New Technologies in Forage Varieties and Production

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Abstract

Yield of field crops is limited primarily by the supply of available water, environmental temperature, and season length. In addition, timing of harvest will markedly alter both the quantity of forage gleaned, as well as its nutritional value for cattle. Plant and management alterations that have helped to enhance the nutritional value of grasses (including corn) and legumes have included: 1) development of cultivars or hybrids with decreased lignin content, and tolerant to herbicides (to simplify weed control) and drought, and 2) selection of plants with an increased concentration of more digestible parts and a higher ratio of live to dead plant tissue within a harvested or grazed crop. With the corn plant, hybrids suitable for very short season use (70 days to maturity) or tropical conditions (128 days or longer) are available. Hybrid selection involves matching a hybrid to the growth conditions and timing, as well as local soil, water availability, and environmental conditions. Incorporation of genes from brown midrib plants, through reducing the amounts of lignin and indigestible NDF of plants, has markedly increased the NDF digestibility of most plant parts. A faster NDF digestion rate and removal of space-occupying NDF helps to relieve capacity limits of the rumen of cows fed forage-rich diets. By allowing intake of feed energy to increase, milk yields usually are increased. Ruminal bulk, however, ultimately depends on both the dietary NDF concentration and its rate of digestion and passage. Amounts of indigestible NDF also can be decreased by increasing the leaf to stem ratio and by high-chopping the forage so that the harvested portion contains a lower percentage of the lignin-rich lower stems. Yet, because various plant parts differ in lignification of NDF and in ruminal residence time, predicting plant digestibility from an "average" rate of in vitro digestion among diverse plant parts and the ruminal retention time of an "average" NDF particle will not provide an accurate estimate of extent of ruminal NDF digestion of a forage with multiple plant parts. Corn silage typically contains over 40% grain. When fed as coarsely processed dry grain, starch digestibility generally is lower for grain with more vitreous starch. Fortunately, several factors (harvest of kernels at an immature stage, kernel processing, and a prolonged fermentation period) have combined to obliterate the adverse effects of vitreousness on starch digestibility of silages. Genetic, engineering, and microbiological advances have made delayed harvest of forages for silage both feasible and desirable. These changes have included improved plant genetics and selection, as well as fungicides that have improved disease resistance and late-season plant health, drought tolerant hybrids that reduce the prevalence of water shortage late in the growing season, kernel

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processing that enhances starch digestibility of more mature grain, equipment to rapidly harvest and thoroughly pack chopped forage into storage, oxygen barrier film coverings to reduce oxidative exposure of the silage mass in bunkers, silage removal equipment that reduces the amount of surface exposed to air, and inoculants that inhibit heating and energy losses during feedout. These advancements have removed most, if not all, of the reasons behind the recommendation that modern corn plants should be harvested early, between 30 and 35% dry matter **(DM)**, for maximum feeding value. Although local Extension personnel and industry representatives can supply detailed production information for comparing hybrids or cultivars from various companies on a local or regional basis, help guide producers to place the right hybrid on the right field, and scout the developing crop for insects and diseases, individual dairy farms in discussions with their nutritionist must make their own informed decisions based on preferences and risks among silage and grain types, their capacity to harvest, process, and store silage, and the local costs and availability of other ingredients included in their diets for dairy cows.

Introduction

Corn silage and alfalfa are the primary forages fed to lactating dairy cows. Interest in grazed grasses, already prevalent in certain regions of the world, has increased in parallel with production of organic milk. Plant genetic and management alterations to enhance the nutritional value of grasses and legumes often have paralleled those for corn outlined below (cultivars with decreased lignin content, tolerant to herbicides, maximum leaf-stem ratio, and minimum dead tissue within the harvested or grazed crop). But in addition, the high concentrations of protein in immature grasses and legumes and its extensive ruminal degradation have stimulated research interest in avoiding protein losses during harvest, fermentation, and ruminal digestion. For further discussion of recent genetic and management practices designed to increase the nutritional value of grasses and legumes, readers should examine papers and presentations by Martin et al. (2005a, b), Hartnell (2005), and Hartnell et al. (2010). For more general reading about various aspects of forage growth and silage production particularly suited for student instruction, Pioneer® (2014) has prepared and can provide a well illustrated107-page "Silage Zone Manual." Various options related to corn silage hybrid types were summarized by Shaver (2012), and Mahanna (2005) outlined numerous aspects of managing corn silage from seed to feed.

Past efforts in corn breeding have widely emphasized grain yield. However, genetic alterations and environmental practices also can add value to the corn crop when grown and fed as silage to ruminants. This paper will outline some alterations and practices that can alter forage productivity and crop feeding values of corn silage and attempt to explain why these changes have proven effective. Although specific plant or management alterations may prove useful under certain conditions, the potential for detrimental effects of individual specific alterations or practices also will be discussed so that individual producers can consider both the upside and downside of a given practice or variety.

Short season corn hybrids

Shorter season hybrids have been and continue to be developed specifically for regions of the world where the growing season has a limited duration (esp., Canada and Northern Europe). Shorter season hybrids also are being used in areas where the growing season is long enough so that a crop of corn can occur before or after a second crop, where irrigation is practiced to reduce the number of irrigation events required for silage or grain production, and in areas with very hot summers where short season plants will silk and pollinate earlier in the summer before heat stress shortens the duration of a successful pollination period. Although cost of production (seed and fertilizer) often is greater for corn silage than for production of small grains (e.g., barley silage), DM yield usually is 25 to 50% greater for modern corn hybrids than for small grains, thanks to continual investments and improvements in genetics and management of corn hybrids (Baron et al., 2008).

If the frost-free growing season is sufficiently long, the two major items that limit development and maturation of corn plants are mean daily temperature and available moisture. The range in days from planting until physiological maturity, e.g., the time of formation of the kernel black layer that denotes the point after which no additional nutrients are deposited within the kernel, usually occurs between 65 and 75% kernel DM, but days required to reach this point for individual hybrids can range from 70 to over 120 days. Because growing conditions, especially temperature, alters the rate of maturation, the number of days from planting to a given stage of kernel maturity (the earliest harvest stage for maximum grain but longer than needed for kernels to reach the half-milkline of maturity for silage harvest) for a corn hybrid varies with location and from year to year. Consequently, a different index of maturation, the number of growing degree days (**GDD**, i.e., the number of growing days multiplied by mean daily temperature) is preferable as an index of maturity being nearly twice as accurate for a comparative relative maturity or "days to maturity." Methods for calculating GDD have been described by Pioneer (2012). GDD is used widely for classifying hybrids into maturity classes (Nielsen, 2012). GDD from planting to grain maturity varies among corn hybrids based on genetics with values ranging from under 2000 to over 3050 for 75 to 125-day hybrids, respectively. Spreadsheets that calculate the accumulation of GDD from planting date throughout the growing season for individual localities are available from various sources, including Pioneer (2012), to help corn growers select appropriate hybrids for planting (especially when planting is delayed) to estimate the maturity of their selected hybrid at any time during the growing season, and predict an optimum harvest date for silage or grain production. Additional monitoring of the corn crop, based on moisture content of chopped plants, milk-line location, or black layer presence, can help to further refine harvest date estimates. Fewer GDD are needed for producing corn silage than needed for full grain development, making silage production more prevalent in regions of the world where the growing season is short. Short season hybrids must have an ability to germinate and emerge with cool soil and reach maturity before frost kills the plant (-2^{o}C; 28^{o}F). Typically, cold tolerance for germination and emergence is correlated with greater prevalence of flint genes, so short season hybrids often produce grain that is more vitreous than longer season hybrids.

The primary limitation of short season hybrids is a reduction in plant size and grain yield due to the cooler temperatures that limit rate of photosynthesis and the supply of sugars required for plant growth and grain deposition. The harvest ratio (grain:stover) value for short season hybrids at grain maturity is near 50% for both short- and longer-season corn hybrids, but when harvested for silage before grain black layer, this ratio can be considerably less than 50%. Yield of various components across Pioneer hybrids ranging from under 80 to 120 days comparative relative maturity is summarized in Figure 1. Plant size and starch content are considerably lower for short season hybrids, yet two short season crops often yields more DM and starch than a single full season corn silage crop.

Yield of dry matter, NDF, and starch summarized across Pioneer hybrids that differed in comparative relative maturity are presented in Table 1. As a percentage of DM, starch content was lower for earlier maturing hybrids, though neutral detergent fiber digestibility **(NDF)** was not altered by maturity class.

Tropical corn hybrids

Because energy content of corn silage is higher than needed for growing heifers or dry cows, some dairy producers have used various alternative methods in an attempt to reduce the grain (starch) content of corn silage. Although very high plant populations will increase the number of barren stalks, most hybrids grown at very high populations still produce some grain. However, most tropical corn hybrids when grown in a temperate zone never reach the appropriate photoperiod for pollination and will be barren. Even without grain, such plants still produce a substantial amount of DM. Barren plants, like hail-damaged plants, have elevated concentrations of sugar, similar to grain-producing plants that for genetic or environmental reasons lack a starch sink to use sugars produced by the plant. Though tropical hybrids may reach heights 40% greater than grain producing hybrids, many tropical hybrids lack grain that comprises 50% of corn crop DM at maturity. Lacking grain, DM yield will be less for tropical hybrids. However, their high sugar content has been of interest for extraction and cellulosic ethanol production.

Corn plants with no grain present (e.g., barren plants; tropical hybrids; plants bagged to prevent pollination) retain more moisture and sugar within the stover. Plant DM of barren plants may never increase to 30%, crop DM often considered necessary to avoid seepage of plant liquids from silo structures. Other procedures for reducing the starch content of forage (e.g., early harvest; dilution with a low quality forage; harvest of stover following harvest of high moisture ears or corn grain; substitution of forage sorghum) would seem more desirable than growing a separate corn crop for dairy cattle groups that need less starch than provided by corn silage.

Leafy corn hybrids

Selected specifically for a large number of leaves above the ear, leafy corn hybrids have more leaves than hybrids commonly marketed (dual-purpose or grain hybrids). Compared with other plant parts, leaves have a substantial amount of NDF, but compared with other plant parts, leaf NDF has a high in vitro NDF digestibility (Figure 2).

Leaves comprise only about 6% of dry weight for typical non-leafy corn plants (Figure 2). Even tripling the number of leaves of a corn plant from 6% of dry weight (19/320 g) to 16% of dry weight (57/358 g assuming that weights of other plant parts do not change), the contribution of leaves to total plant weight remains quite small. Nevertheless, greater prevalence of leaves in leafy hybrids contributes to the energy and NDF supplies in the rumen, and thereby, leafy hybrids should prove more useful for diluting grain in high concentrate diets (Figure 3), even though leafy hybrids usually have more NDF that may increase ruminal bulk fill with high forage diets. The history and advantages of leafy hybrids were outlined by Glenn (2013).

Silage yields, composition, and potential milk per ton and milk per acre for multiple hybrids with various altered genetic or plant characteristics summarized over 13 years from various locations in Wisconsin by Lauer et al. (2009) is replicated in Table 1. Based on this summary, except for lower starch content, the tested leafy hybrids had forage yields and silage compositions at silage harvest that fell within 3% of the single to triple stacked corn hybrids. Starch content of leafy plants was 11% lower. Paired comparisons across the US summarized by Pioneer (2006) are shown in Table 2 where compared hybrids were grown in the same field show less depression in starch content (-7%) but greater increases in NDF content (4%) and NDF digestibility (8%), more in line with expectations from an increased leaf content of leafy hybrids. A depression in starch content for leafy hybrids might be expected, especially at high plant populations. With leafy hybrids, the amount of sunlight reaching leaves near the ear that supply much of the sugar used by the ear for starch synthesis is shaded by extra leaves above the ear. High plant populations for both leafy and non-leafy hybrids through shading of ear leaves typically lower starch yields. Plant selection for more upright leaves and planting rows in a North-South direction, especially at higher latitudes, allows more sunlight to reach leaves near the ear and often has been associated with an increased grain yield and starch content of corn plants.

If digestibility of starch in fermented corn silage is 96%, the summary from Lauer et al. (2009) would predict that digested organic matter averaged across the leafy hybrids tested would be 96% that of single to triple stacked hybrids, and based on the Pioneer summary, would be near 99% that of single to triple stacked dual purpose hybrids. Ruminal fill, based on NDF content and NDF indigestibility at 30 hours, is predicted to be 2% greater for leafy hybrids from the Lauer et al. (2009) summary but 2% less for leafy hybrids from the Pioneer summary.

Lignin alterations

Plant cell walls are composed of three polymers – cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are sugar polymers; whereas, lignin is composed of multi-branched polyphenols. The physical rigidity provided by cell walls, combined with intracellular turbidity, provides structure and strength to plant tissues. Reduction of cell wall strength can sacrifice stalk strength and lead to stalk breakage and plant collapse under stress. In addition, lignin content of vascular tissue walls is greater in drought-tolerant plants, presumably because lignin combined with closure of stomata reduces the rate of evapotranspiration and water loss by plants. Plants not requiring support (e.g., water suspended plants) contain less lignin. To produce plants with lower lignin content, the metabolic pathways involved with lignin synthesis can be disrupted. Mutations at specific points in lignin synthesis are responsible for the lower lignin content of brown-midrib (bmr) plants. Discovered and named over 80 years ago, the term "brown-midrib" refers to a tan to brown coloration of the center leaf veins of plants, evident in plants with altered lignin. Within corn plants, bm1, bm2, bm3, and bm4 refer to plants where lignin synthesis is disturbed at different points. Only the mutants bm1 and bm3 of corn have been commercialized to date, though other C4 plants (e.g., sorghum) may have many more bm types. Additional mutants with altered lignin structure or content that have less adverse effects on structural integrity of plants currently are being studied.

Why is lignin content of plant cell walls of interest? Due to its water-repelling characteristics and high degree of saturation, lignin itself and lignin linked with hemicellulose resist attack by enzymes from bacteria, protozoa, and animals. Exposure to oxygen, ozone, and peroxidases will degrade lignin and lignin linkages to hemicelluloses. This allows ruminal fungi, as well as aerobic microbes, to degrade lignin.

Figure 4 provides a schematic illustrating cell wall composition and digestibility within the rumen. Even after being incubated with rumen fluid anaerobically for 240 hours (10 days), lignin plus some attached hemicelluloses remains undigested. Note that lignin is not digested by most ruminal microbes, so plants or plant parts with higher lignin content are less extensively digested. Thereby, direct selection for reduced lignin content automatically increases the extent to which NDF can be digested. The NDF lost during 240 hours of incubation with rumen fluid is considered "potentially digestible." Given sufficient time, potentially digestible NDF would be attacked and solubilized or digested by ruminal microbes. But, residence time for NDF in the rumen for microbial attack typically is limited to a maximum of about 48 hours. The in vitro incubation time period used by analytical labs to estimate the extent of ruminal NDF digestion typically is only 30 hours. Disappearance of potentially digestible NDF at multiple time periods (e.g., 24, 30, and 48 hours) should provide a more realistic estimate of rate of NDF digestion than a single 30-hour time point. However, measuring potentially digestible NDF probably has greater merit than measuring NDF digested to predict the amount of NDF digested at various incubation times.

As might be expected from their differing and specific physiological functions, corn plant parts differ in the ratios among the components that comprise NDF (Figure 5). The NDF of support tissues of the lower stalk have the highest lignin content; whereas, grain has the least. For most tissues, the extent of NDF digested at 30 hr is less for plants where lignin comprises a higher portion of NDF. This supports the concept that potentially digested NDF is inversely related to lignin content. However, the digestibility of NDF from cob is considerably lower and is considerably greater in leaves than one might expect from lignin content of NDF alone. This may be related to differences in particle size and the amount of surface and stomata exposed for digestion by rumen fluid in vitro, delayed wetability of cob component fractions, or presence of digestion inhibiting compounds. How realistic are in vivo NDF digestibilities of corn silage at 30 hr to what happens within the rumen? Would one expect plant parts that differ in particle size and fragility (associated with mechanical processing, as well as mastication), wetability and the time lag before digestion begins, and ruminal density to universally and consistently spend 30 hr within the rumen for digestion? Certainly not. Differences in extent of lignifications among various plant parts and differences in ruminal residence time of various plant parts will cause the extent of digestion of different plant parts at any time period to differ. Extent of ruminal digestion of a plant part will be less for particles that spend less time in the rumen. Prediction of rate of ruminal NDF digestion (kd) of a mixture of plant parts when multiplied by some estimate of the MEAN rate of passage (kp) across various plant parts is not likely to realistically predict extent of ruminal NDF digestion. Furthermore, preferential ruminal retention time of particles that have more potentially digestible remaining NDF, though useful for ruminants to maximize digestion, complicates accurate prediction of ruminal retention time and extent of ruminal digestion of a feed component that has multiple separable parts or components.

As noted in Tables 1 and 2, in vitro NDF digestibility at 30 hr for mixed samples from bmr corn hybrids is 8 to 10 percentage points greater than for samples from non-bmr hybrids. Faster removal of the NDF that occupies space in the bulk-limited rumen, in turn, permit intake by high-producing lactating cows fed coarse forage diets to increase as well, illustrated by Oba and Allen (1999) and Allen and Bradford (2006). Indeed, much of the response to bmr hybrids can be attributed to this increase in feed and energy intakes, not to the increased energy derived from more extensive NDF digestibility from the bmr forage. This increase in intake and in energy supply for milk production should increase level of milk production. If cost of energy from forage is lower than from supplemental concentrates and forage content of the diet can be increased with bmr, this will reduce the cost of feed for milk production. Furthermore, higher intake and an increase in NDF digestion will increase both the energy supply for ruminal microbes to synthesize protein, and by speeding passage through the rumen, increase the efficiency of growth of ruminal microbes. When combined with a reduced ruminal residence time for degradation of dietary protein from feeds, this should increase the postruminal supply of microbial protein and permit dietary protein concentrations to be reduced when bmr forages are fed.

Unfortunately, there is no such thing as a "free lunch." Though milk per ton of silage often is somewhat greater for bmr hybrids than for single and triple stacked hybrids as shown in Tables 1 and 2, silage yield was reduced an average of 21% and milk per acre reduced by 17%. Though content of NDF usually is similar for bmr and non-bmr hybrids, starch content typically is reduced. Selection of bmr hybrids for increased grain yield would be expected to result in sacrifices in both NDF digestibility and intake of silages because the NDF would contain more cobs that have low digestibility. This would be expected to reduce the extent to which NDF is digested in the rumen, reducing the supply of energy available for ruminal microbes and increasing the quantity of undigested bulk-filling NDF that remains in the rumen and potentially limits intake of forage-rich diets. Heavier ears also would be expected to increase the incidence of structural failure of corn stalks.

Splitting the hemicellulose-lignin linkage

As illustrated in Figure 3, indigestible NDF of a forage includes not only lignin but some hemicellulose that is bound to lignin. Supplementation of the diet or addition of fibrolytic enzymes to ensiled crops in some trials has increased the rate and extent of NDF degradation within the rumen (Adesogan, 2005). Ferulate ester and ferulate ether linkages appear primarily responsible for binding hemicellulose to lignin. A limited number of species of microbes can produce enzymes that will split these links. Nsrenko et al. (2008) and Kang et al. (2009) indicated that extent of NDF digestion could be enhanced by inoculating silages with a specific *Lactobacillus buchneri* selected to produce these enzymes. Performance benefits were noted in a feeding trial by Addah et al. (2012) with an inoculant that contained this specific culture added to barley silage. Shifts in the timing of gas production during in vitro incubation and a shift in time of gas production indicative of movement of carbohydrate from the slowly to the rapidly fermented pool also has been evident with corn silage treated with this inoculant. To date, this particular microbe has been incorporated into commercialized inoculant products from

Pioneer (11CFT, 11AFT, and 11GFT for inoculation at ensiling of chopped corn, alfalfa, and grasses, respectively) as discussed in Pioneer (2014).

Grain type and kernel processing

Corn silage ideally contains over 28% starch. With grain being about 70% DM, this means that over 40% of corn silage DM is derived from the grain (Figure 3). Thereby, starch from grain is a major contributor to the energy value of corn silage. Within corn kernels, the embryo is diploid, but the starchy endosperm and aleurone layer are triploid, with two-thirds of the genetic input being from the female. The hard pericarp is of maternal origin only. Most of the corn silage produced in North America is from hybrids with a yellow dent type, but hybrids producing flint (highly vitreous) grain are popular in Europe and South America, especially for grain production, due to increased disease and insect resistance and less kernel fracture during grain handling that generates kernel fragments that hinders air flow through grain during drying and storage, a problem that has hindered widespread commercial acceptance of floury grain hybrids. The starch within grain of the "waxy" type is largely devoid of the less slowly digested amylose that comprises 20 to 28% of the starch in dent grain being replaced with the more rapidly fermented amylopectin. When fed as grain, waxy starch is more extensively digested. Likewise, waxy grain is less responsive to extensive grain processing (high moisture harvest and fermentation or steam rolling or flaking). However, several studies with corn silage produced from waxy hybrids have shown little, if any, advantage over hybrids with a typical starch type, probably because starch digestibility from corn silage already is above 95% due the increases in starch availability that occur with longer silage storage time and disruption of the vitreous portion of dent kernels by kernel processing.

Starch content of corn silage increases markedly as harvest is delayed. Weight of starch per kernel increased by 27% in one week when kernel DM increased from half milk line to black layer (62 to 70% kernel moisture), reaching a maximum when kernels reached the "black layer" maturity stage. Immature corn plants (< 28% DM) may contain over 15% sugars, but plant concentrations of sugars decline as more sugar is stashed into starch to serve as an energy source for the germinating kernel. When starch deposition in grain is inhibited (raising tropical hybrids outside their day-length for pollination) or preventing grain from forming (bagging ears to prevent pollination), plant concentrations of sugars remain high. Per unit weight, sucrose has only 95% the energy value of digested starch. Sufficient amounts of sugars are present in corn plants within the silage harvest window (30 to 40% plant DM) to produce enough fermentation acids to readily preserve corn silage. So instead of being an advantage over starch energetically, elevated sugar concentrations of hybrids instead may reflect some genetic or environmental limitation in the capacity of plants to convert sugars to starch. Thereby, high plant sugar concentrations may reflect conditions where extent of starch deposition and energy retention by the plant has been compromised. Purple-streaking of leaves and stalk also may be a non-specific symptom of an excess supply of carbohydrate relative to the size or availability of the starch sink available for the plant or of certain mineral deficiencies.

Mechanical processing of corn silage consists of crushing the complete chopped corn plant through a narrow gap (e.g., 1 mm) between corrugated rollers that run at differential speeds. Various types of rolls are available, so degree of kernel fraction will vary with roll gap setting and roll type, often being greater with “Shredlage” rollers. Coarse particles are crushed and kernels are fractured by the kernel processing procedure. Fracturing kernels increases the amount of endosperm starch exposed for digestion and shredding of coarse particles into strips retains effective fiber of the silage but still prevents sorting by cows of certain rigid plant parts, such as cobs. Degree of kernel processing can be assessed by physically counting the number of kernels remaining that are larger than half a kernel in a given volume of chopped plants or silage or at a commercial laboratory by sieving to determine the amount of starch larger than a given size. Although kernel processing scores can be precisely determined with corn silage or with harvested samples in a laboratory, frequent but crude estimates of efficacy of kernel processing during harvest of a hybrid in the field is essential so that inadequate processing problems can be corrected immediately so that grain to be fed for the following year meets desired specifications (Tietz, 2009; Dann Bolinger, 2012 personal communication, Pioneer Dairy Specialist). Based on kernel processing scores needed for maximum starch digestion, lab assays indicate that most corn silage is not adequately processed. Because kernel processing requires horsepower and often reduces harvest speed, commercial harvesters prefer to minimize the degree of processing. But without adequate kernel processing, starch digestion, particularly from more mature and small diameter kernels, will be incomplete, and fecal starch concentrations will be elevated. Need for and the starch digestion response to kernel processing varies with processor settings, as well as moisture content of the kernels being processed.

Total tract starch digestion measurements from trials where a single corn silage was harvested at multiple DM contents are presented in Figures 6 and 7. Without kernel processing, total tract starch digestibility decreased from an average of 97 to 95% as plant DM increased from 30 to 40% (Figure 6). With very dry harvest, starch digestibility dropped below 90%. But when corn silage was adequately processed, this decrease in starch digestibility with plant maturation was considerably less (98 to 97.7%) across this same range in silage DM. Results imply that when harvested below 32% plant DM, kernel processing may not prove worthwhile. A similar interaction between the benefit from kernel processing and plant DM was detected in the meta-analysis of trials by Farraretto and Shaver (2012).

When fed dry after being coarsely ground, rate and extent of starch digestion from corn grain is less for more vitreous grain. Some workers have extrapolated this observation to corn silage and suggested that softer texture grain within corn silage is more extensively digested by lactating cows than grain with a higher proportion of starch in the vitreous form. Several obvious differences exist between grain present within corn silage and dry rolled or dry ground corn grain, even if grain is harvested at an early stage and dried prior to analysis. First, kernels harvested in corn silage will be less mature and higher in moisture content than grain harvested dry or dried prior to feeding or analysis. In digestion trials, ruminal and total tract digestibilities of high moisture corn were equal whether prepared from a hybrid known to have more vitreous starch than from a hybrid with less vitreous starch (Szasz et al., 2007). Second, if corn silage is kernel processed, kernels will be fractured, increasing the surface area for ruminal microbes to attack and digest the starch. Indeed, fine grinding appears to fully counteract the adverse effects of kernel vitreousness on starch digestibility, even for dry grains (Ramos et al., 2009). Third, during fermentation and ensiled storage of grain within corn silage or high moisture corn, starch availability increases continuously over several months. This increase in starch availability has been suggested to be the cause of "spring acidosis" of lactating cows being fed a combination of corn silage and high moisture corn. For maximum starch availability from corn silage, many dairy farms allow corn silage to ferment for several months prior to feeding.

Additional corn grain types or hybrids have been selected or bred and developed for specific end-uses. These would include hybrids that produce starch that is more readily extracted (for high fructose syrup), that are more completely digested by swine or that have higher concentrations of corn oil (to increase available energy), that yield more ethanol during fermentation (high total fermentable hybrids) or contain amylases that can be activated (to reduce enzyme cost for ethanol plants), that have specific colors and handling or milling properties (for food manufacturers), and those that are particularly rich in either amylose (high amylose types) or amylopectin (for producing gels). Although some selected grain types may have a "yield drag" and thereby are not widely produced commercially, others may prove advantageous for feeding ruminants. For example, with dry grain, hybrids with less amylopectin or lower density when not finely milled contain starch that is more rapidly and completely digested by ruminants, and grain with greater ethanol yield typically have higher postruminal starch availability.

Drought tolerant hybrids

Several seed suppliers have screened current hybrids and are involved with genetic manipulation to reduce the adverse effects of drought on grain and silage yields. Water restriction typically reduces plant size and grain yield. For grain and silage, yield per available inch of available moisture (rainfall, irrigation, plus soil reserves) typically is limited to 0.1 to 0.15 ton of DM for grain and 0.3 to 0.4 ton of DM for corn silage. When grown with adequate water, potential yields of gene modified drought tolerant types often have reduced yields, but they still yield some grain. By comparison, hybrids screened and selected among commercially available elite hybrids not only withstand moderate drought but typically have greater yields than hybrids with less drought tolerance, even when symptoms of drought are not evident. This indicates that under normal rain-fed conditions, temporary or intermittent drought periods probably occur that hinder plant growth or kernel filling. Drought tolerance and water use efficiency of corn has been discussed by Soderlund et al. (2014).

Stage of harvest

Though controllable by corn growers, silage yield and composition are influenced more by stage of harvest than most of the other factors discussed. Kernel weight and size increase very rapidly but curvilinearly as plant DM content increases to 30 to 40%. Whenever silage is harvested before kernels reach the black layer stage, full starch yield is not being realized, and the full energy value of a silage crop will not be obtained. So why was harvest of corn plants between 30 and 35% DM recommended by many animal nutritionists in the past? With the many changes in plant genetics and silage management, is this recommendation still valid?

Certainly, harvest below 30% DM is more likely to cause liquid effluent loss of soluble nutrients, particularly from upright silos. Hydrostatic pressures will be less with silage in bunkers or plastic tubes, but harvest below 30% DM of grain-yielding hybrids will sacrifice both DM yield and silage starch content. As plants mature, the prevalence of dead leaves and husks increases. Death, dehydration, and loss of certain plant parts can partially explain decreases in NDF digestibility seen with more mature plants in the past. With modern hybrids, the adverse effects of delayed harvest on NDF digestibility in performance trials are less obvious based on meta-analysis of published trials (Figure 8).

Causes of leaf death include plant diseases, drought, and plant damage caused by aerial or subterranean insects. With genetically modified hybrids, insect damage is reduced. Drought resistant hybrids retain their leaves and usually exhibit increased resistance to late-season leaf diseases. Similarly, fungicide treatments help retain leaf health later in the season. Although the "stay green" trait was initially developed to maintain stalk strength and reduce downed stalks and ear drop, hybrids selected for this trait usually have greater resistance to leaf diseases. Finally, the more mature corn kernels within corn silage, if not kernel processed, often has reduced starch digestibility. This depression often is more than compensated by the increased starch content of more mature plants. When adequately kernel processed, starch digestibility in the rumen and total tract was not depressed until plant DM exceeded 40% (Figures 7 and 9). Steep discounts in starch availability within Milk 2006 equation markedly depress the predicted energy value for corn silage with high DM content. One would hope that the size of this discount in this widely used index of feeding value of silage will be revised in light of results from this meta-analysis.

Yield of silage wet matter is greater for wetter than drier corn plants because of the additional water present. Some silage growers and harvesters are paid on the basis of wet silage. When marketed appropriately, corn growers and harvesters should be paid on the basis of DM, not wet matter. Price paid per ton, if based on grain equivalent, will be greater if delayed harvest increases starch content of silage, but corn silage with higher grain content will have higher net energy for lactation.

Before the advent of modern silage harvest equipment, limits in power capacity probably limited the ability to finely chop larger stalk particles and thoroughly pack the chopped material. This in turn would lead to less densely packed silage with more air spaces that trap air at the start of fermentation, as well as allowing greater oxygen infiltration and heating during feedout. Combined with a higher yeast count of more mature corn plants, loss of DM and nutrients decreases the value of a poorly processed or uncovered pile of corn silage. Fortunately, advances in harvest and packing equipment, use of oxygen barrier film to decrease air infiltration, and *Lactobacillus buchneri* inoculants to inhibit yeast growth during feedout have helped address these specific issues. Consequently, as a result of these advances in plant selection and genetics, in engineering, and in microbial inoculants, most of the reasons for plant harvest below 35% DM have disappeared.

What is the optimal moisture range for modern hybrids using these advanced management procedures? Although starch content of plants continues to increase until hybrids reach black layer at about 45% plant DM, DM yield generally plateaus at between 38 and 40% DM. Precisely why DM yield peaks before starch yield reaches its peak might suggest that some plant energy reserves are being raided for deposition as starch within kernels. Though many silage users successfully harvest corn silage above 40% DM, benefits above 38% DM appear small. However, harvest delays increase the risk of inclement or adverse weather or harvest conditions. Consequently, setting 40% DM as the maximum point and initiating corn silage harvest so that harvest of all fields is completed by that point seems sensible and logical. Certainly, risks involved with delayed harvest appear less today than would have been true 20 years ago.

Conclusions

Dairy producers that grow or purchase forage have a wide variety of hybrids or varieties from which to choose. Hybrids or varieties differ widely in type, productivity, and response to environmental stresses. Although yield of field crops is limited primarily by supply of available water and the environmental temperature, timing of harvest and storage and processing, especially for corn silage, will markedly alter both the quantity of forage gleaned, as well as its nutritional value for cattle. Plant and management alterations that have helped to enhance the nutritional value of grasses (including corn) and legumes have included: 1) development of cultivars or hybrids with decreased lignin content and tolerance to herbicides (to simplify weed control) and to drought, 2) plants with an increased concentration of more digestible parts and a greater ratio of live to dead plant tissue within a harvested or grazed crop. Hybrid selection involves matching a hybrid to the growth conditions and season length, as well as local soil, water availability, and environmental conditions. Incorporation of genes from brown midrib **(bmr)** plants, through reducing the amount of lignin and indigestible NDF of plants, has markedly increased the NDF digestibility of most plant parts. Faster NDF digestion and removal of space-occupying NDF allows feed intake by lactating cows fed bmr bulky diets to increase, which usually results in increased milk yield. Amounts of indigestible NDF also can be altered by increasing the leaf to stem ratio and by high-chopping the forage so that the harvested portion contains a lower percentage of the high-lignin lower stems. Maturity at harvest probably has the greatest impact on corn silage yield and starch content. Genetics, engineering, and microbiological advancements have made later harvest both feasible, and thanks to increased starch yield with more mature plants, desirable.These advancements include progress in plant genetics and in fungicides that improve disease resistance and late-season plant health, drought tolerant hybrids that reduce the incidence of water shortage late in the growing season, kernel processing to enhances starch digestibility of more mature grain, development of large equipment to rapidly harvest and thoroughly pack chopped forage into storage, oxygen limiting film to reduce oxidative losses, and inoculants that inhibit heating and energy losses during feedout. These changes have removed most, if not all, of the reasons behind the traditional recommendation that corn plants should be harvested between 30 and 35% DM for maximum feeding. Although local Extension personnel and industry representatives can supply detailed production information for comparing hybrids from various companies on a local or regional basis, help guide producers to place the right hybrid on the right field, and scout the developing crop for insects and diseases, individual dairy farms in discussions with their nutritionist must make their own decisions based on preferences and risks among silage and grain types and harvest dates based on their capacity to efficiently harvest, process, and store silage and the local costs and availability of other ingredients that can be included in diets for their cows.

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Table 1. What is an average yield? (1995 to 2008, Lauer et al. , 2009).[1]

Trait	N	Forage yield (Ton/acre)	NDF (%)	NDFD (%)	Starch (%)	Milk/ton (lb/ton)	Milk per acre (lb/acre)
bmr	56	6.2	48.3	68.4	26.3	3380	21,300
Corn borer resistant (CB)	343	7.9	46.5	60.2	30.5	3260	25,600
CB/Liberty link	142	7.9	46.6	60.2	30.5	3250	25,700
CB/Roundup ready (RR)	161	7.8	46.1	60.0	31.4	3270	25,600
CB/RR/Rootworm resistant	171	7.8	46.1	59.9	31.2	3270	25,400
Leafy	96	7.8	48.2	59.3	27.5	3190	24,900
RR	125	7.6	47.0	59.4	30.2	3220	24,500
Normal	1304	7.6	47.1	60.0	29.7	3230	24,500
LSD		0.8	2.7	1.8	3.9	110	2,500

[1]NDF = Neutral detergent fiber, NDFD = neutral detergent fiber digestibility, and LSD = least significance differences.

Table 2. Chemical compositions based on paired comparisons in published trials.[1]

Characteristic	Dual purpose	bmr	Leafy
Crude protein, %	7.7	8.1	7.9
Starch, %	30.1	29.5	28.0
NDF, %	43.0	41.9	45.1
Cellulose, %	22.2	22.0	23.4
Lignin, %	2.8	1.8	2.8
IVDDM, %	74.8	80.4	75.7
NDFD, % of NDF	42.6	52.7	46.4

[1]NDF = Neutral detergent fiber, IVDDM = in vitro digestibility dry matter, and NDFD = NDF digesetibility.

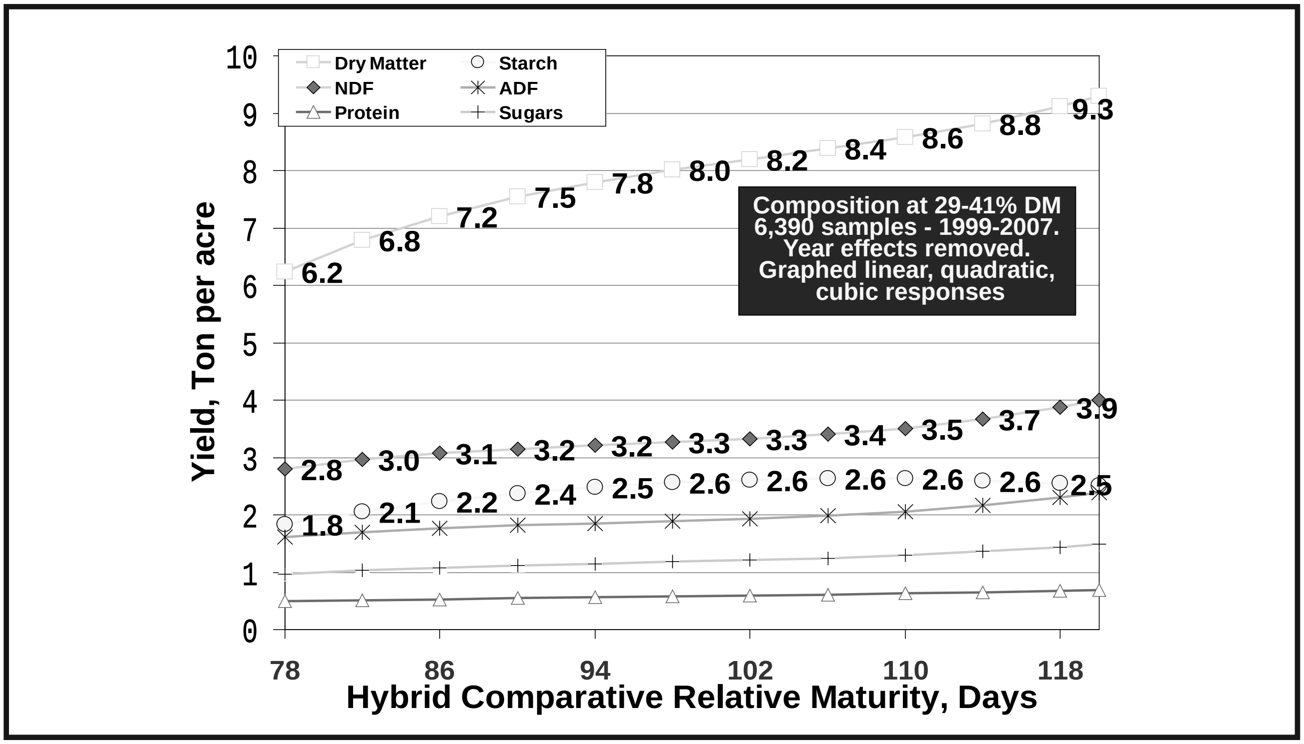

Figure 1. Yield of various components across Pioneer hybrids ranging from under 80 to 120 days comparative relative maturity.

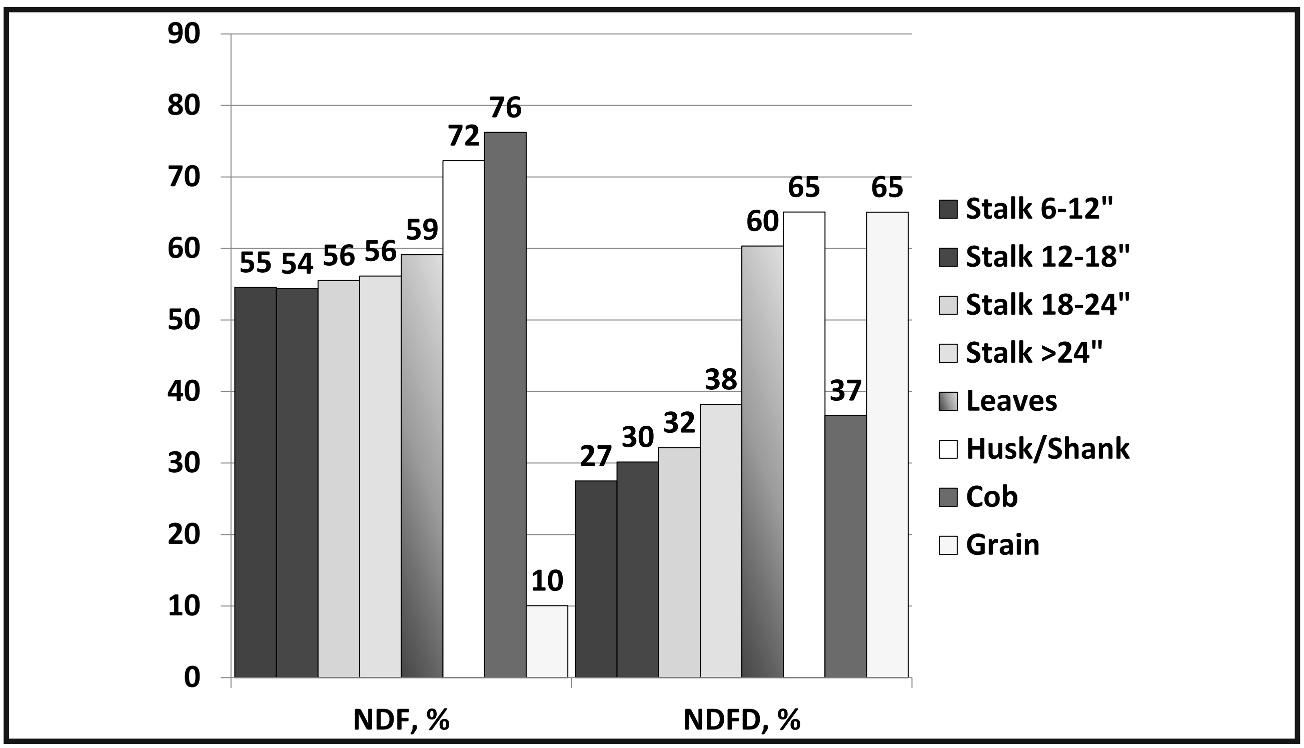

Figure 2. NDF and NDF disappearance after 30 hr of in vitro incubation of various typical corn plant parts.

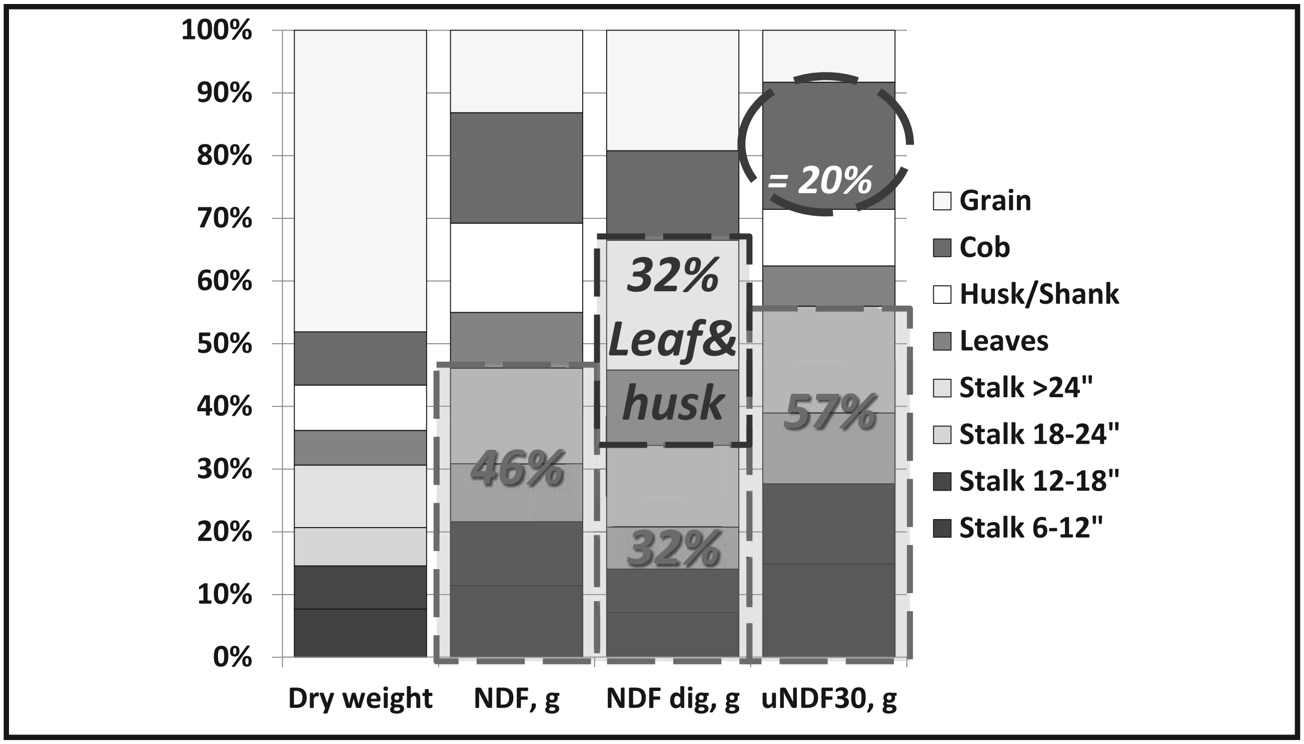

Figure 3. Weights of dry matter, NDF, digestible NDF, and undigested NDF (NDF minus the amount of NDF not digested after 30 hr of in vitro incubation) for various parts of typical corn plants harvested between 30 and 40% dry matter.

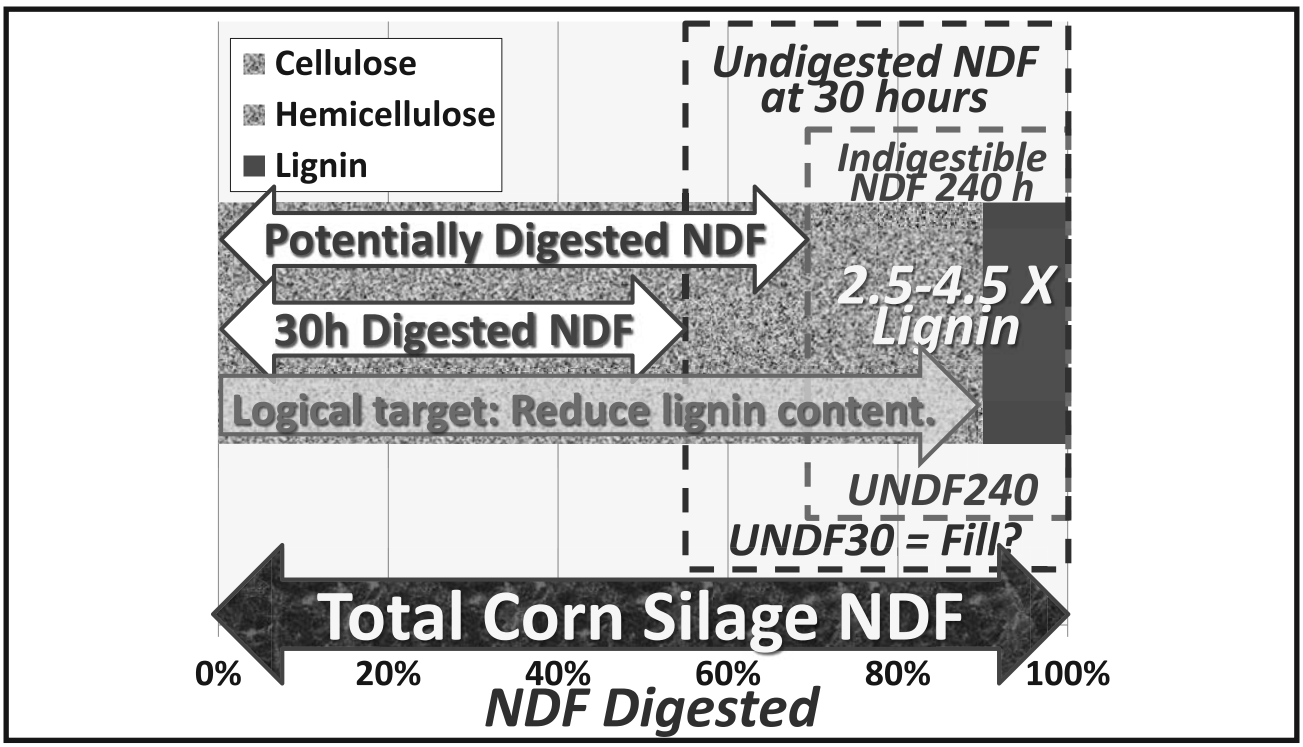

Figure 4. Illustration of NDF and extent of digestion by ruminal microbes at various incubation times.

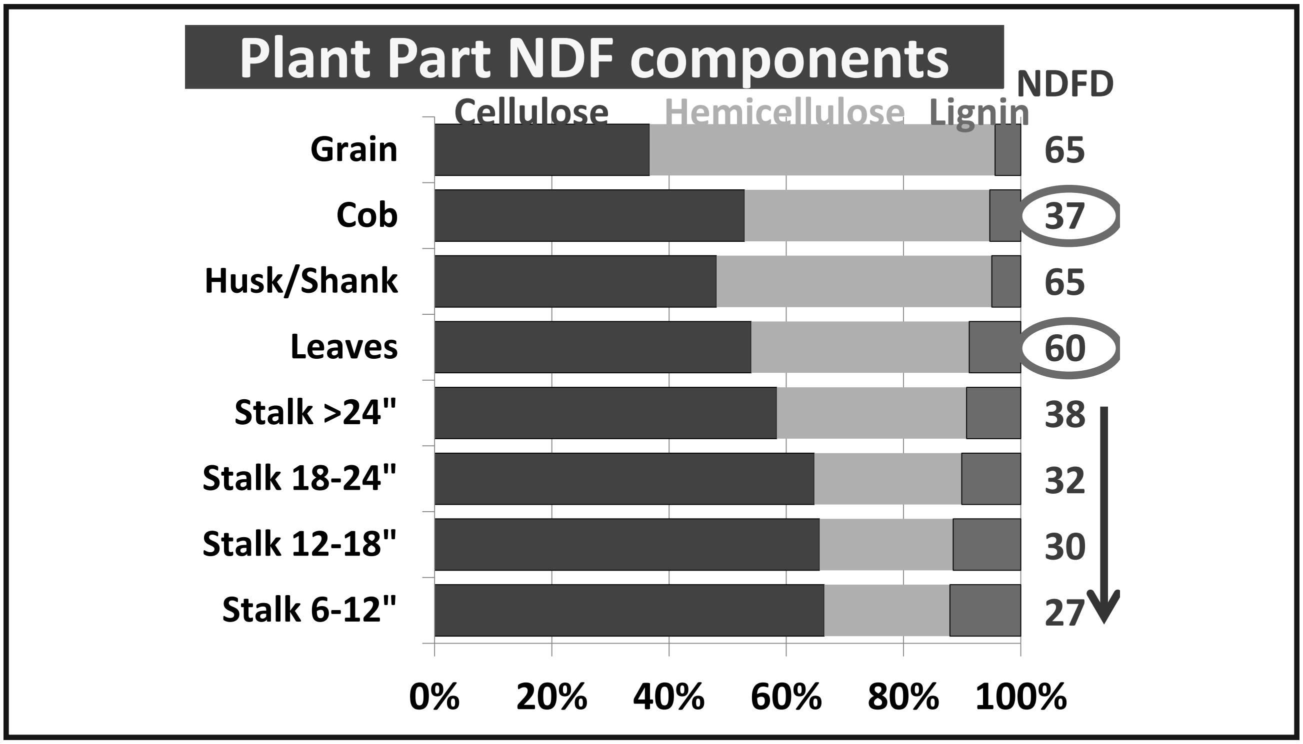

Figure 5. NDF composition and 30 hr in vitro NDF digestibility (NDFD) of various corn plant parts harvested between 30 and 40% dry matter.

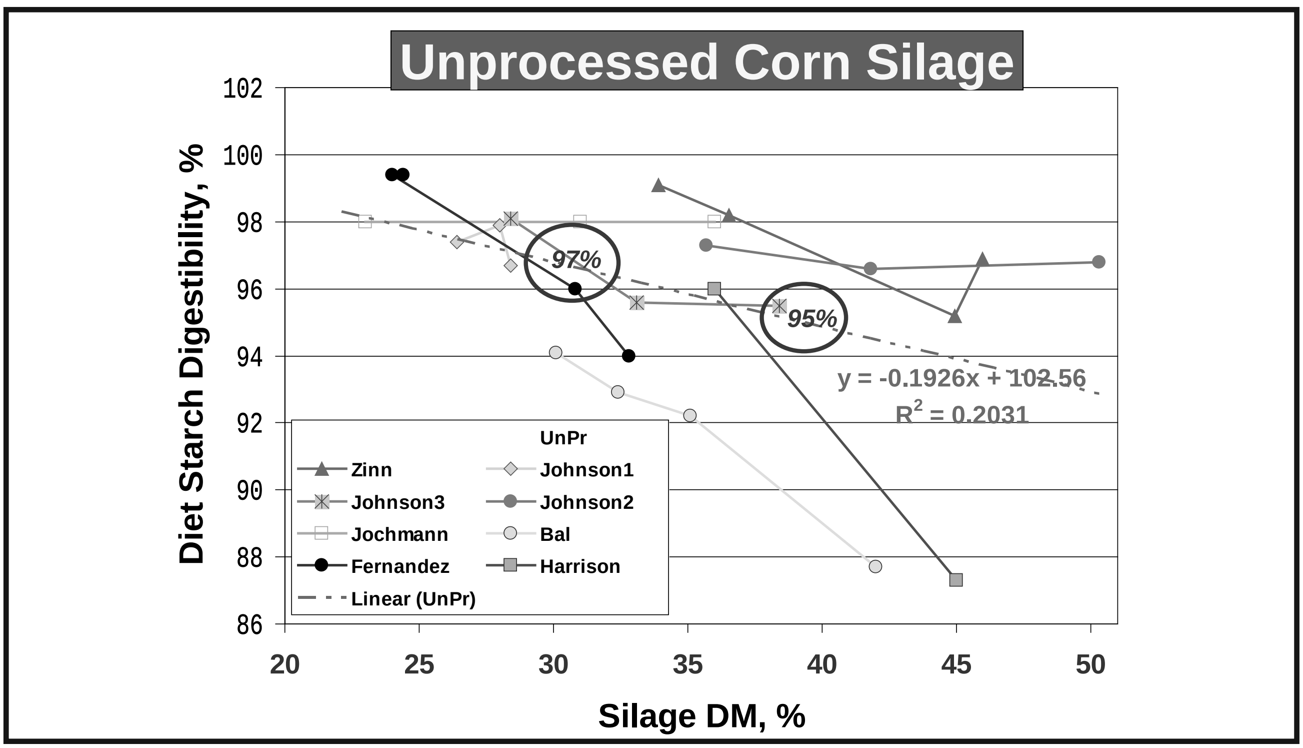

Figure 6. Diet starch digestibility from trials where cattle were fed unprocessed corn silage.

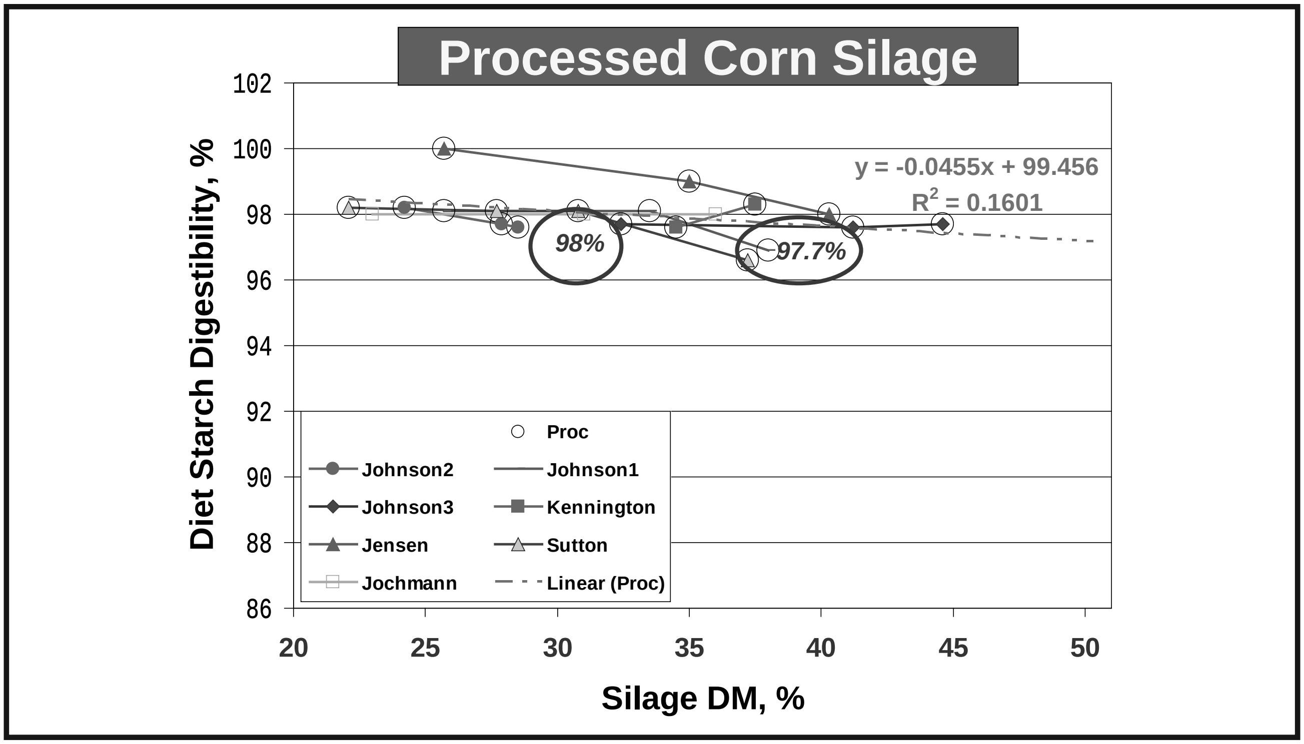

Figure 7. Dietary starch digestion from trials where cattle were fed processed corn silage.

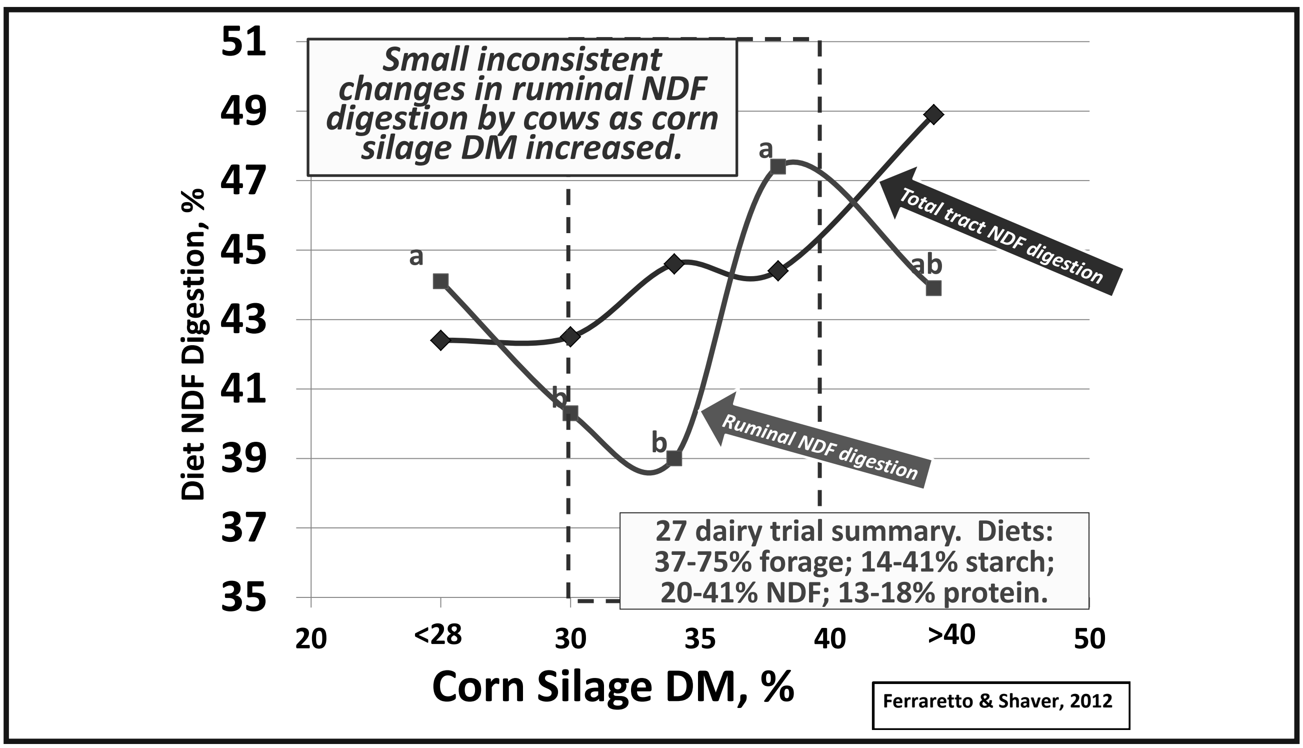

Figure 8. Influence of dry matter content of corn plants on site and extent of NDF digestion.

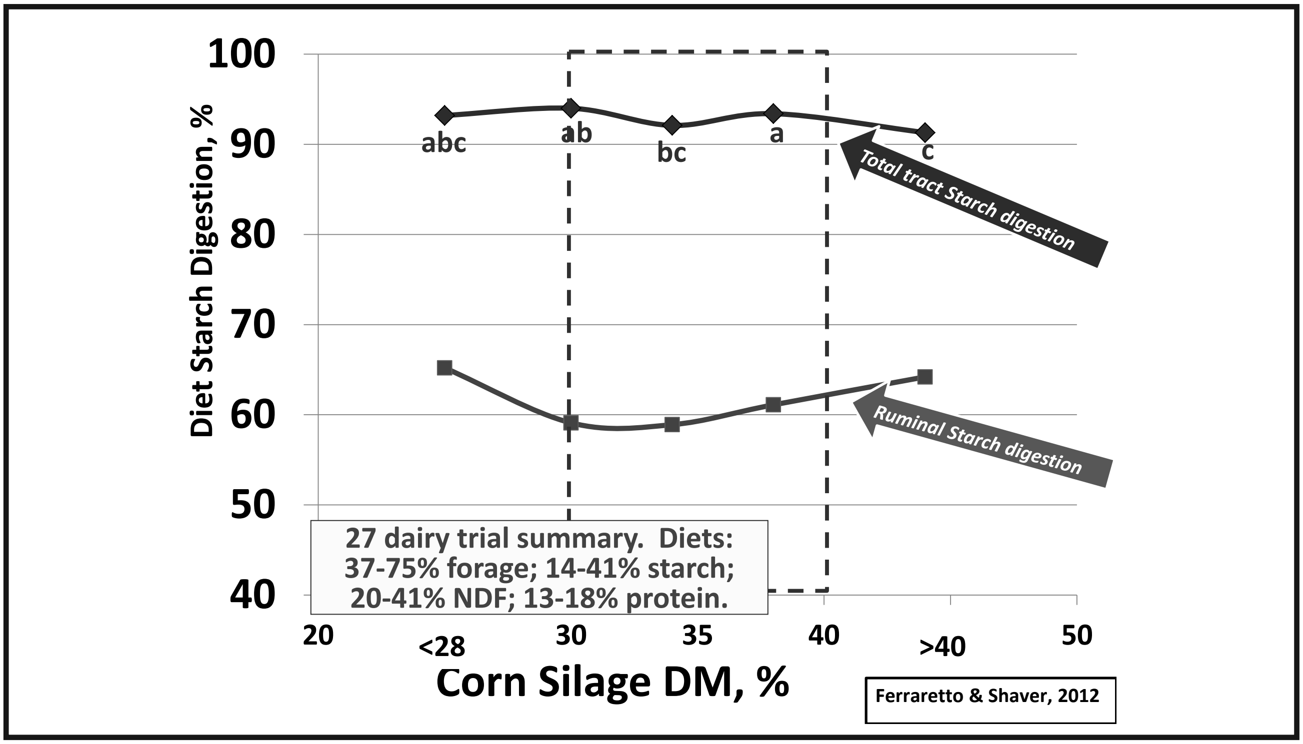

Figure 9. Influence of dry matter content of corn plants on site and extent of starch digestion.