selecting a longer-season hybrid thinking it will produce more biomass. However, if that longer-season hybrid encounters an early killing frost, starch deposition will be terminated, which will negatively impact both DM yield and energy density.

Fibre Digestibility

A trait of minimal importance during silage hybrid selection is fibre digestibility. The growing environment (e.g., amount of moisture the plant receives during vegetative growth stage) is three times more influential on fibre digestibility than is hybrid genetics (Owens, 2012). While fibre digestibility is highly heritable, variation among elite silage genetics is minimal. Despite years of academic research to improve fibre digestibility, limited success has been achieved.

Lauer (1997) summarized the annual corn grain and silage trials at the University of Wisconsin and published the order of items considered important for selection of a corn hybrid. First, the hybrid must be adapted to the area of production in terms of maturity, standability, disease and insect resistance, and drought tolerance. The hybrids that meet those criteria should then be ranked in order of yield potential. Hybrids with high grain content typically have high silage yield. Last, quality (e.g., NDF digestibility for

silages) should be considered. Except for hybrids with the BMR trait that consistently have higher NDF digestibility, the environmental conditions for plant growth and harvest timing have a greater impact on yield and nutritional value (NDF and starch content and digestibility) of corn silage than does genetics (Owens, 2014).

University or company plot data show that only a few standard hybrids are statistically different when grown in the same plot. Only the BMR hybrid entries consistently show a statistical advantage in fibre digestibility. A 3–4 percentage point difference in NDF digestibility is needed to be biologically significant given the inherent error of measuring NDF in laboratory fibre digestion methodologies (Hall and Mertens, 2012; Mertens, 2019).

Corn silage plots of several hybrids grown in Michigan in a drought year followed by a normal precipitation year resulted in lower starch levels in the drought silage but a 20% improvement in NDF digestibility (NDFD) along with lower lignin levels in the silage. By tassel stage, plant stover growth has terminated. Under wetter than normal growing conditions during vegetative growth stages, plants have longer internodes and grow taller. Differences in lignin content are difficult to measure but increased lignin cross-linkage to hemicellulose is likely the cause for lowered fibre digestibility in these plants. This may be why corn silage grown under irrigation appears to be lower in fibre digestibility than the same hybrids grown in dryland conditions (Mahanna, 2010).

In drier than normal vegetative growth environments, internode length is shorter and fibre digestibility of the plants tends to be higher than in plants grown in normal conditions (Van Soest, 1996). While total biomass yield may be lower due to a shorter plant, fibre digestibility is typically higher. Also, with a shorter plant, starch is further concentrated. Research at Cornell University suggests the moisture the plant receives is seven times more influential on fibre digestibility than are the heat units the plant receives (VanAmburgh, 2015). The growing environment post-tassel appears to have minimal effect on fibre digestibility but does exert a significant influence on ear development and silage starch content. Unlike starch digestibility, fibre digestibility does not change during fermented storage so the fibre digestibility at harvest will be the fibre digestibility for the entire feed-out period.

While there is an abundance of knowledge about how to irrigate corn for grain yield, there is a lack of information about how to irrigate the corn plant for silage production. Granted, starch will drive yield and overall energy density, but what is of interest are vegetative stage irrigation regimes that might manipulate fibre digestibility. Agronomists are wary of reducing irrigation schedules with pivot irrigation given concerns about not being able to keep up with plant evapotranspiration needs. Producers using flood irrigation may be in a better situation to experiment with reducing irrigation during vegetative stages to increase fibre digestibility without reducing plant growth. These growers should then fully irrigate as the plant enters the reproductive stage to ensure high starch content. This is an area in need of further research.

Another issue related to growing environment is within-field variability. Corn silage fields do not possess the same soil profile, water-holding capacity or fertility. Unpublished Pioneer data suggest within-field variability in fibre digestibility and starch content may be greater than the differences between hybrids (Bolinger, 2019). One way for silage feeders to manage this variability is to “face” the entire bunker or pile and in this way, average out the variation that might exist in any one area of the bunker or pile.

While growers have limited control over the growing environment, they do have control over chop height as a method to manipulate fibre digestibility. A review of 11 published studies on high chopping corn silage by researchers at Pennsylvania State University (Wu and Roth, 2003) reported that increasing chop height from seven inches to 20 inches increased fibre digestibility by 6.7% and concentrated starch by 6%. Research by Pioneer and the University of Idaho demonstrated all hybrids do not respond to high chopping in the same manner. There appears to be a strong genetic by environment interaction with high chopping. To predict what effect high chopping might have on increasing fibre digestibility, plants must be chopped at different heights and analyzed to see if increasing chop height is worth the loss in stover and

effective fibre. Unpublished research by Pioneer indicates that for every 4–6 inches of increased chop height, the average hybrid will be reduced in yield about 1 ton (30% DM) per acre.

One of the newest laboratory analytical measurements relating to forage fibre is undigested NDF (uNDF). The research is clear that NDF does not degrade in the rumen at a constant rate, but rather as three pools: fast, slow, and undigested NDF. Large slow and uNDF pools in the forage and diet cause greater rumination and slower eating speeds but problematically, lower intake potential due to increased rumen fill. One of the advantages of corn silage as the primary forage ingredient is that it typically has the lowest uNDF of all forages. The uNDF is further diluted in a diet that incorporate corn silages possessing high starch content. Nutritionists are starting to observe depressed DM intake and lower milk production when total uNDF240 (NDF that is still undigested after a 240-hour incubation) intake/cow/day for forages (over 4 mm in length) in the entire diet exceeds about 5.0–5.5 lbs (or about 0.35–0.40% of body weight). Undigested NDF is only appropriate for cows where DM intake is limited by rumen fill, which is typical of intakes during peak milk production. Exceeding these amounts may lower peak production, especially if cow persistency is high.

An exception to ignoring fibre digestibility has been the plant breeding efforts around commercializing BMR hybrids with reduced lignin content in the stalk and leaves resulting in improved fibre digestibility. Rate and extent of ruminal NDF digestion are greater for corn hybrids whose parents possess the BMR mutant, but compared with non-BMRBMR (standard) hybrids, most BMR hybrids have lower silage yields and greater susceptibility to nutrient and water stress (Owens, 2014).

The main nutritional advantage of BMR silage is higher fibre digestibility due to less lignin, which interferes with rumen bacteria degradation of cell walls. Higher fibre digestibility impacts: 1) the amount of forage in the diet (typically more forage equates to a cheaper ration), 2) energy obtained from the corn silage, and 3) amount of forage cows can consume per day. Fibre in BMR hybrids appears to be more fragile and exits the rumen faster than does fibre from standard hybrids. While DM yields of BMR hybrids are behind standard silage hybrids by 5–15% depending on geographical yield potentials, some silage growers and their nutritionists are adopting agronomically improved BMR hybrids and are willing to sacrifice yield to obtain higher fibre digestibility. This is not that different from alfalfa growers harvesting at late-bud stage rather than full-flower, sacrificing alfalfa yield to obtain forage with higher fibre digestibility and intake potential.

Silage producers who are considering BMR hybrids need to have realistic expectations including: 1) potential for more agronomic risk, i.e., reduced standability, 2) reduced yields, 3) additional land base because of reduced yields and extra inventory because of higher feed intake of BMR silage, and 4) possible need to segregate this silage given the biggest benefit will be in diets fed to transition and early-lactation cows. High chopping, while increasing fibre digestibility, will not drive DM intakes as much as the fragile fibre found in BMR hybrids.

Current estimates are that BMR hybrids constitute less than 10% of all North American silage acres. However, as their agronomics and yield improve, it is conceivable that 20 years from now, almost all silage hybrids will have the BMR trait. Another limiting factor to BMR adoption has been the difficulty of price discovery between silage growers and large dairies buying that silage. While the BMR trait should drive intakes and offer feeding advantages, especially to transition and high-production groups, it is difficult for dairies to know how much to pay for BMR silage to compensate growers for increased agronomic risk and lower yields. Commercialization of new BMR genetics with more parity yield to standard silage hybrids should help resolve these impediments to acreage growth.

Starch Digestibility

The starch in corn silage is from relatively immature kernels (pre-black layer) and the desired starch level is a moving target. The fact that the starch is from a relatively immature kernel is important because

kernels at this stage do not contain very much vitreous starch, which is the starch that is responsible for the high test weight in fully mature kernels at combining maturity.

The 7-hour ruminal starch digestibility of new-crop corn silage is about 70% and drifts upwards (about 2 percentage units/month) for about six months before plateauing (Mahanna, 2007). Junges et al. (2017) recently published research suggesting that the bacterial activity, not just acid load, appears to cause the solubilization of the proteinaceous matrix surrounding corn starch granules that results in increased ruminal starch digestion over time in fermented storage.

The greatest mechanical tool to improve corn silage in recent times has been the development and adaption of on-chopper kernel processors that significantly improve both ruminal and total tract starch digestibility. One of the first studies involving kernel processors (Andrae et al., 2001) showed kernel processing increased in situ 24-hour starch digestion from 73.4% to 85.8%. More recent studies show significant increases in improved kernel processing scores with silage harvested with a Shredlage® processor (Ferraretto et al., 2018). Today, very little corn silage is harvested in the U.S. that has not been kernel processed at the time of harvest. The main factors influencing kernel damage at the chopper are: 1) chop length (shorter chop length typically results in better kernel processing if effective fibre from corn silage is not an issue), 2) synchronized timing between header and feed rolls, 3) roller mill wear, 4) roller mill gap setting (typically 1 to 3 mm), and 5) roller mill differential speed (many at 50% or greater).

Many laboratories offer kernel-processing scores (Ferreira and Mertens, 2005) that are helpful to nutritionists balancing diets. There is, however, a need for protocols to ensure corn silage is being evaluated for processing at the time it is being harvested. Pioneer developed a field test employing a 1-liter cup where the goal is to have less than two whole or half kernels in that volume of silage. Fecal starch analysis can be a good post-harvest indicator of degree of kernel damage. In a Pioneer field study of the high-production strings in 32 Wisconsin dairies, only two of the dairies showed more than the goal of < 3% fecal starch and those two dairies had poor corn silage processing scores (Powel-Smith et al., 2015).

There have been recent discussions about the value of soft-floury (low vitreous, low prolamin) endosperm in corn silage kernels. There does not seem to be significant variation in the amount of hard, vitreous starch or starch digestibility in corn silage given the immature kernel maturity (pre-black layer) at normal corn silage harvest. Pioneer field studies from side by side trials (hybrids grown in the same field receiving the same environment) showed no significant difference in 7-hour ruminal starch digestibility between advertised “floury-kernel” and normal hybrids at silage (or high-moisture corn) kernel maturities (Wiersma et al., 2015). Ohio State University researchers concluded that the amount of vitreous starch in corn silage kernels was of relatively little value whereas the amount of vitreousness in dry corn grain should be considered, particularly to help growers know when to grind corn more finely (Firkins, 2006). This makes sense because the level of vitreousness increases as kernels mature past black layer as reflected in differing test weights (more vitreous starch) among hybrids at combining maturity. The fine grinding of dry corn, commonly practiced in the dairy industry, is supported by research in France (Ramos et al., 2009) showing that the negative effects of flint corn (very high vitreous levels) on total tract starch digestion could be eliminated by grinding dry corn to 550 microns.

▪ Plant Population

It is important to target plant population based on individual hybrid recommendations. Typical seed corn germination is about 95%. Overplanting by at least 5% can help reduce the effects of germination-induced skips and for expected reductions due to insects and soil conditions.

Summarizing corn population research is difficult because varying maturities across diverse growing environments make it difficult to draw sweeping conclusions. However, over the last 25 years the average U.S. corn planting population has risen from 23,000 plants per acre (PPA) to about 30,000 PPA. High-yielding environments allow for increasing populations to 36,000–38,000 PPA depending upon individual

hybrid genetics. Higher population increases competition among plants for water, sunlight and soil nutrients. Pioneer has conducted studies comparing hybrids sold during previous decades. There is modest improvement in grain yield production because of higher leaf area index, efficiency of leaf photosynthesis, number of kernels per ear and weight of each kernel. However, the genetic selection of corn hybrids for stress tolerance has accounted for the majority of the 1.0–1.5 bushels/year grain yield increase over the past 80 years. This is a result of higher population increasing the number of ears per acre. More precise soil fertility practices and technology traits that improve resistance to insect and weed pressure have also significantly improved average yields.

Further driving yield is that the average grower is planting earlier than in the past, somewhat the result of improvements in seed treatment options. Silage growers should be cautioned not to rely on ear flex scores when considering planting populations. Ear flex refers to the ability of a plant to extend ear size as plant density is reduced or as growing conditions improve. Many seed companies have abandoned evaluating ear flex and advise growers to rely on actual population recommendations from research trials planted at upwards of 70,000 PPA. Ear flex scores have their primary utility in deciding if a hybrid can deliver higher yields under possible replant situations such as emergence problems or hail, which reduces populations to less than 12,000 PPA (Thomas and Mahanna, 2011).

It is important to differentiate between grain production and silage production when discussing plant populations. The effect of lower plant populations on increasing grain yield is greater in low grain-yielding environments (< 130 bushels/acre) and makes variable rate seeding more beneficial in lower yield environments. Grain yields tend to drop off gradually with higher populations, although much less than hybrids of decades ago that were prone to barrenness under high plant densities. Due to improved hybrid stress tolerance, many seed companies routinely evaluate hybrids at plant populations as high as 50,000 PPA.

There also appears to be slight differences in ideal plant populations by hybrid maturity. Shorter-season hybrids (< 100-day hybrids) tend to show the greatest grain response to higher populations, followed by 101–113-day hybrids and finally longer-season hybrids (> 113 days). Researchers theorize that higher populations overcome some of the disadvantages of smaller stature and lower leaf area index exhibited by shorter-season hybrids. A few seed companies provide a planting rate calculator to determine economic grain planting rates based on hybrid genetics, yield environment, seed cost and grain price.

Silage is a more complex situation. Traditional recommendations have been to increase plant populations in hybrids destined for silage by 10–20% per acre. However, with the increasing value of starch, newer recommendations suggest planting silage at no more than 2,000–3,000 PPA above the recommended planting population for that hybrid if planted for grain. Higher populations might provide more yield of stover but reduce yields of starch (grain; Lauer, 2008). Higher plant populations tend to decrease stalk diameter and increase potential for lodging. This is much less of a concern for silage than for grain corn harvested at a much later maturity. Research has consistently demonstrated that higher populations (upwards of 40,000–42,000 PPA) increase silage yield while decreasing quality only slightly. The decrease in quality is caused by increased stover yield diluting the grain (starch) portion of the plant causing slightly higher fibre levels.

Some earlier research suggests the smaller diameter stalk found in higher populations altered the rind: pith ratio causing slightly lower fibre digestibility. Research conducted in 2008 and 2009 with conventional, leafy and BMR hybrids planted at populations ranging from 25,000–40,000 PPA showed no significant effect of increasing population on fibre digestibility (Thomas and Mahanna, 2011). There are some silage growers who prefer to plant at lower populations, more optimal to grain yield, in an attempt to increase the starch content of silage in response to increasing supplemental grain prices.

▪ Frosted Corn

Corn plants that have been frosted prior to harvest can experience premature leaf or whole-plant death. The plant may remobilize stored carbohydrates from the leaves or stalk tissue (leading to standability issues and potentially reduced fibre digestibility) to the developing ears but yield and nutritional potential will still be lost mostly from the cessation of starch deposition.

Approximate yield losses due to premature death of leaves (but not stalks) are 36, 31, and 7% when the leaf death occurs at R4 (dough), R5 (early dent), and ½ milk line (R5.5) stages of kernel development. Loss of nutrient value from leaf loss or undesirable microbial or fungal growth can be minimized if the crop is harvested as soon as possible after the frost. Post-frosted corn is predisposed to spoilage organisms with the onset of warm days and cool nights, coupled with high humidity from rainy or drizzly conditions. Fortunately, husks tend to open and dry down rapidly following a frost, which mitigates the ear condensation, although stalks will retain considerable moisture. Fungi growth often attributed to conditions set up by a frost is commonly active in the field prior to the frost event.

Corn that has experienced a killing frost at ⅓ to ½ milk line maturity will typically be below 72% moisture and can be harvested soon after the event. Corn that is pre-dough stage will be too wet (> 75% moisture) to harvest and may require several days in the field to dry to acceptable harvest moistures (to prevent excess effluent). If the frost event did not freeze kernels and only damaged the top of the plant leaving leaves around the ear still healthy, the plant will continue to mature and lay down starch in the kernel.

Leaves of immature frosted plants make the crop appear very dry but most of the moisture is in the stalk; starch, which serves to dry down the plant, is lacking in these plants, further adding to the moisture problem. If harvest must proceed, it is possible (but laborious and inconvenient) to add dry materials (e.g., dry corn, beet pulp) to the silage to increase the DM. For example, one bushel of dry corn per ton of immature silage will increase the silage DM by only 1.5% units. Immature corn that has experienced a killing frost will have high sugar content in the stalk from sugars that will not be translocated to the kernel. This helps to improve the crop's nutritive value to offset reduced starch levels. However, these excess sugars will also provide nutrients for spoilage organisms to grow during feed out. These high sugar corn plants will also have a natural population of fermenting bacteria (epiphytes) that will be greatly reduced by the frost event. For these reasons, a combination *L. buchneri* inoculant is highly recommended. A "combination" product means that the inoculant contains both homofermentative strains to quickly reduce pH along with a *L. buchneri* strain to inhibit yeast at feed out.

Cotanch (2015) investigated the impact of frost and subsequent mould and fungal growth on NDF digestibility, using corn that experienced a hard frost that killed much of the top third of the plant. The crop remained in the field for another week until it dried down enough to harvest, and during that time, experienced significant mould and fungal growth on the damaged portion. Frost and resulting fungal deterioration of corn leaves resulted in a 6% unit drop in NDF digestibility (30-hour) and a 5% unit increase in uNDF30 (undigested NDF after 30 hours of incubation) compared to that of the lower, healthy green leaves. The frost and subsequent mould and fungal growth not only reduced the energetic value of the crop but also decreased intake potential because of the increased uNDF. The researcher concluded that NDFD and uNDF are influenced not only by hybrid selection or crop maturity at harvest, but also by any anti-nutritional factors such as of the quality of growing season, presence of weeds, and pest or fungal damage.

▪ Chop Length

It is difficult to offer generalized chop length recommendations because proper length depends on several factors including: 1) the need for physically effective NDF (peNDF) levels in the ration, 2) particle size of the other dietary ingredients, 3) the type of storage structure, and 4) silage compaction capabilities and unloading methods (e.g., silo unloaders, bunker facers). Other factors affecting chop length include the need to chop finer to damage corn kernels if on-chopper processing is not available or to chop longer to

compensate for particle reduction from bagging or feed mixing.

In general, shorter chop tends to improve compaction in the storage structure and increases surface area of fibre (or kernels) to improve rate of digestion by rumen bacteria or intestinal enzymes. Longer chop increases the peNDF of the feed; however, excessive length can contribute to sorting by cattle in the feed bunk. Producers should work with the harvesting crew and nutritionist to decide on the proper compromise, recognizing that particle length in the final ration is what is most important. Start at the feed bunk and work backwards to the amount of each feedstuff in the ration and how much peNDF each one of those feeds needs to contribute to the entire diet.

▪ Ensiling Issues

Corn silage fermentation can be simplified into three phases. Silage experiences aerobic (with oxygen) conditions during harvest and filling, followed relatively quickly by anaerobic conditions that initiate lactic acid bacterial (LAB) growth and pH decline, and finally, back to aerobic conditions during feed out.

The natural microbial (epiphytic) populations that exist on the fresh corn crop at harvest exert a tremendous influence on the stability and feeding value of the resulting ensiled feed. Factors such as temperature, humidity, solar radiation, plant maturity and moisture influence the type and quantity (colony forming units (cfu) per gram of forage) of epiphytes populating the crop. The goal of ensiling is to stabilize the crop via the action of LAB. This reduces pH through the efficient conversion of sugars to lactic acid. As livestock operations transitioned to larger bunkers and drive-over piles, it created a greater need to reduce aerobic deterioration on the face of the silage during feed out.

The ensiling advantage to corn silage is that the crop is high in sugars and low in buffering capacity and is not wilted on the ground for exposure to soil-borne spoilage organisms. The ensiling negatives of corn silage, especially if the crop is stressed by drought or early frost, is high yeast counts. The proliferation of yeast in silage re-exposed to oxygen at feed out can have a detrimental impact on DM loss, heating and palatability. In the presence of oxygen, certain yeast species can metabolize lactic acid, causing an elevation in silage pH which reduces the inhibitory effect on other heat-generating spoilage organisms such as mould, bacilli and acetobacter species. Yeast and acetobacter can also produce aromatic compounds such as esters, aldehydes and ethyl acetate (smells like fingernail polish) which can significantly reduce feed palatability (Mahanna et al., 2018).

The impact of yeast and other spoilage organisms can be minimized by proper harvest moisture (to reduce silage porosity), silage compaction, the use of an oxygen-barrier film and plastic cover, silage facing equipment and the use of silage inoculants containing viable strains of *Lactobacillus buchneri* (Kleinschmit and Kung, 2006).

▪ Feeding Issues

Corn silage inclusion rates in dairy diets are on the rise because of high yields, energy density, consistency and palatability. When formulating diets around corn silage, nutritionists should focus on starch content and digestibility, NDF content and digestibility and physical attributes such as peNDF, kernel damage and feed storage and delivery management.

The starch in high corn silage-based diets (e.g., > 8 kg corn silage DM/cow/day) is often considered a “villain” when herds experience erratic intake, butterfat depression or inconsistency in manure scores. However, the villain image has lessened as 7-hour ruminal starch digestibility laboratory values have become readily available allowing nutritionists to adjust for fermentation-induced increases in ruminal starch availability by reducing both quantity and ruminal fermentability of supplemental starch sources.

Linoleic acid, found in corn germ, can also play a role in butterfat depression (Baldin et al., 2018). Ruminal starch overload and lowered rumen pH can result in reduced intakes and facilitate the

conversion of linoleic acid to conjugated linoleic acid, that can have a huge impact on fat yield (Mahanna, 2009). Butterfat depression can be avoided given current understanding of the trans-fatty acid theory of butterfat depression along with the ability of ration software to track estimates of unsaturated (especially linoleic acid) intakes (Perfield and Bauman, 2005) and the recent development of fatty acid milk analysis (Dann, 2017),

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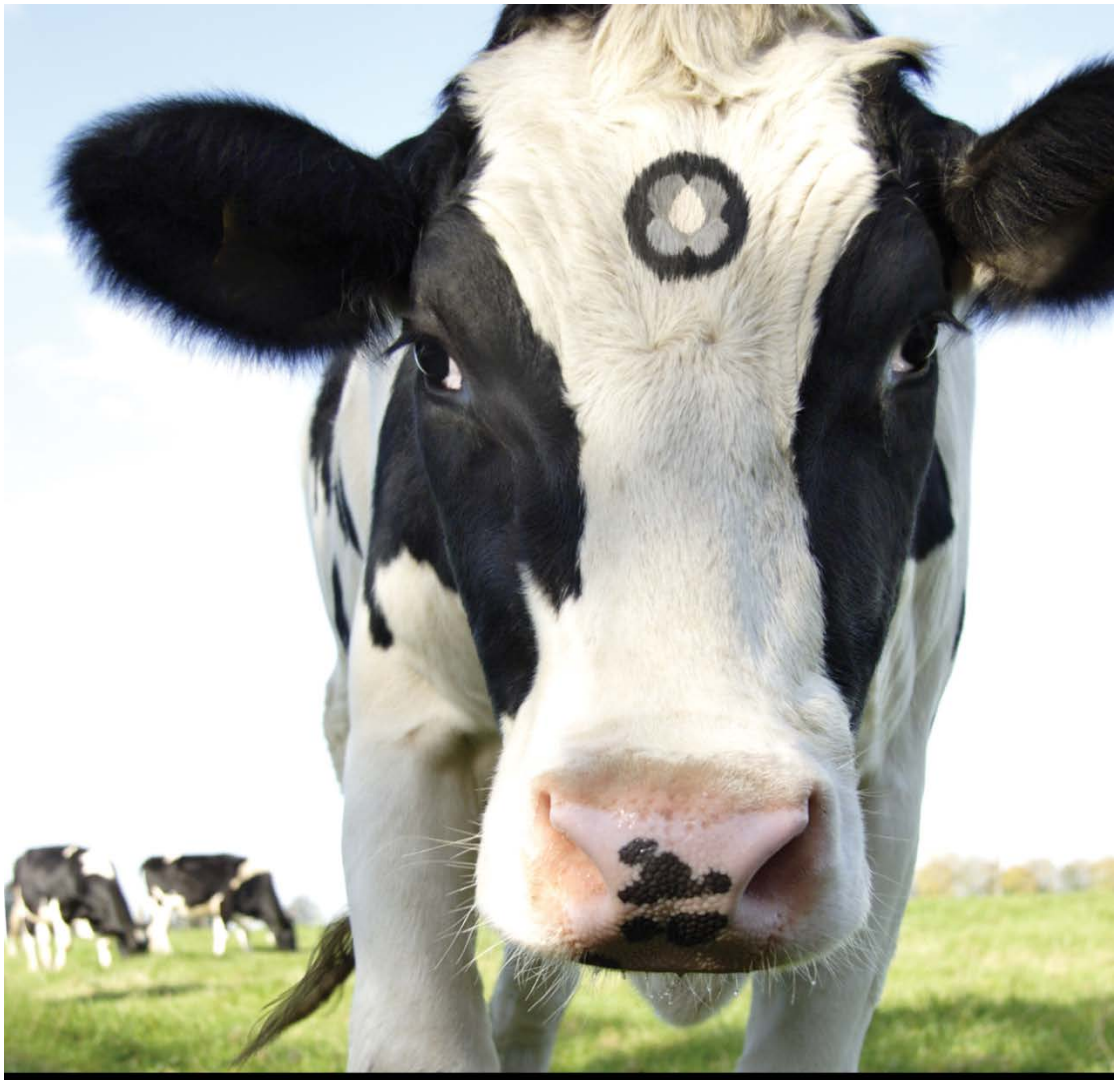

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