# Corn Silage – Facts, Fantasies and the Future

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#### Introduction

Advanced Corn Silage Production 605. Circle all correct answers and Discuss.

- 1. With corn silage, high grain yield reduces fiber production per acre.
  - a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- Delaying harvest decreases digestibility of NDF from corn silage.
   a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- 3. More mature corn silage has less NDF only because it is diluted by starch. a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- Digestibility of starch decreases markedly as maturity at harvest increases.
   a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- 5. Corn silage that contains 30% starch (DM basis) has too much starch. a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- In vitro NDF digestibility is a useless measurement.
   a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- Milk line accurately reflects moisture content of corn plants.
   a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- Yield of corn silage DM reaches a maximum at 35% DM.
   a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- 9. To maximize net energy for lactation, corn silage should have 35% DM. a. True. b. Likely. c. Doubtful. d. False. e. Conditional.
- 10. At what DM should corn be harvested for silage?
  - a. 30%. b. 32%. c. 35%. d. 38%. e. I don't know. It depends!

Following an executive summary that addresses each question, more detailed discussion is provided based on information compiled from published and unpublished research trials and corn silage hybrid tests results from the University of Wisconsin and Pioneer Hi-Bred International.

Grain yields have increased an average of 1.9% per year since 1940. This means that today's hybrids will produce about one third more grain than in 1990. Yet recommendations concerning silage harvest and management generally have not changed during this time period; they may be obsolete considering these genetic changes in the corn crop as well as changes in handling, processing, and storage that have occurred in the past several decades.

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#### 1. Fiber production versus Grain Yield.

*Executive summary:* Available data indicates that selection for high grain yield will increase, not decrease, yield of NDF. However, NDF content of silage is lower when grain yield is greater. And hybrids differ in potential grain yield.

Certain silage producers have expressed concern that genetic selection for high grain yield has decreased silage production. This is based on two assumptions: first that the corn plant allocates a limited supply of energy to either growth (stover) or to reproduction (grain) and second, that plant breeders successfully altered allocation of energy by plants. To examine the relationship between yield of forage and grain, yields of NDF and grain yield for individual corn silage hybrids tested in the different maturity zones in Wisconsin in 2004 (Wisconsin Corn Agronomy, 2007) were compiled and are graphed in Figure 1. Although the relationship between NDF yield and grain yield (calculated from starch content) within any maturity group was not particularly high, NDF yield in all cases increased as grain yield increased. These data do not support the contention that hybrids with greater grain yield produced any less NDF yield per acre. Results generally confirm the direction and the magnitude of the correlation previously noted by Lauer (2006).



Figure 1. NDF yield versus grain yield from Wisconsin yield tests of 2004.

To examine this relationship across locations and across and even wider ranges in grain yields, best fit regressions (linear, quadratic, cubic components included) were calculated using the Pioneer corn silage data base that contains chemical analysis and yields for nearly 100,000 unfermented corn plant samples harvested at a DM content between 29 and 41% between 1999 to 2006. Results are shown in Figure 2. As indicated from the Wisconsin data with four locations and multiple hybrids, yield of NDF increased at a slightly decreasing rate as grain yield increased when averaged across an even broader range of hybrids, harvest dates, and locations. Certainly, poor growing conditions prior to pollination can limit the photosynthetic capacity for forage yield, excess heat during pollination can reduce kernel numbers, and inadequate sunlight, heat, moisture, and time can limit kernel fill following pollination. In addition, biotic and abiotic stresses can reduce both silage and grain yields. But selection for grain yield alone does not appear to decrease NDF yield. Indeed, higher grain yield generally appears to be associated with more plants per acre or with larger plants.



Figure 2. Component yields per acre versus grain yield.

Consequently, the concept that high grain yield reduces fiber production per acre seems doubtful or false. Instead, maximizing DM yield appears to maximize both grain and stover yield. Exceptions to this relationship might occur at an extremely high plant population, with inhibitors of starch deposition, or through selection of inbreds with small stature or based solely on harvest index (grain weight / total plant weight). Though harvest index for hybrids is reported by some hybrid testing organizations, the fact that harvest index changes with grain maturation (stage at harvest) makes this index meaningless for comparison among hybrids that differ in moisture content, particularly before grain fill reaches a maximum.

Although yield of NDF is no lower for hybrids with high grain yield, COMPOSITION of corn silage certainly is altered by grain yield. Indeed, as illustrated in Figure 3, NDF content decreases markedly and protein and ash content decrease slightly as grain yield increases. NDF digestibility, estimated by incubation of samples with fiber digesting enzymes (De Boever et al., 1997), decreased from a mean of about 48% to 43% as grain yield increased from 50 to 300 bushel per acre.





#### 2. NDF digestibility versus Plant Maturity at Harvest.

*Executive summary:* NDF digestibility within a hybrid and location declines as DM content of harvested corn increases. Digestibility values based on 48-hour laboratory incubation procedures markedly overestimates NDF digestibility by ruminants.

Effects of plant maturity on NDF content and NDF digestibility were examined using plant DM content as an index of plant maturation. Composition means across whole plant samples ranging from 29 to 41% DM are shown in Figure 4. Across this range, NDF content decreased from 41.7% to 38.4% but NDF digestibility remained surprisingly constant at 46.0%. This measurement, based on susceptibility of NDF to fiber digesting enzymes (De Boever et al., 1997) used to register silage hybrids in Europe, does not support the general concept held by nutritionists and plant physiologists that NDF digestibility decreases as plants mature due to lignification of fiber. The large number of hybrids and locations involved in the data of Figure 4 might dilute or hide this response. But in comparison with hay crops, corn silage is harvested at a very early stage of maturity. To examine this relationship more closely within corn hybrids and locations but across DM levels, the available literature was compiled relating harvest DM to plant or silage NDF content. A total of 26 trials were located where 58 comparisons could examine effects of harvest DM on composition at a single location and within a single hybrid. In 10 of these comparisons, NDF digestibility from corn silage was measured using ruminants as shown in Figure 5.



## **Corn Plant Composition Changes with Maturation**



Lines connect results from individual studies. Note the very wide range in DM content of these silages. When trial effects were removed, NDF digestibility declined (P < 0.05) as DM content increased; the best fit line (dashed) indicates that NDF digestibility dropped by 3 percentage points as DM content increased from 30% to 40%. This drop was steeper for samples harvested at less than 30% DM. Much more information is available where NDF digestibility was examined by laboratory methods. Responses with in vitro NDF digestibility of harvest or silage DM from this same series of trials is shown in Figure 6. In this case, NDF digestibility also decreased by 3% as DM increased from 30% to 40%. However, values were 13 percentage points higher when measured by these in vitro procedures than when measured using animals.



Figure 5. NDF digestibility by ruminants versus silage DM.



Figure 6. NDF digestibility at 48 hours measured by in vitro incubation.

This comparison between in vivo and in vitro measurements indicates that in vitro procedures correctly predicted the magnitude of the animal response in total tract NDF digestion. However, absolute values for NDF digestibility with ruminal fluid or ruminal contents exceeded total tract digestion of NDF by cattle by a mean of 26%!

#### 3. Why does NDF decrease as the corn plant matures?

*Executive summary:* Digestibility of NDF decreases as plant or silage DM increases though this decrease over the typical DM range for silage was only 3%. NDF content of plants also decreases, partly due to mobilization of NDF during plant maturation, not to lignification of fiber. Consequently, this decrease in NDF digestibility does not represent a reduction in the digestibility of a constant amount of plant NDF, but instead reflects loss of NDF from the plant. On this basis, NDF digestibility appears more closely related to plant maturity than an increase in the amount of indigestible NDF present in the crop. If so, NDF digestibility can be improved simply by harvesting corn at an earlier stage of maturity at some sacrifice in DM yield. Without knowledge of NDF content, NDF digestibility is a useless figure to appraise net energy value of a feed. If hybrids in test plots are harvested at different stages of maturity but on a single date, as often is the case, NDF digestibility among hybrids can differ simply as a result of maturity differences at harvest. To fully appraise genetic differences, hybrids should be harvested at multiple stages of maturity so that differences in composition and yield are not hopelessly confounded with differences in plant maturity.

As crop or silage DM content increases, starch content increases while NDF content declines (Figure 4) with starch increasing a whopping 4% when plant DM increased by 5 points (from 30 to 35%)! This increase is partly due to reduction of sugars and partly to an increase in kernel size. Like NDF, protein and ash decline as starch increases. Is this change in NDF simply due to dilution of other components by the increase in starch or does the NDF amount or composition change as corn plants mature? To answer this question, weights of DM as stover or as NDF per plant or per acre have been measured. Kezar and Vinande in work later summarized by Hunt (1994) measured the dry weight in various plant sections for 6 hybrids grown in two locations (ID and CA) each harvested at three stages of maturity (1/3 milk line, 2/3 milkline, and black layer). As shown in Figure 7, as plants matured, dry weight of ears increased significantly at each step as would be expected. But guite surprisingly, dry weight of stover decreased significantly from one stage to another shown in Figure 7! Losses of over half a ton of stover during these time intervals that lasted approximately 10 days indicates that the DM reserves within stover reserves are being raided rapidly. Does this merely reflect leaf loss or are sugar and other nutrients translocated from stover to grain? Is NDF mobilized?



Figure 7. Dry weights of ear and stover at three maturity stages.

To examine the whether NDF yield (tons per acre) changes during corn plant maturation, information is needed concerning both DM yield and NDF composition at various harvest dates within a trial. Two papers published by Cornell researchers (Lewis et al., 2004; Cox et al., 2005) contained sufficient information so that yield of total NDF and indigestible NDF (based on in vitro assays) for three different hybrids harvested at three different stages of maturity could be calculated (Figure 8).



Figure 8. Yield of digestible and indigestible NDF at various harvest DM contents.

Although authors had not calculated these specific relationships, NDF yield (tons per acre) decreased linearly (P = 0.001) but indigestible NDF yield did not change significantly (P = 0.19) as silage DM increased. The fitted regression lines (dotted) adjusted for hybrid and study indicates that as plant DM increased from 30 to 40%, NDF yield decreased by 360 pounds per acre (9%) while indigestible NDF only increased slightly (80 pounds). These two changes when combined resulted in a decrease in NDF digestibility of 4 percentage units (65.6 to 61%). But rather than being due to lignification of the NDF already present in the plant, these changes were due largely to loss of NDF from the plant! This change parallels or exceeds the decrease in NDF digestibility noted with corn plant maturation that was discussed above. This would indicate that NDF (presumably hemicellulose) is lost during grain fill with only a small change in the amount of indigestible NDF within the plant. That NDF digestibility changes with NDF content matches with the observation from this series of studies that in situ NDF digestibility of silages linearly decreased (P = 0.01) as NDF content decreased. If NDF digestibility decreases primarily due to changes in plant metabolism as the plant matures, plant selection for higher NDF digestibility at a specific silage DM content should produce hybrids that have less mature (or higher moisture) stover relative to grain and favor hybrids with the "stay-green" trait. Such a change would reduce starch digestibility unless the product is kernel processed.

#### 4. Impact of harvest maturity on starch digestibility.

*Executive summary:* Deposition of total and digestible starch increases as DM content of corn silage increases to at least 41%. Starch availability from silage is increased markedly by kernel processing as well as by the fermentation process with a

continued increase as silage storage time increases. Digestion of starch from corn silage is not related to vitreousness of the grain ensiled. With only a 5% range in total digestibility of starch from corn silage that has been kernel processed, nutritive value of corn silage appears much more dependent on starch content than on starch availability or digestibility. However, when formulating diets for lactating cows, the increased extent of ruminal starch digestion from corn silage that has fermented for several months must be considered. When combined with finely ground or processed grain, high starch availability from corn silage that has been stored for many months likely is involved with "spring acidosis" in dairy herds.

Because starch provides more than half of the digestible energy from corn silage, starch digestibility has been of considerable academic and commercial interest in recent years. Indeed, assays for starch availability from silage have been developed and discounts for reduced starch digestibility associated with more mature corn silage have been incorporated into estimates of milk production per ton and per acre (Milk2000 and Milk2006 programs; Shaver et al., 2000, 2006) and a "processing discount" has been proposed by Weiss (personal communication) that reduces the TDN of more mature corn silage within the NRC (2002) equation that is used to predict NEI of silage from its nutrient content. To examine effects of silage DM content on starch digestibility, results of research trials where starch digestibility had been measured with cattle were summarized. Values from individual trials were plotted against silage DM content and further classified by whether the silage had or had not been kernel processed, two factors that will alter digestibility of starch from corn silage. Results are presented in Figure 9.



# Total Tract Starch Digestion-Silage Diets

Figure 9. Total tract starch digestion of corn silage diets.

In two studies with unprocessed corn silage, starch digestibility for the total diet (starch from all sources) dropped below 90%. In general, starch digestibility was lower for drier corn silage. Further, compared with diets where corn silage was not processed, starch digestibility was greater for processed corn silage with benefits being greater for corn silage harvested later and drier.

Unfortunately, less than half of the dietary starch came from corn silage in most of these trials, and digestibility of the starch from the grain being fed can markedly alter digestibility of starch of the total diet. The contribution of other sources of dietary starch must be subtracted from both starch intake and starch excretion in order to calculate digestibility of starch from the silage alone. Unfortunately, digestibility of grain starch will differ with grain source, fineness of grind, and fermentation as reviewed by Firkins et al. (2001). Nevertheless, using his estimates of digestibility for the starch from the grain portion of the diet, starch digestibility of silage starch alone was calculated for these same trials (Figure 10).



**Corn Silage Starch Digestion-Difference** 

Figure 10. Digestibility of starch from corn silage after adjusting for digestibility of grain in the diet.

Starch digestibility for the starch in corn silage from the same two diets fell below 90% though, amazingly, some starch digestibility estimates exceeded 100%! Values exceeding 100% probably reflect an underestimation of digestibility of starch from the grain, but corn silage in the diet could have an impact on digestibility of the starch from grain. Some legumes including alfalfa contain compounds that inhibit starch digestion, and extent of chewing and rumination as well as rate of passage from the rumen can be altered by characteristics of the forage being fed. However, as noted with total tract starch digestibility in Figure 9, digestibility of silage starch still declined (P < 0.05) as DM content of the silage increased. The rate of decline observed was considerably smaller than used in the current silage evaluation programs. The equation generated from these curves was: Starch digestibility from corn silage = 99.0456 – 0.0455 times whole plant DM content (%). Though high, these starch digestibility estimates match quite closely with total tract starch digestibility values (typically over 98%) measured with feedlot cattle fed high moisture corn grain. And like the grain in corn silage, high moisture corn grain is harvested moist and fermented prior to feeding. But compared with corn silage, kernels in high moisture corn typically are fractured by being rolled or ground prior to storage and thereby would be more akin to grain within kernel processed corn silage. Other procedures that can be used to predict starch digestibility based on the size of grain particles and sensitivity of starch to enzymatic digestion are included within the Milk2006 program.

Harvesting corn silage later at a higher DM content will increase starch yield and starch content of the silage as noted in Figure 4, but will the decreased digestibility of starch counterbalance any advantage of the increased starch content? To examine this question, amounts of digested starch from corn silage from research trials were calculated (Figure 11). Note that despite the decrease in starch digestibility, the amount of starch digested from corn silage continued to increase to DM levels considerably greater than recommended for production and storage of corn silage. Clearly, yield of starch is sacrificed when corn silage contains less than 35% DM.



# Starch Content times Starch Digestibility

Figure 11. Digested starch from corn silage at various stages of maturity.

Compared with unfermented corn grain, starch digestibility estimates for corn silage and for high moisture corn are quite high, often approaching or equaling those for steam flaked corn grain. High starch digestibility of fermented feeds generally is

ascribed to the action of microbes or acidity of the fermentation process. Research by Benton et al. (2004) based on high moisture corn grain illustrates that ruminal availability is greater when the grain has a higher moisture content (Figure 12). Values cited in that figure are MOISTURE content of grain, not DM content. Moisture content of the grain within corn silage usually reaches the 30% moisture (70% DM) when the total corn plant reaches 45 to 50% DM, so the grain in virtually all corn silages will contains much more moisture than any of these high moisture corn samples. Note that in addition to the increased ruminal digestion to higher grain moisture levels, these curves illustrate that ruminal digestion of high moisture corn continued to increase as fermentation time is extended (Figure 12) for many months. Several recent studies with corn silage Jensen et al. (2005) and Jurjanz and Monteils (2005) similarly indicate that ruminal degradation of starch was greater for ensiled than fresh corn silage, particularly at higher DM levels where ruminal starch digestion was lowest, and continue to increase with silage storage time. Failure to account for this increase in ruminal starch digestion with fermentation time may be responsible for the "spring acidosis" seen in some dairy herds.



Figure 12. Influence of moisture content and fermentation time on in situ digestion of high moisture corn grain.

Precisely what is responsible for the increased starch availability is not certain. However, vitreous starch within corn kernels is shielded by zein proteins and the increase in starch availability over time in high moisture corn typically parallels protein solubility.

Within this research, dry corn reconstituted with water and allowed to ferment was surprisingly similar to corn harvested at a high moisture content. Higher and

increasing ruminal digestion were present whether the moisture was present in the grain at harvest or if added to dry corn. If ruminal starch digestion can be increased simply by addition of water prior to fermentation, as suggested in Figure 12, perhaps addition of water to drier corn silage similarly would enhance fermentation and improve starch digestibility similarly. Is the ratio of grain moisture to plant moisture the same for all corn hybrids at the silage stage of maturity? Incorporation of the "stay green" trait into corn plants may increase the ratio of DM between grain and the total plant.

Compared with floury corn kernels, corn grain with harder, more vitreous kernels have lower starch digestibility with dried grain that is dry rolled or ground prior to feeding. This observation has stimulated interest in developing silage hybrids whose kernels have more of their starch in the soft or floury form. Generally, low test weight grains are less vitreous, so hybrids that produce lower test weight dry grain have been proposed as being preferable for producing corn silage. However, several ugly facts invalidate such beautiful reasoning. First, vitreousness increases with grain maturity, so extrapolating from vitreousness of mature dry grain to the grain in corn silage where the grain is immature is invalid. Second, the fermentation process, through solubilizing proteins, markedly increases digestibility of the starch. Third, the range in vitreousness in dent, high yielding hybrids is quite small, considerably less than has been used experimentally to compare floury types with the very hard, flint grains grown in South America and Europe. Although vitreousness of grain remains important for selection of grain types to be rolled and ground and fed as dry corn grain, differences in vitreousness of the grain within high moisture corn appears irrelevant nutritionally (Szasz et al., 2007) and thereby presumably for corn silage.

#### 5. Does corn silage contain too much starch?

*Executive summary:* Today's corn silage is not the same as our fathers produced. Some studies indicate that fiber has become less digestible through the decades, but grain yields and potential starch content for corn silage certainly have increased greatly. Cows and diet formulations also have changed markedly in the past 20 years with greater emphasis on maximizing production level and efficiency. When formulating diets for dairy cows, nutritionists must balance starch content and starch availability from the multiple sources of starch to obtain optimum production and animal health.

On a DM basis, corn silage that contains 30% starch should have about 43% grain. This is based on the observation that typical corn grain has about 70% of its DM as starch. This estimate can be used to calculate the amount of grain in silage and thereby the value of grain purchased within silage. However, this calculation for grain generally favors silage feeders over silage producers starch deposition is incomplete and, particularly with wetter plants, sugars have not been fully converted to starch. However, grain producers also lose grain weight due to ear drop and continued metabolism by the grain when harvest is delayed until grain is dry in the field. Is a diet containing 43% grain too rich for lactating dairy cows? Most diets for lactating cows in the US contain more than 43% grain. For the samples in Figure 3, starch content

averaged 31.2% but the range was 5% to 45.5%. With high chopped corn silage from high yielding corn hybrids harvested at a late stage of maturity, starch content can exceed 50% of DM. Such silage may have too much grain when fed as the total diet for dry cows or growing heifers, but when included in typical diets fed to high producing lactating cows in the US, the starch from corn silage simply displaces the grain that otherwise would be included in the diet and may need to be purchased outside the farm.

#### 6. Utility of NDF digestibility measurements.

*Executive summary:* Laboratory estimates of digestibility face many hurdles and cannot accurately predict the small differences noted in NDF digestibility among non-BMR corn silages. Yet feeding forages and silages that have more rapid or complete NDF digestion (or considerably less lignin) often increases feed intake of moderately high forage rations and consequently will increase level of milk production. Among the factors involved with selecting an ideal hybrid for silage production, NDF digestibility should be secondary to selection of a hybrid of the proper maturity class and optimum agronomics for yield. Except for brown midrib (BMR) hybrids, differences in genetics among hybrids for nutritional value are small. In contrast, differences among hybrids in genetic potential for dry matter and starch yield are large. Once a hybrid is selected, silage producers should concentrate their efforts on factors that they can control. These include choice of the most appropriate harvest stage, chop length, kernel processing, silage packing, and storage management to reduce fermentation and post-fermentation losses.

Digested NDF provides net energy for lactation. But NDF is not a single, chemically defined feed component. Consisting of three fractions, a more readily, a less readily, and an indigestible component, namely hemicellulose, cellulose, and lignin, ratios of these individual constituents of NDF will differ. When lignin content is decreased, as with most brown midrib BMR corn silages, rate of NDF digestion within the rumen is increased. But surprisingly, total tract digestibility of NDF by lactating cows typically is no greater for BMR than non-BMR silages or forages. Instead, feed intake is increased; this increased feed intake in turn often increases level (but often not efficiency) of milk production (Oba and Allen, 1999a, b, c; 2000a, b). The NDF digestibility by the animal is not increased because an increased feed intake decreases the amount of time available for microbial digestion of NDF. This intake and digestibility response to BMR parallels that of grinding alfalfa or straw or of treating low guality forages with ammonia. Each of these processing methods speeds rate of ruminal digestion, increasing in vitro digestibility of NDF. These processes will increase an animal's digestibility of NDF if and when feed intake is restricted. But with ruminants fed relatively high forage levels and when intake is not restricted, each of these processing methods will increase feed intake and productivity but will not increase digestibility by ruminants.

Several laboratory procedures have evolved that simulate ruminal digestion in an attempt to rapidly screen samples for forage quality. For lab assays, samples typically are dried and ground finely to obtain a small sample that represents the forage. A

forage that has been dried and ground provides ruminal microbes with markedly different challenges and opportunities for digestion than wet, chewed, and potentially ruminated feed. Source and handling of ruminal fluid as well as providing proper incubation conditions for maintaining an active ruminal microbial population in terms of nutrients, temperature, and absence of oxygen also can delay digestion or depress its rate. Surprisingly, many analytical laboratories that use batch fermentation systems for evaluating NDF digestibility of corn silages do not supplement with extra protein or urea despite the fact that researchers 40 years ago (Johnson and McClure, 1968) and consistently since that time have demonstrated that extent of in vitro digestion of corn silage, particularly corn silages rich in starch, will be depressed if urea is not supplemented. Expecting microbes to remain viable and actively ferment forage for more than 20 hours after an incubation run is started can be questioned based on the composition of fermentation end-products. And to calculate digestion, filtration is employed to quantify the amount of the initial nutrient that was not digested and particle size is reduced. During filtration, soluble compounds and small particles are lost, with more small particles being lost when samples are ground more extensively. Small particles generated but not recovered are assumed to be digested, but recent measurements of gas production of wash particles (Cone et al., 2006) indicates that washed particles have digestion rates and extents quite similar to those particles retained on screens or within Dacron bags. To circumvent problems with microbial culture conditions, some analytical laboratories now place dried ground feeds within small pore Dacron bags and suspend those bags within the rumen of cattle for various time periods. Within these bags, particles are retained for ruminal fermentation and are not flushed out of the rumen. Consequently, extent of digestion is overestimated if bags are fermented for a time interval equal to that of the mean retention time for feed particles. Further, more digestible particles are preferentially retained within the rumen; this challenges retention time assumptions and complicates estimation of passage rate measurements based either on inert labeled fiber or by ruminal evacuation. Finally, some 10 to 40% of NDF digestion with cattle fed corn silage occurs in the large intestine, not the rumen.

Despite all these limitations, in vitro and in situ estimates of NDF digestibility are widely employed to estimate the digestibility of dry matter and NDF and to predict net energy for lactation. And when considered across forages and across types of corn silage (BMR versus non-BMR), in situ or in vitro estimates of NDF digestibility appear correlated with feed intake and milk production (Oba and Allen, 1999b). Usefulness of a NDF digestibility measurement for predicting feed intake and digestibility becomes more questionable when applied within a forage type or among non-BMR corn silages because the range in NDF digestibility among such samples or hybrids typically is quite small. Nevertheless, efforts to enhance NDF digestibility through reducing lignin content or through inoculating forage at ensiling time with bacteria that produce enzymes that degrade chemical bonds that link lignin with other feed components can prove fruitful. Indeed, the increased NDF digestibility and widespread testimonials that endorse a recently released corn silage inoculant containing a ferulate esterase-producing bacteria (Pioneer's 11-CFT) supports the contention that improving rate or extent of NDF digestion can improve milk production level and efficiency.

#### 7. Kernel milk line as a silage harvest signal.

*Executive summary:* With changes in genetics and improved late season plant health, milk line of corn kernels has become less reliable and repeatable as an index of the most appropriate harvest date. Whole plant moisture content tempered by appraisal of plant health (drying of lower leaves presumably reflecting a decrease in fiber digestibility) currently is recommended as an alternative index to avoid harvest at excessively low or excessively high moisture content. Dry matter yield and starch content are increased by delayed harvest, but delayed harvest and high DM content can increase storage losses associated with undesirable fermentation (increasing the value of silage inoculants) and inadequate packing for air exclusion at ensiling and air penetration during feedout.

The "milk line" of corn kernels, the fraction of grain that is hardened and no longer "milky" as well described by Ashley (2001), traditionally has been used as an index for maturity for determining when to harvest corn silage. Recommendations to harvest the corn crop for silage at 1/2 to 3/4 milk line have been employed since the classical trials by Wiersma et al. (1993) based on maximizing yield of digestible DM of the harvested forage. Plant DM levels that matched the milk lines in that study are 34 and 37%. Since that time, corn plants and processing methods have changed. Plant geneticists have developed corn hybrids with the "stay green" trait and have selected hybrids for rapid grain dry down (upright ears; loose husks) to reduce fuel needs for drying grain. These factors have increased the ratio of grain to plant DM. Conversely, maintenance of stover moisture has been improved with selection and engineering for resistance to plant diseases, drought tolerance, and parasites. These have improved plant health later into the fall. Consequently, the previously close relationship of milk line to plant maturity and moisture content no longer are clear and will differ markedly among hybrids. Although milk line might be correlated with starch availability of unprocessed corn silage, accuracy of predicting plant moisture content from milk line of kernels is no longer reliable. Compared with milk line, plant DM content is a more consistent and repeatable measurement to employ for selection of the most appropriate stage for harvest, particularly if plant growth conditions are less than ideal. However, if milk line more closely reflects kernel maturity, milk line-based harvest still may be useful when kernel processing is not used. In contrast, when kernels are well processed, kernel maturity has little impact on starch digestibility, so DM-based harvest may be preferable. Hybrids or fields with poor plant health should be harvested first. Planting hybrids that differ in maturity date for harvest at different times helps producers harvest a larger proportion of their silage within the proper harvest moisture window. Dry matter boundaries typically discussed include a minimum of 30% plant DM to avoid loss of liquid effluent and a maximum of 40% for optimum packing and air exclusion unless oxygen-limiting structures are employed. As shown in Figure 4, composition of corn plants can differ markedly within this wide window. Dry matter levels recommended by silage specialists from various states are shown in Table 1.

Recommended Harvest DM	Basis	Source <sup>a</sup>
>30%	Feeding value	Ashley, 2001.
Begin at 31% for bunkers	Digestibility and yield	Cox and Cherney, 2005
32%	In situ digestion (plants)	Hunt et al., 1989.
30-35%	Losses and digestibility	Schroeder, 2004.
30-35%	In situ digestion	Bal, 2006.
30-35%	Yield and digestibility	Loy, 1993.
30-35%	Fermentation	Ashley, 2001.
30-35% Horizontals	Losses and digestibility	Roth and Heinrichs, 2001.
30-35% Horizontals	Digestibility	Ross, 2007.
30-35% Horizontals	Digestibility	Sulc, 2004.
		Anonymous, Michigan State
30-35% Horizontals and bags	Losses and digestibility	University.
>33%	Milk yield	Huber, 1965.
30-36%	Digestibility	Hutjens, 1998.
32-35%	Starch digestibility	Bal et al., 1997.
32-35%	Digestibility	Linn and Kuehn. Undated.
30-38%	Silage yield	Ma et al., 2004.
32-37%	Digestibility	Linn Undated.
32-37% Towers	Losses and digestibility	Roth and Heinrichs, 2001.
35%	Digestibility	Shaver, 2003.
30-40% Bunkers	Digestibility	Sulc, 2004.
35% Bags	Losses and digestibility	Roth and Heinrichs, 2001.
	Yield of in situ digested	
34-37%	DM	Wiersma et al., 1993.
Up to 37%	Milk efficiency	Forouzmand et al., 2005
	Fermentation and	
35-40% Top unloading towers	performance	Sulc, 2004.
25 40% Toward	Loopoo and digestibility	Anonymous, Michigan State
35-40% Towers		
35-40% Towers		Ross, 2007.
		Phipps et al., 2000.
40-45% Oxygen limited	Losses and digestibility	Roth and Heinrichs, 2001.
40-45% DOLLOTT UNIDADING		Sulc 2004
		Anonymous Michigan State
40-50% Oxvaen limited	Losses and digestibility	University.
	Organic matter digestion	Johnson and McClure.
To over 50%	by sheep	1968.

### Table 1. Recommended harvest DM from various sources and basis.

<sup>a</sup>Reference details available on request.

Only one of these recommendations was based on kernel processed corn silage. Recommendations for harvest at lower DM content usually are based on in vitro measurements of digestible energy, usually of the harvested crop, not the fermented silage. Intermediate DM recommendations more likely are attempts to consider both yield and digestibility, and some of the high DM recommendations have emphasized silage yields and animal digestibility and productivity. Different values may be recommended for different silo structures, being lowest for horizontal and bags and greatest for oxygen limiting tower silos, perhaps reflecting differences in the likelihood of effluent losses. Considering the plateau in net energy yield at 37 to 40% DM for processed corn silage noted below, it seems surprising that any recommendations would exceed 40% unless capacity of the unloading equipment to handle wetter products for wetter silage is limited.

#### 8. When does yield of DM and energy peak?

*Executive summary:* The optimal harvest DM to maximize DM yield appears to be about 37% DM. However, for yield of NEI, harvest DM for corn silage appears optimal at 34 to 35% for unprocessed material but 37% to 40% for processed corn silage. Yield of both DM and net energy is reduced when plants are harvested at less than 34% DM. By increasing digestibility of starch particularly for drier silage, kernel processing will increase the optimal harvest DM level by 3 to 5 points. These DM recommendations for unprocessed corn silage match those (34 to 37%) from Wiersma et al. (1993) but the optimum DM tends to be greater (34 to 37%) for silage that is kernel processed.

Silage growers who sell silage seek to harvest corn silage when the maximum number of tons can be harvested and sold. Chopper operators prefer high tonnage and rapid harvest which means coarse chopping without kernel processing. Silage feeders and nutritionists emphasize nutritional value tons of silage. To locate DM levels for maximum nutrient and DM yields, values from multiple hybrids and maturities from 1999 to 2006 in the Pioneer silage data base were averaged. Results are shown in Figure 13.



Yield of Corn Plant Components Changes with Maturation

Figure 13. Relationship of yield to corn plant DM content across locations and hybrids.

Starch content continued to increase over this full range of DM levels. But DM yield peaked at 37% DM, a point before starch content was maximum, probably due to a reduction in stover weight noted in Figure 7. Yield of NDF across this range in DM remained surprisingly constant (a range of only 14 pounds of NDF or 0.2%). However, location of NDF probably changed as shank and cob weight will decrease while stalk weight decreases. Using these yield values, one also can estimate the energy yields using equations based on nutrient composition as shown in Figure 14.



### Yield of NEI per Acre Changes with Maturation



Predicted net energy yields differ among the various equations that are available to predict net energy from nutrient composition. The seven equations that were employed included those from the Nutrient Requirements for Dairy Cattle (NRC 2001) both with and without including a processing adjustment factor, Milk2000 (Shaver et al., 2000) with and without kernel processing, Milk2006 (Shaver et al., 2006) with and without kernel processing, and Robinson (2001). In all cases, kernel processing increased NEI yield at all levels of plant DM by 5 to 15%; response to processing increased as plant DM increased. Note that yield of NEI was suboptimal when plant DM was under 34% from all equations. This is due partially to reduced DM yield but primarily due to lower starch content of the crop. The decline in NEI above this point for some equations was primarily due to reduced digestibility of starch, an effect that was reduced when corn silage was kernel processed. Because kernel processing increased starch digestibility, the point of optimum harvest DM for maximum NEI yield was increased by 3 to 5 percentage points by kernel processing. This indicates that the optimal DM for harvest is greater for processed than unprocessed corn silage. Several precautions regarding field application should be noted. First, these values are based on multiple hybrids at multiple locations and may not apply universally. Second, estimates are based on enzymatic NDF digestibility, an appraisal that seems less responsive to silage DM changes than in vitro and in vivo estimates. Finally, values are based on plant yields alone ignoring any differences in losses of DM and energy during fermentation and storage that would occur following plant harvest and might differ with DM content of the crop.

#### 9. At what maturity does silage feeding value peak?

*Executive summary:* Energy values for corn silage predicted from corn plant composition at harvest differ depending on which base equation is being used. Equations consistently predict that kernel processing will increase NEI value of silage as well as increase the DM content at which NEI value of the crop is maximized. Though generated from lower cost assays, fiber-based NEI prediction equations generally give higher NEI values and likely presumably are less accurate because they were not customized specifically for corn silage.

The primary interest among silage feeders is intake of net energy by cows. Intake of net energy is the multiple of DM intake and net energy. Responses in intake, as mentioned previously, are difficult to measure and predict even though DM intake appears correlated with NDF digestibility for corn silages that differ widely in lignin content (Oba and Allen, 1999b). However, net energy for lactation can be predicted from nutrient composition of feeds as mentioned by various equations noted above. One factor that silage producers can control is harvest date, and because nutrient content differs with harvest DM content, the relationship of harvest DM to NEI content of the harvested crop to harvest DM can be calculated. These relationships based on the various net energy prediction equations itemized above are presented in Figure 15.



# Harvest Moisture and Net Energy of Corn Silage

Estimated net energy content of corn silage predicted from corn plant composition at various harvest DM differs depending upon which prediction equation is used. Responses to a change in harvest DM also differs among various prediction

Figure 15. Net energy for lactation versus harvest DM for corn silage.

equations with maximum NEI per pound of silage DM ranging from 30.5% to over 41% depending on the specific prediction equation. The lower NEI for wetter silage in most equations is due to lower starch concentrations and higher NDF concentrations whereas the lower NEI for drier silage is due primarily to decreased starch digestibility. Because starch digestibility is increased by kernel processing, the optimal harvest DM to maximize net energy for lactation content of corn plants will be increased by kernel processing by 6 to 8 percentage points, from being optimal at 30 to 33% DM without processing to being optimal at 38% to 41% DM for kernel processed corn plants. Again, precautions in extrapolation of these data should be kept in mind regarding 1) applicability of these general relationships to specific hybrids and specific locations, 2) imprecision of estimates of NDF digestibility within this data set, and 3) potential differences in energy loss during storage and feeding from silages that differ in DM content.

Net energy often is predicted from fiber (ADF or NDF) content of feedstuffs. Developed to appraise a wide variety of feeds, those equations generally were not geared specifically for corn silage. Nevertheless, some analytical laboratories calculate and provide fiber-based NEI estimates in their feed analysis reports. Using the harvest composition data discussed above, NEI values for corn plants harvested at various DM contents were calculated. Those values are illustrated together with the NEI values predicted from equations based on nutrient composition in Figure 16.



#### Harvest Moisture and Predicted NEI

Figure 16. Net energy for lactation versus harvest DM for corn silage.

Predicted NEI values (dotted lines in Figure 16) differed markedly among the fiber-based equations. With the exception of two of these eight equations, predicted net energy was greater for equations based on ADF or NDF than for equations based on

nutrient composition. Furthermore, all the fiber-based equations predicted that the optimal harvest DM to maximize NEI of harvested corn plants would exceed 41% DM. These fiber-based NEI prediction equations consider fiber analysis alone and do not consider that starch digestibility will decline as harvest DM concentration increases. Certainly, cost and complexity of nutrient analysis for calculating NEI is considerably less for fiber-based NEI prediction equations (ADF or NDF assays) than for composition-based NEI prediction equations (NDF, protein, starch, NDF digestibility at a minimum with the addition of protein content of NDF, fat, ash, and starch digestibility for certain prediction equations). But because composition-based NEI estimates were designed specifically to match measured digestibility values for corn silage, they would be expected to be more accurate and precise for predicting animal responses with these commodities than the fiber-based NEI equations would.

#### 10. At what DM should corn plants be harvested for silage?

*Executive summary:* As corn plants mature, increases in starch content compensate for decreases in starch digestibility, NDF content and digestibility, and sugars. As a result, calculated nutrient digestibility is virtually equal for corn plants harvested anywhere between 30% and 40% DM. Compiled information from lactation studies supports the contention that energy availability does not noticeably decline across this range in harvest DM. For corn silages from high grain hybrids that are kernel processed, available energy might even be greater for corn silage at 40% than at 30% DM. If milk production level and efficiency are not lower for drier corn silage, delaying harvest until the plant reaches 36 to 38% DM would take full advantage of the increased net energy yield per acre from high yielding grain hybrids. However, with drier corn silage, the need for and benefit from kernel processing, high grain hybrids, thorough packing, and silage inoculants increase. As losses during fermentation and feedout may be greater for silage over 40% DM, using 40% as the target maximum DM content for silage seems desirable. Planting hybrids with multiple maturities and calculating harvest dates back from this DM level should maximize harvest potential with no sacrifice in efficiency or level of milk production. A checklist of several factors that can help determine or enhance the relative value of low versus high DM corn silage is provided.

Kernel processing during corn silage harvest, through increasing digestibility of starch particularly from silage containing more DM, has increased the optimum DM content that will maximize both net energy yield and net energy content of the corn crop. Unfortunately, extent of kernel processing varies widely among corn silage samples. Equations for kernel processed samples are based on trials where kernels were thoroughly processed. If kernel processing is inadequate or incomplete, net energy responses and optimal harvest DM values would be intermediate between those for processed and unprocessed products. Processing certainly widens the harvest window available for silage producers. But should the mean target DM level for harvesting corn for silage be raised as high as 38 or 40% DM? Considering that a portion of the crop will be harvested with less DM than a chosen target and a second portion of the crop will be harvested with higher DM than the target, adverse effects of harvest at both ends

of the spectrum must be considered. Although harvest at 32% DM might maximize energy value per ton of unprocessed corn silage, yield of silage and NEI will be reduced if the crop contains less than 35% DM. In contrast, corn silage that is harvested above 40% DM may have greater loss of DM during harvest and storage. Loss of DM during storage and extent of spoilage differs widely among farms depending largely on harvest and feeding management factors. Storage and fermentation losses can be reduced through use of an appropriate chop length, dense packing into storage for air exclusion, silo covering to avoid entry of air and rainwater, and inoculation with active strains of appropriate bacterial cultures to reduce fermentation losses and heating. The drier the corn silage, the more critical each of these factors becomes. Research trials indicate that silage density increases with grain content. Consequently, the higher grain content of a more mature crop may improve silage pack density to reduce the losses associated with air presence at the start of fermentation and air penetration during feedout.

Considering the time required and potential delays associated with weather and equipment for harvest of corn silage, rather than simply increasing the mean target DM level for harvest for corn silage that is to be processed, a more realistic and applicable recommendation would be to harvest corn silage so that the full crop is harvested before it reaches 40% DM. Fortunately, plant DM contents that maximize NEI yield per acre and NEI content per pound are quite similar if the corn silage is kernel processed, generally ranging from 37 to 39%. Kernel processing becomes more important as DM content increases. Depending on the chop length and extent of kernel processing as well as adequacy of the storage structure and packing equipment, this target may need to be lowered. Importance of inoculation with active microbial cultures also appears to be more important with drier corn silage.

What is the bottom line regarding estimated energy availability as corn plants mature (increase from 30 to 40% DM)? Four factors that contribute to energy value of corn silage decrease with plant maturity (NDF content; NDF digestibility; starch digestibility; sugars); only starch content increases (Figure 17).



Figure 17. Influence of plant DM on component levels and digestibility.

When these values are summed and multiplied, the increased starch concentration appears sufficient to counterbalance the decreases in sugars, presumed to be totally digested, and the combined decreases in NDF content and digestibility so that total digested components for 40% DM corn silage falls within 1% of that for corn silage at 30% DM (Figure 18). However, nutrient source has changed with less energy from NDF and more energy from starch. This could have an impact on the ruminal acid load and increase the incidence of subclinial acidosis. Sugar content also is lower. Sufficient sugar remains for fermentation to stabilize the silage mass, but the decreased sugar and VFA content should compensate partly for the increased ruminal starch load. Note that among the trials measuring starch digestibility at various DM levels, only one trial had used kernel processed the grain. Had kernel processing been used, one would expect higher starch digestibility particularly with the drier silage. Studies by Jensen et al. (2005) indicate that more starch escaped ruminal digestion even after corn silage was kernel processed. Effects of an increased post-ruminal starch supply on its digestibility in the small intestine and the destination of energy have been discussed by Huntington et al. (2006).

Because other factors including DM intake might depress milk production, trial responses in yield of milk (fat or energy corrected) from the 7 trials (11 comparisons) where corn silage containing corn silage harvested at different DM contents were calculated (Figure 19).



Figure 18. Amounts of digestible corn silage components at various DM levels.



Figure 19. Milk production versus silage DM.

Although linear and quadratic effects were detected (P < .05), the compiled line across these experiments indicates that increasing DM from 30 to 40% decreased milk yield by 0.2 kg per day (less than 1%). Are cows eating more or less feed when silage is higher in DM content? Figure 20 shows intake values for these same trials.



Figure 20. Daily DM intake by lactating cows fed silage harvested at different DM levels.

Though the change was not significant, intake tended to peak near 35% DM for silage. Calculated milk efficiency (milk/DM intake) is shown below.



Figure 21. Milk efficiency at various silage DM levels.

Effects of silage DM on milk efficiency were not significant though the best fitted line indicated that milk efficiency declined by less than 2% (1.24 to 1.22 lb milk per pound of feed) across this range in silage DM. This would support the digestibility estimates noted above indicating that the changes in nutritive value associated with harvest DM are much smaller than expected. However, these values do not support the contention that silage should be harvested below 35% DM if it is not kernel processed. Had silage been kernel processed, starch digestibility and milk efficiency. If nutritive value is not decreasing as DM increases, the potential to increase yield of net energy per acre by delaying harvest should be considered. However, fermentation and spoilage losses might be greater for silage over 40% DM. Certainly, with no increase in yield of net energy per acre, no logic would justify or support the recommendation that silage should ever contain more than 40% DM even if kernels are thoroughly processed.

Why have recommendations for silage DM content increased? Reasons could include: grain yields have increased, plant breeders have improved late season plant health and tolerance to abiotic and biotic stressors, the cost of grain has increased drastically while the relative cost of lower starch byproducts has decreased, development and availability of kernel processors and powerful harvest equipment, the realization that the fermentation processes increases starch digestibility, and greater reliance on animal than on laboratory measurements of NDF digestibility. However, numerous factors can influence the choice of hybrids, harvest factors, inoculation and growth conditions that would make harvest of low or high DM silage preferable. These are enumerated in Table 2.

Table 2. Factors influencing value of low and high DM silage harvest.

Low (31-33%)	Desired Harvest DM	High (36-40%)
Low	Land cost	High
Total dry matter	Yield concern	Grain or starch
Low	Grain cost/availability	High
High	Forage cost/availability	Low
Low	Quality-Other forages	High
Important	SILAGE NDF digestion	Not important?
Desirable	BMR hybrids	?? Lodging
Useful?	Leafy hybrids D	etrimental (yield)
Irrelevant	Stay-green	Useful?
<u>Unimportant</u>	Grain vitreousness	If not fermented
High	Plant density	Lower
Less important	Good pollination	Essential
Never	High chop	Useful?
Medium	Chop length	Fine
Not needed	Kernel processing	Essential
Useful	Inoculation	Very important
Homolactic?	Inoculant type	Buchneri, CFT
Important	Packing/covering	Very important
Irrelevant	First in-First out	Beneficial

Recommended responses and reasoning:

- With corn silage, high grain yield reduces fiber production per acre.
   d. False. Grain yield and NDF yield generally increase together.
- 2. Delaying harvest decreases digestibility of NDF from corn silage.
  - a. True.
- 3. More mature corn silage has less NDF only because it is diluted by starch.
   d. False. Some NDF appears mobilized and lost as the corn plant matures.
- 4. Digestibility of starch decreases markedly as maturity at harvest increases.
  - e. Conditional. The decrease seems reasonably small, particularly if silage is kernel processed.
- 5. Corn silage that contains 30% starch (DM basis) has too much starch.
  - d. Conditional. For dry cows and growing heifers, less starch is needed, but for lactating cows, starch from corn silage can displace other sources of starch in the diet.
- 6. In vitro NDF digestibility is a useless measurement.
  - e. Conditional. Though imprecise as an estimate of NDF digestion by animals, in vitro or in situ NDF digestion is correlated with feed intake.
- 7. Milk line accurately reflects moisture content of corn plants.
  - d. False. Milk line is poorly correlated with DM content of many hybrids, probably due to changes in plant genetics and improved late season plant health.
- 8. Yield of corn silage DM reaches a maximum at 35% DM.
  - d. False. Across hybrids and locations, DM yield is maximized at about 37% DM.
- 9. To maximize net energy for lactation, corn silage should have 35% DM.

- e. Conditional. For unprocessed corn silage, 30 to 33% DM appears to optimize NEI value of silage DM despite a sacrifice in yield of DM. For well processed corn silage, harvest at 37 to 40% DM appears to maximize both NEI yield and NEI content of silage DM.
- 10. At what DM should corn be harvested for silage?
  - e. It depends on whether the grain is kernel processed as well as other factors that will influence losses during storage and feedout.

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# **SESSION NOTES**