EFFECT OF STAY-GREEN RANKING, MATURITY AND MOISTURE CONCENTRATION OF CORN HYBRIDS ON SILAGE QUALITY AND THE HEALTH AND PRODUCTIVITY OF LACTATING DAIRY COWS

By

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by

Kathy Gisela Arriola
To my adorable son Wilhelm Andre.
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EFFECT OF STAY-GREEN RANKING, MATURITY AND MOISTURE CONCENTRATION OF CORN HYBRIDS ON SILAGE QUALITY AND THE HEALTH AND PRODUCTIVITY OF LACTATING DAIRY COWS

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Major Department: Animal Sciences

Two experiments were conducted to evaluate how maturity affects the nutritive value of corn (Zea mays L.) hybrids with contrasting (stay-green) SG rankings and the performance of dairy cattle. Experiment 1 determined how maturity affects dry matter (DM) yield, nutritive value, and aerobic stability of 2 corn hybrids differing in SG ranking from each of two companies. The hybrids were harvested at 25, 32, and 37 g DM/100g from four replicated plots and separated into thirds for ear vs. stover chemical analysis, whole plant chemical analysis, and ensiling. The latter was ensiled (15 kg) in quadruplicate in 20-L mini-silos for at least 107 d. The best combination of DM yield, nutritive value, fermentation quality and yeast counts was obtained when the corn hybrids were harvested at 32 g DM/100g. The higher SG ranking changed the moisture distribution of hybrids from both companies in different ways, reduced the nutritive value of hybrids from one company, but did not affect silage fermentation and aerobic stability.

Experiment 2 determined the effect of SG ranking and maturity of corn hybrids on the health, feed intake and milk production of dairy cows. Two corn hybrids with high (Croplan Genetics 691, HSG) and low (Croplan Genetics 737, LSG) SG rankings were harvested at 26 (Maturity 1) or 35 g DM/100g (Maturity 2) and ensiled in 32-ton plastic bags for at least 77 d.
Each of silage was fed in ad libitum amounts as part of a total mixed ration consisting of 35, 55 and 10% (DM basis) of corn silage, concentrate and alfalfa (*Medicago sativa* L.) hay, respectively to 30 Holstein cows (92 average days in milk). The experiment was a completely randomized design with two 28-d periods. Harvesting corn silage at 35 instead of 26 g DM/100g increased the efficiency of feed utilization for milk production but decreased or tended to decrease intakes of CP and NDF, apparent digestibility of NDF and starch and milk yield. The higher SG ranking was associated with poorer feed intake and nutrient digestion, but it did not adversely affect any of the health indices that were monitored.
CHAPTER 1
INTRODUCTION

Several dairy producers in Florida have experienced considerable losses in milk production in the past few years due to Variable Manure Syndrome and Hemorrhagic Bowel Syndrome. Many producers believe that these problems are caused by corn silage with high stay-green (SG) ranking. Stay-green hybrids have asynchronous ear and stalk dry down rates, therefore their ears turn brown and their kernels dry down and mature faster than their stalks and leaves which remain green. Thomas and Smart (1993) characterized a SG trait (i.e., the phenotypes that exhibit delayed senescence) as having higher water and chlorophyll concentration in the leaves at maturity. Therefore, high SG rankings are genetically correlated with high stalk and leaf moisture concentrations (Bekavac et al., 1998). The presence of this characteristic implies that the traditional relationship between whole plant silage, moisture and kernel milk line may no longer hold because it probably results in silages that have milk lines that are more advanced relative to whole-plant maturity (Bagg, 2001). This could lead to either harvesting the corn plant when it is really too wet or to disease infestation due to delaying the harvest till the stalks get drier. Harvesting forages when they are too wet or too dry makes the silage susceptible to effluent losses and respiration losses, respectively (Barnett, 1954). Crops ensiled with excess moisture are often poorly fermented due to proliferation of butyric acid-producing clostridia. It is also difficult to ensile crops with excessive DM concentrations because they are difficult to consolidate adequately in the silo, and the residual oxygen in the silo hinders the fermentation.

Corn varieties without the SG characteristic are no longer readily available commercially because most current hybrids have the SG phenotype. Only two studies have investigated the effect of SG hybrids on the performance of dairy cattle and in sheep. However, these experiments did not compare a SG variety with a conventional variety and they did not determine how the SG
ranking affects the ideal maturity at harvest of corn silage. Therefore, there is a need to determine the ideal maturity stage for harvesting SG corn hybrids that are widely used for silage production. The aim of this study was to determine the effect of maturity at harvest on the nutritive value of the corn silage hybrids with contrasting SG rankings, and to determine the effect of feeding corn silages differing in SG ranking, maturity and moisture concentration on the performance of dairy cattle.
CHAPTER 2
LITERATURE REVIEW

Factors Affecting the Nutritive Value of Corn Plants

Hybrid

Corn silage is one of the most popular forages fed to dairy cows because it has good agronomic characteristics; it has high concentrations of key nutrients, ensiles well, and incorporates easily into the total mixture ration (TMR). In the past, much emphasis was placed on the total yield of dry matter and amount of grain produced from corn hybrids. Other traditional criteria for selecting corn hybrids have been based primarily on agronomic factors, including disease and lodging resistance and drought tolerance. However these measurements alone are poor indicators of nutritive value (Cox and Cherney, 2001). More recent criteria utilized for hybrid selection include fiber and starch digestibility in order to maximize milk production per hectare or milk production per ton of silage (Hunt et al., 1993; Barriere et al., 1995).

In selection of corn hybrids, more emphasis has been placed on grain production than silage production. Grain producers have been reluctant to select hybrids based on nutritional quality because this attracts relatively little economic value. Yet hybrid selection for agronomic potential and nutritive value is one of the most important management decisions influencing corn silage production and subsequent milk yields (Allen et al., 1997). Xu et al. (1995) reported that corn silage hybrid and maturity affected the DM concentration of various plant parts including leaves, ear, husk, stalk and stover. Johnson et al. (2001) harvested corn hybrids 3845 and Quanta at one-third milkline, two-thirds milkline, and blackline stages of maturity and found that hybrid 3845 had greater concentrations of ADF (P < 0.0001), NDF (P < 0.0001) and lignin and lower (P < 0.001) concentrations of starch, non fiber carbohydrates (NFC), and crude protein (CP) than
Quanta. Some current areas of focus in hybrid selection that have nutritional implications will be discussed in the following paragraphs.

**Brown midrib hybrids**

The recent focus of most of the genetic improvement of corn silage has been on enhancing fiber digestibility in order to increase DM intake (DMI) and milk yield by the dairy cow. The genetic variability in ruminal cell-wall digestion of corn stover has prompted numerous studies on this topic (Hunt et al., 1992; Flachowsky et al., 1993; Verbic et al., 1995; Tovar-Gomez et al., 1997). A landmark discovery in the search for more digestible corn silage was the identification of the Brown midrib (BMR) trait. About 40 years after their initial discovery, BMR mutations were found to have a major effect on lignin concentration (Lechtenberg et al., 1972) leading to improved digestibility of corn silage by ruminants. Brown midrib hybrids contain less lignin in the stalks and leaves than normal hybrids, resulting in greater stover digestibility and in vitro true digestibility (IVTD) (Lechtenberg et al., 1972; Colenbrander et al., 1973).

Some studies have shown that BMR hybrids gave substantially lower DM yields and produce 10 to 15% less DM (Frenchick et al., 1976; Miller and Geadelman, 1983; Cherney et al., 1991; Allen et al., 1997), and had increased susceptibility to lodging (Cherney et al., 1991). Feeding studies with BMR corn silage have resulted in greater milk yields (Rook et al., 1977; Block et al., 1981; Stallings et al., 1982). However, others have reported no improvement in milk yield after feeding BMR hybrids (Rook et al., 1977; Block et al., 1979; Stallings et al., 1982). According to Oba and Allen (1999), DMI, yield of milk, protein, fat and lactose were greater for cows fed a bm3 corn hybrid vs. a control hybrid, but milk fat concentration was not changed. Some authors (Frenchick et al. 1976; Block et al., 1981) reported milk fat depression when bm3 corn silage was fed, but others (Rook et al., 1977) reported an increase in milk fat concentration.
Bal et al. (2000) evaluated Pioneer 3563 as a conventional hybrid (CH) and Cargill F657 as a BMR hybrid in feeding trials with lactating dairy cows. They found lower NDF, ADF and lignin concentrations for BMR vs. CH. Dry matter intake was not different between treatments groups, perhaps due to higher forage concentration in the BMR diet. Milk production was lower for cows fed the bm3 than the CH hybrids. Milk fat percentage was greater by 0.08 percentage units and milk fat yield was greater by 0.28 kg/d in cows fed the bm3 diet compared to the CH diet.

Cox and Cherney (2001) stated that though BMR hybrids have high NDF digestibility, which is positively correlated with in vitro true digestibility (IVTD), they do not recommend their use because of inconsistent milk yields and high seed costs. In one study, the lack of response to total tract NDF digestibility was attributed to greater DMI for the bm3 mutant treatment (Rook et al., 1977), because total tract digestibility declines as feed intake increases (Tyrell and Moe, 1975). Greater DMI for brown midrib hybrids might be associated with a faster rate of digesta passage, diminishing potential digestibility. Brown midrib 3 (bm3) is a gene mutation that has been incorporated into corn plants to improve fiber digestibility. This bm3 mutation resulted from structural changes in the caffeic acid O-methyltransferase (COMT) gene, which encodes the enzyme O-methyltransferase (COMT; EC 2.1.1.6) involved in lignin biosynthesis. Therefore, the lignin biosynthesis in bm3 is restricted and structural carbohydrates are more accessible by ruminal microorganisms.

Oba and Allen (2000) showed that, in spite of increased in vitro NDF digestibility (NDFd), bm3 corn silage did not have greater NDF digestibility in vivo than the control silage in the rumen, postruminally, or in the total tract. This indicates that in vitro NDFd does not necessarily closely predict NDF digestibility in vivo or energy density of forages. These authors noted that
the bm3 corn silage had a greater passage rate for indigestible NDF and NDF, and surmised that enhanced in vitro digestibility of NDF might indicate greater fragility of plant cell wall and reduced physical fill in the rumen, thereby increasing DMI.

Ballard et al. (2000) compared three corn hybrids, namely 1) Mycogen TMF94 (Mycogen), a leafy hybrid developed for corn silage, 2) Cargill F337 (Cargill), which is a BMR hybrid, and 3) Pioneer 3861 (Pioneer), which is a dual purpose hybrid for silage and grain yield. Using a plot trial, they found no differences in plant population, infected ears, or lodged plants between hybrids. However, it should be noted that there was no excessive rain or heavy winds late in the season. The Cargill F337 hybrid had a higher DM and NDF digestibilities but a lower DM yield than the Mycogen TMF94 hybrid, and a lower DM concentration than the Pioneer hybrid. The Cargill hybrid had the highest in vitro true dry matter digestibility (IVTDMD) and in vitro neutral detergent fiber digestibility (IVNDFD), which were attributed in part to the lower lignin concentration compared with Mycogen and Pioneer hybrids. During a subsequent feeding trial no differences were observed in DMI by cows fed the diets based on the Mycogen and Cargill hybrids, even though the Cargill hybrid was more digestible in vitro. Cows fed the Cargill silage-based TMR had greater yield of milk and 3.5% FCM compared with cows fed the Mycogen silage-based TMR. This may be attributed to the higher in vitro digestibility of the Cargill hybrid, which suggests that more energy was available from the Cargill silage than the Mycogen or Pioneer silages.

**Grain digestibility (flint vs. dent hybrids)**

Few studies have reported the ruminal starch digestion of corn silage hybrids. Verbic et al. (1995) and Philippeau and Michalet-Doreau (1997) reported a large variation in the ruminal degradation of dent and flint corn grain genotypes. Dent type corn grains tend to have a greater percentage of floury endosperm, whereas flint type corn grains have a greater percentage of
vitreous endosperm. In the vitreous endosperm, the starch granules are surrounded by a protein matrix which limits digestion, whereas those in floury endosperm, starch granules are more available for digestion (Kotarski et al., 1992). The site of digestion of dietary starch strongly influences the nature of the end products of digestion and how starch is utilized by the animal (Nocek and Tamminga, 1991; Huntington, 1997). Therefore knowledge of the rate of ruminal starch degradation of a hybrid is important in ration formulation.

Some authors reported that the lower in situ degradability of starch in flint corn was caused by a lower proportion of the rapidly degradable fraction, a lower rate constant of degradation, or both (Michalet-Doreau and Champion, 1995; Verbic et al., 1995; Philippeau and Michalet-Doreau, 1997). Philippeau and Michalet-Doreau (1998) evaluated the influence of genotype and ensiling of corn grain on the rate and extent of ruminal starch degradation using two cultivars of corn that differed in texture of the endosperm; that is, dent (Zea mays, ssp. indentata) and flint (Zea mays, ssp. indenture). They found that for unensiled samples, ruminal DM degradability was similar for both hybrids, but ruminal starch degradability differed (72.3 vs. 61.6% for dent and flint genotypes, respectively). This was mainly due to a difference in the rapidly degradable fractions (34.8 and 9.9%) of the respective hybrids. The difference in ruminal starch degradability between these two hybrids also could be explained by the difference in the grain DM content for dent (46.4%) and flint (52.3%) genotypes.

**High-oil hybrids**

Many studies have reported that milk production from dairy cattle can be increased by replacing dietary conventional corn and supplemental fats with high-oil corn (Palmquist and Jenkins, 1980; Casper and Schingoethe, 1989; Schingoethe and Casper, 1991). The polyunsaturated fatty acids in many supplemental fat sources are biohydrogenated in the rumen, and they can inhibit the growth of cellulolytic ruminal microbes. Using oilseeds such as soybean
(Glycine max) or high-oil corn (HOC) as the fat source may slow the release of oil into the rumen and lessen ruminal biohydrogenation (Aldrich et al., 1997), which may minimize ruminal disturbances while still delivering fatty acids to the animal. High-oil corn is typically reported to contain 7 to 8% ether extract on a DM basis, nearly double the concentration found in conventional corn hybrids (CH), whereas protein concentration is typically 1 to 2% units higher (Dado, 1999). Dietary feeds that contain lipids with low susceptibility to ruminal biohydrogenation (e.g., oilseeds vs. free oil) can influence milk fatty acid composition (Grummer, 1991; Palmquist et al., 1993; Avila et al., 2000). Milk from cows fed HOC contained more unsaturated fatty acids than milk from cows fed conventional corn (Elliot et al., 1993; LaCount et al., 1995), even though Weiss and Wyatt (2000) reported that ear (cob + kernels), as a percentage of whole plant DM, was similar between conventional (57%) and high-oil (55%) hybrids.

Lysine and other essential amino acid (AA) concentrations in HOC are slightly higher compared with regular corn because HOC contains more germ protein. However, lysine is still markedly deficient for milk production when HOC is fed. Because lipids contain about 2.25 times the number of calories as a similar weight of carbohydrate, HOC contains about 4% more gross energy than does regular corn. However HOC may contain more NDF than regular corn, which may be a potential limitation to its nutritional value (Drackley, 1997).

Smaller amounts of endosperm in HOC kernels result in less starch in both grain and silage compared with normal corn grain and silage (68 vs. 71% of the grain DM; Hammes, 1997). Because oil is not fermentable in the rumen and starch is, a smaller quantity of starch in HOC may result in less microbial growth and protein synthesis, though it could also decrease the incidence of acidosis (Dado, 1999; Andrae et al., 2000). Feeding trials with HOC for various
livestock indicate that feeding HOC improves feed efficiency and increases rate of gain over livestock fed conventional corn (Lambert, 2001).

Whitlock et al. (2003) evaluated the performance of dairy cows fed conventional corn or HOC-based on TMR. They found no differences between the 2 groups in DMI, milk production, milk fat concentration, and milk protein concentration. The concentration of short-chain fatty acids (4:0 to 12:0) in milk was not affected by corn source; however, the concentration of medium-chain fatty acids (14:0 to 16:1) decreased (P < 0.01) and the concentration of long-chain fatty acids (17:0 to 22:6) increased (P < 0.01) when cows were fed the HOC. Unsaturated fatty acid concentration increased (P < 0.01) and saturated fatty acid concentration decreased (P < 0.03) when cows were fed the HOC diets compared with the CC diets.

According to Weiss and Wyatt (2000) the total digestible nutrients (TDN) concentration of diets with unprocessed HOC silage was about 5% higher than for those with conventional unprocessed corn silage. However, when the silage was processed, the TDN concentration of HOC silage was similar to that of conventional silage. Kernel processing increased TDN concentration of the conventional corn silage diet by 5.3%, but had no effect on TDN concentration of diets based on HOC silage. Assuming no associative effects, unprocessed HOC silage had 8.2% more TDN than unprocessed conventional corn silage and processing increased TDN of the conventional corn silage by 8.4%. The increased TDN of HOC corn silage was largely caused by increased fat concentration and that of processed corn silage was largely caused by increased starch digestibility. Dry matter intake was not affected by treatment, though processed silage had higher starch and non-fiber carbohydrate (NFC) digestibility than unprocessed silage. Milk yields were similar between processing treatments when high oil corn silage was fed, and no interaction was observed between varieties and processing for FCM yield.
The variety of corn silage did not affect milk fat concentration or yield, but cows fed HOC silage produced milk with less protein.

**High-grain yield and leafy hybrids**

Most researchers have related maximum DM yield and quality with high grain concentration (Phipps et al., 1979; Coors et al., 1997). However, corn hybrids have been developed to have more leaves, which should lead to improved digestibility and better animal performance (Tolera and Sundstol, 1999; Cox and Cherney, 2001). Thomas et al. (2001) reported that Novartis NX3018 corn hybrid (selected for increased leaf proportion and digestibility) had a higher proportion of stover and lower proportion of grain compared with their Novartis NF29-F1 dual-purpose corn hybrid despite the use of similar plant populations, their similar DM yields, and similar percent barren and lodged plants. Even though the nutrient composition of the two corn hybrids was relatively similar, NX3018 had higher IVTDMD and IVNDFD both before and after ensiling in mini silos and silage bags. Cows that were fed a TMR containing NX3018 corn silage produced more milk, 3.5% FCM, milk CP, and milk lactose compared with cows that were fed the TMR containing N29-F1 corn silage. Bal et al. (1998), however, reported that cows fed TMRs containing leafy or high-grain corn silages had similar milk yields. Bal et al. (2000) evaluated Mycogen TMF106, a leafy hybrid (LFY), and Pioneer 3563, a conventional hybrid (CH) in a feeding trial with lactating dairy cows. Each hybrid was planted at low and high plant populations. They found that the moisture concentration of LFY was higher than that of CH at both plant populations. A diet containing the LFY hybrid diet resulted in lower DMI and higher milk fat percentage compared with one containing the CH hybrid, though milk yield did not differ among treatments. Apparent digestibilities of DM, organic matter (OM), ADF and NDF were higher for diets containing CH than LFY.
Kuehn et al. (1999) grew and fed 3 corn hybrids: 1) Mycogen TMF94, (94-d maturity) a leafy hybrid, 2) Dekalb 442 (Dekalb Genetics Corp., Dekalb, IL; 95-d maturity), a high grain hybrid, and 3) Dahlco No. 2 blend (Dahlco Seeds, Inc, Cokato, MN; 90-d maturity), a blend of hybrids. They found that NDF and ADF concentration did not differ among the three hybrids and starch concentration of the high grain silage (26.1% DM basis) was greater than that of the blend (23.8% DM basis) and leafy (23.5% DM basis) silages. The leafy silage had greater IVNDFD compared with the other hybrids. Dry matter intake by lactating cows was not affected by dietary treatment during the third and fourth weeks of the study, though cows fed the leafy silage had a lower DMI than did cows fed the high grain silage diet. Multiparous cows fed the high grain silage diet consumed more DM during Week 5 of lactation than cows receiving the blend or leafy silage diets. Dietary treatment did not affect yields of milk and 3.5% FCM, or milk composition.

Clark et al. (2002) compared a leafy hybrid (Mycogen TMF94) selected for its silage yield and leafiness (94-d maturity) with a high grain corn hybrid (Pioneer 3751) selected for its high yield for grain or silage (99-d maturity). They observed that the leafy corn hybrid used in the diet for silage at a level of 42% of dietary DM, supported higher DMI as well as increased milk, 4% FCM and milk protein yield compared with a control grain type hybrid variety. When used in the diet as high moisture shelled corn, the leafy corn hybrid stimulated higher DMI, but no difference in milk yield, 4% FCM yield, or milk composition was observed.

**Cutting Height**

Increasing the cutting height of corn plants decreases silage yield but increases nutritive value because the lower portion of the corn plant is less digestible (Tolera and Sundstol, 1999).

Corn silage yield decreased by 15% as the cutter bar was raised from 15.2 to 45.7 cm above the soil surface; however, silage quality (milk per ton) increased (Lauer 1998). Cummins and
Burns (1969) reported that corn forage yields decreased by about 18% but that IVTD increased by 60 g kg$^{-1}$ as cutting height increased from 15 to 90 cm. Harvestable digestible DM (IVTD x yield) was the same at 15-, 45-, and 90-cm cutting heights (6.0, 6.0, and 5.9 t ha$^{-1}$, respectively). According to Curran and Posch (2001), as cutting height increased from 10 to 50 cm, the yields of eight dual-purpose hybrids decreased by 11%, whole-plant IVTD increased by 16 g kg$^{-1}$, NDF digestibility increased by 8 g kg$^{-1}$, and starch concentration increased by 27 g kg$^{-1}$. Consequently, calculated milk yields decreased by only 3.7%, and Curran and Posch concluded that cutting height management can influence corn forage quality and potential animal performance.

Lewis et al. (2004) compared the predicted animal response to harvest date and cutting height of three corn hybrids, Pioneer 34B23 (dual purpose), Mycogen TMF108 (leafy), and Cargill F757 (brown midrib), harvested at cutting heights of 15, 30 and 46 cm, respectively. They reported that calculated milk yields from TMF108 did not differ as cutting height increased from 15 to 46 cm because the increase in milk per ton of silage or forage quality offset the decline in DM yields. In contrast, calculated milk yields for F757 decreased with increasing cutting height because the additional removal of highly digestible stover reduced forage quality and further reduced the inherently low DM yields. This shows that responses to cutting height changes depend on hybrid stover digestibility.

Starch concentrations did not change as cutting height increased from 15 to 30 cm but increased by 11 g kg$^{-1}$ as cutting height increased from 30 to 46 cm (Lewis et al., 2004). Average stover and whole-plant NDF digestibility increased by about 15 to 20 g kg$^{-1}$ with each 15-cm increase in cutting height. Average stover IVTD increased by 16 g kg$^{-1}$ as cutting height increased from 15 to 30 cm but remained unchanged as cutting height increased to 46 cm.
Average whole-plant IVTD increased by a consistent 8 g kg\(^{-1}\) with each successive increase in cutting height. Although stover CP concentrations increased by 4 g kg\(^{-1}\) as cutting height increased from 15 to 30 cm, cutting height did not affect whole-plant CP concentrations. Neylon et al. (2002) also reported only a small change in whole-plant CP concentration of leafy hybrids as cutting height was increased from 13 to 46 cm.

Bernard et al. (2004) evaluated two corn hybrids, Pioneer 31G20 and Pioneer 32K61 that had similar ratings for yield and nutrient concentration. Half of the forage on plots containing each variety was cut at a height of 10.2 cm (normal) and the remaining half was cut at a height of 30.5 cm (high). They reported that corn silage harvested at 30.5 cm had lower concentrations of ADF compared with that harvested at 10.2 cm, but there were no differences in concentrations of NDF or IVTDMD. There was an interaction between cutting height and variety because of increased IVTDMD for 31G20 harvested at 30.5 cm compared with that harvested at 10.2 cm. No differences in milk yield, milk concentration, yield of milk fat and protein, or energy-corrected milk yield (ECM) were observed among varieties or cutting heights.

In a trial utilizing several leafy corn silage hybrids harvested at two maturities, Neylon and Kung (2002) found that increasing the cutting height of corn silage from 12.7 cm, normal cut (NC), to 45.7 cm, high cut (HC), improved nutritive value by decreasing the concentrations of ADF, NDF, and ADL but increasing the concentration of starch. In vitro NDF digestibility after 30 h of incubation was affected only by height of cutting and was greater in HC (50.7%) than in NC (48.3%). Kruczynska et al. (2001) observed a reduction in crude fiber and ADF, and greater effective degradability of silage that was cut at 50 vs. 10 cm.

Dominguez et al. (2002) evaluated two corn hybrids, brown midrib (bm3) corn silage cut at a normal height of 23 cm, and conventional corn silage cut at height of 23 cm (NC) or 71 cm
They reported that HC had greater DM concentration than NC (40.9 vs. 38.4%), but HC had lower NDF concentration (33.9 and 38.6%). No differences in milk yield were found.

Most of these studies indicate that forage digestibility and animal performance is enhanced at cutting heights of 45 to 50 cm. but is at the expense of DM yield.

**Maturity**

Whole corn plants are harvested, ensiled, and fed to lactating dairy cattle throughout the United States (Johnson et al., 1999). However, the nutritive value of corn silage is affected by the fibrous (stover) portion and grain portions (kernel). As the corn plant matures, the ratio of stover to grain decreases, and digestibility of the whole plant tends to increase until two-thirds milk line (ML) (Johnson et al., 1999). This is because maturity of corn at harvest influences DM, WSC, NDF and starch concentration and IVDMD (Russell, 1986; Tolera et al., 1999). The NDF concentration of whole plant corn silage declined as maturity advanced from milk to ½ ML (Ganoe and Roth, 1992; Wiersma et al., 1993), and plateaued (Wiersma et al., 1993) or declined (year 2, Ganoe and Roth, 1992) as maturity advanced from ½ ML to black layer (BL). As kernel fill increased from ¾ ML to BL, DM digestibility decreased in whole-plant corn silage both in vitro (Hunt et al., 1989) and in vivo (Bal et al., 1997) despite an increase in starch concentration and a decrease in fiber concentration (Harrison et al., 1996; Bal et al., 1997).

Bal et al. (1997) evaluated the effect of harvesting corn silage at four stages of maturity on the performance of dairy cows. They found that moisture concentration declined from 69.9 to 58.0% as maturity of the corn advanced from the early dent (ED) stage to the BL stage; and concentrations of NDF and ADF declined while starch concentration increased. However, no decline in NDF and ADF concentration or increase in starch concentration was observed from the ¾ ML stage to the BL stage.
Poor starch fill (and grain yield) can cause photosynthetic energy to remain as sugar in the stover and leaves, thus diluting fiber content but not yielding the expected net energy (Fairey, 1983; Coors et al., 1997). Johnson and McClure (1968) reported an increasing concentration of soluble carbohydrate in stalks from tasseling to the milk stage and this declined thereafter.

According to Darby and Lauer (2002), the relationship between DM yield and growing degree units (GDU) is linear. The nutritive value of unfermented forage and silage increased and stover quality decreased as harvest time progressed through the growing season. Generally, forage quality was always lowest when harvest time coincided with flowering. Fiber constituents were lowest between 1100 and 1110 GDU (650 g kg\(^{-1}\) of moisture). In vitro true digestibility was maximized at 1025 GDU (700 g kg\(^{-1}\) of moisture). Milk per ton of silage and milk per hectare were optimized at 1075 and 1105 GDU (670 and 630 g kg\(^{-1}\) of moisture), respectively. Therefore, these authors suggested that yield, quality and performance indices will remain at 95% of the optimum values if corn forage is harvested between 700 and 600 g kg\(^{-1}\) of moisture.

Hunt et al. (1989) reported that corn DM yield and quality were greater at 315 vs. 390 g kg\(^{-1}\) of DM concentration in an irrigated California study. Wiersma et al. (1993) reported that DM yield and IVDMD of corn forage were greater at 330 vs. 260 g kg\(^{-1}\) of DM concentration in a Wisconsin study. According to Wiersma et al. (1993), CP concentration declined rapidly with increasing maturity, averaging a drop of 2 percentage units from soft dough to no ML for whole corn plants and 3 percentage units for stover. Decreasing CP concentration appears to be the result of continued carbon assimilation, even though N uptake probably was completed, thereby diluting plant N concentration. Stover fiber concentration increased by an average of 3.2 and 2.9 percentage units of NDF and ADF respectively during the period from soft dough to no ML.
Whole plant fiber concentration generally declined from soft dough to ½ ML and then plateaued after ½ ML. Decreases in whole plant fiber concentration from soft dough to ½ ML averaged 7.6 and 4.4 percentage units for NDF and ADF, respectively.

Stage of maturity has important effects on many characteristics of corn crops grown for silage. Total crop yield, grain and DM concentration, stover digestibility (Daynard and Hunter, 1975), ensiling losses (Giardini et al., 1976), and silage intake (Malterre, 1976) can all be influenced by crop maturity and are important considerations in corn silage production. For many years, corn was harvested for silage when the kernels reached the BL stage of development. Recently, the recommendation has been to harvest corn plants when the ML is half to three quarters of the way down the kernel. This was based on observations that corn forage harvested at these stages contained more grain, had higher digestibility and higher yields compared to corn harvested at the BL stage (Wiersma et al., 1993). Huber et al. (1965) reported an increase in silage DMI and in milk production of cows as the maturity of whole-plant corn at harvest advanced from the soft stage to the hard dough stage and Harrison et al. (1996) found higher milk production for cows fed silage from whole-plant corn harvested at the one-half milk-line stage versus the BL stage. Havilah et al. (1995) reported that the maximum yield of the crop was produced at milk line score (MLS) 3.4, and harvesting at MLS 2-3 (under Australian conditions) would provide near maximum yield, optimum DM content for ensiling, and high digestibility.

Whole-crop DM concentration has been a useful determinant of the correct stage of harvest. The ideal DM concentration for the coincidence of optimum DM yield, ensiling suitability, and feed quality is in the range of 300 - 400 g/kg (Wiersma et al., 1993). Within this range adequate compaction and preservation of silage can be achieved. Harvesting forages when
they are too wet or too dry makes the silage susceptible to effluent losses and respiration losses, respectively (Barnett, 1954). Ensiling crops with lower DM concentration also poses a risk of poor fermentation while adequate packing of high DM crops in the silo is difficult, and typically results in increased ensiling losses (Havilah et al., 1995).

Dairy producers with bunker silos typically begin corn silage harvest at DM concentration of about 300 g kg⁻¹, about 50 g kg⁻¹ wetter than the target DM for silage stored in upright silos, because silage effluent production from bunker silos is minimal at DM concentration of 300 g kg⁻¹ and above (Bastiman and Altman, 1985).

**Digestibility**

As with all forages, the digestibility of the stover portion of corn silage declines dramatically with progressive maturity. Nonstructural carbohydrates and IVDMD decreased and fiber concentration increased in stover with advancing maturity (Russell, 1986). Russell et al. (1992) reported that IVDMD of corn stover decreased with advancing maturity and was highly correlated with ADF and lignin concentrations. The increasing proportion of grain as the corn plant matures obscures the relationship between plant maturity and digestibility of whole plant corn silage. Hunt et al. (1989) studied maturity effects of six corn hybrids across 2 yr and two locations. Concentrations of NDF and ADF in the whole plant decreased as maturity proceeded from early one-third ML to mid two-thirds ML, and did not change from mid to late BL maturity.

Cummins (1970) reported that whole plant digestibility increased with advancing plant maturity until DM concentration reached 35 to 40%, but Daynard and Hunter (1975) found whole plant digestibility to be constant from 24 to 44% DM concentration. This discrepancy could be due to differences between the corn hybrids examined.
One of the factors that alter the digestibility of corn silage is the vitreous endosperm in corn kernels within the corn silage. The vitreous endosperm contains starch that is embedded in a dense protein matrix (Kotarski et al., 1992). The vitreousness of starch in corn kernels increases as maturity advances and decreases ruminal starch digestibility (Philippeau and Michalet-Doreau, 1997).

**Animal performance**

Two continuous studies (20 wk and 4.4 wk, respectively) were conducted to determine how maturity at harvest of corn silage affects dairy cows in early lactation (Huber et al., 1965; 1968). In the first study CP and crude fiber concentration tended to decrease and nitrogen-free extract tended to increase as maturity of corn silage advanced from 25.4 to 33.3% DM (Huber et al., 1965). Dry matter intake (P < 0.05) and milk production (P < 0.08) increased as DM of the corn silage increased from 25.4 to 33.3% DM. Milk composition, BW gain, and apparent digestibility of nutrients were not affected by maturity (Huber et al., 1965). In the second study, ADF and lignin concentrations decreased as corn silage maturity advanced from 30 to 36% DM, and increased as maturity advanced from 36 to 44% DM (Huber et al., 1968). Lactic and acetic acid concentrations declined and ADIN increased as maturity of corn silage advanced from 36 to 44% DM. Milk production, DMI, and corn silage intake tended to be greatest for cows fed corn silage harvested at 36% DM compared to cows fed corn silage harvested at 30 and 44% DM (Huber et al., 1968).

Buck et al. (1969) conducted two trials with primiparous Holstein cows to evaluate the effect of maturity on intake and milk production. The forage:concentrate ratio of the diet was approximately 60:40. Corn silage DMI increased as plant maturity increased to approximately 35 g DM/100g. Stage of maturity ranging from 22 to 34% DM (Trial 1) and 32 to 40% DM (Trial 2) did not alter milk production or digestible energy estimates. In recent studies, the
concentrations of NDF, ADF, and CP tended to decline and DM and starch increased with advancing maturity from milk to BL stages (Hunt et al., 1989; Xu et al., 1995; Harrison et al., 1996; Bal et al., 1997). In addition, silage pH was lowest and lactate concentration was greatest with the more immature silages (Bal et al., 1997). However, the relationships between maturity of corn silage and DMI, milk production, milk component yield, and digestibility of nutrients were not consistent because when corn silage of varying maturities (early dent: ED to BL) were fed at approximately 35 to 37% of diet DM, no differences in DMI or milk fat yield were found (Harrison et al., 1996; Bal et al., 1997). In contrast, milk and milk protein yields were maximized when corn silage was harvested between $\frac{1}{2}$ and $\frac{2}{3}$ ML (Harrison et al., 1996; Bal et al., 1997). Harvesting corn silage at BL maturity resulted in decreased total tract digestibility of starch by approximately 5 and 9 percentage units, respectively, when compared with corn silage harvested at $\frac{2}{3}$ ML and $\frac{1}{2}$ ML (Harrison et al., 1996; Bal et al., 1997). Forouzmand et al. (2005) also found that feeding corn silage harvested at BL stage of maturity decreased TMR, silage and nutrient intake but did not have a major impact on performance of mid-lactation dairy cows.

Most of these studies suggest that the DM concentration ranges at harvest that optimize the nutritive value of corn silage and animal performance are between 30 to 39% DM and $\frac{1}{2}$ to $\frac{2}{3}$ ML.

Factors Affecting the Fermentation of Corn Silage

Important criteria for the effective preservation of an ensiled crop include a high degree of lactic acid production and a pH below 4.2 after the fermentation phase (Cleale et al., 1990; Bolsen et al., 1996). These criteria usually produce silage that is stable under anaerobic
conditions. However, several factors affect lactic acid production during silage fermentation including the following:

**Maturity**

High DM silage typically has higher pH because the increased osmotic pressure in high DM silages inhibits the growth of lactic acid bacteria (Woolford, 1984). MacDonald et al. (1991) suggested that pH tends to increase and organic acids tend to decline as maturity advances because there is less fermentable substrate available. McDonald et al. (1991) suggested that the lower pH of less mature corn silage could be related to higher moisture and water soluble carbohydrate concentrations.

Others also have reported a decline in lactate (Huber et al., 1968; Bal et al., 1997; Johnson et al., 1997), acetate (Huber et al., 1968; Bal et al., 1997), and ethanol (Bal et al., 1997) concentration as maturity advanced. However, Johnson et al. (2002) showed that lactate and acetate concentrations and pH were similar across different maturities of corn silage in two experiments. In the first experiment, Pioneer hybrid 3845 was harvested at 1) the hard dough stage, 25.3% DM, 2) ⅓ ML, 28.5% DM, and 3) ⅔ ML, 27.9% DM. In a second experiment at ⅓ ML, 27.1% DM, ⅔ ML, 33.3% DM, and BL, 38 % DM. Ethanol concentration was greatest (P <0.0001) at the advanced maturity stage (two-thirds ML) in Experiment 1, and greatest (P <0.06) at the early maturity stage (one-third ML) in Experiment 2.

Foruzmand et al. (2005) studied the effect of maturity of two corn hybrids, Single Cross 704 and Three-Way Cross 647, harvested at ⅓ to ⅔ ML and ⅔ ML to BL respectively, and they found that pH was less acidic as maturity increased.

**Inoculants**

Inoculation of forage crops with homofermentative lactic acid bacteria (LAB) can improve silage fermentation (Muck and Bolsen, 1991) if sufficient fermentable substrate is available
Inoculation of grass or legume silage with bacteria has lowered silage pH, reduced NH₃-N, and increased the lactate: acetate ratio in >70% of studies published between 1985 and 1993 (Muck, 1993). Inoculation of corn silage, however, has failed to improve fermentation quality in many studies (Muck, 1993), and had little effect on final silage pH or fermentation acids (Bolsen et al., 1980; Cleale et al., 1990), though the rate of pH decline or production of lactic acid in the first 4 to 7 d of fermentation has been increased in some studies (Bolsen et al., 1989).

Hunt et al. (1993) studied the effect of two corn hybrids (Pioneer 3377 and 3389) with similar total plant and grain yield characteristics, ensiled with and without a microbial inoculant (Pioneer inoculant 1174, Pioneer Hi-Bred International, West Des Moines, IA). They found that inoculated whole-plant corn silage had lower (3.49 vs. 3.55) pH and tended to have greater lactate concentrations (6.59 vs. 5.45 \% of DM) than non-inoculated silages. The butyrate concentration was greater (0.08 vs. 0.06\% of DM) for inoculated than for non-inoculated corn silages samples. They concluded that all responses due to their microbial inoculant seemed to be minor and of little nutritive significance.

Higginbotham et al. (1998) reported that lactic acid of corn silages was not influenced by inoculants (propionibacteria or propionibacteria with LAB) throughout the fermentation and storage periods. Acetic acid was not affected; propionic and butyric acid were generally undetectable. The small difference in concentrations of lactic, acetic, and propionic acids between the silages from forages inoculated with propionibacteria and the control silage suggests that the added propionibacteria did not affect normal metabolic activity with respect to carbohydrates and lactic acid during the ensiling period.
Chop Length

Particle size plays a key role in digestion and passage of feed through the gastrointestinal tract of ruminants and therefore in feed intake. Fernandez and Michalet-Doreau (2002) studied the fermentation characteristics of four corn silages (Safrane variety, Limagrain Genetics, Limagne, France) with two chop lengths, namely fine (4.2 mm) and coarse (12.0 mm) harvested at early stage (24% DM) and late stage (31% DM) of maturity. At the early maturity stage, chop length had no effect on ensiling fermentation variables. At the late maturity stage, coarsely-chopped silage was more fermented than the fine silage, resulting in higher lactic acid (52.5 vs. 37.1 g/kg DM) and ethanol (4.7 vs. 1.5 g/kg DM) concentrations, despite the slightly higher DM concentration.

Fernandez et al. (2004) compared two corn hybrids of whole plant corn silage (WPCS) at two theoretical chop lengths (TCL), namely fine (5.0 mm) and coarse (13.0 mm). They found that lactic acid concentration was greater for the coarse WPCS than the fine WPCS, and silage pH was lower for the coarse WPCS. The pH and lactate concentrations of the coarsely chopped silage were indicative of desirable silage fermentation.

Processing

Silage fermentation characteristics, DM concentration and DM loss are affected by mechanical processing (Johnson et al., 1997). Rojas-Bourillon et al. (1987) reported lower pH and higher lactate concentration in corn silage processed prior to ensiling. On the other hand, Cooke and Bernard (2005) reported that pH of kernel processed corn silage tended to be higher and lactic acid tended to be lower than that of the unprocessed corn silage. Weiss and Wyatt (2000) also reported greater pH for processed corn silage than unprocessed silage. However, Dhiman et al. (2000) found similar pH for processed and unprocessed corn silage.
Chemical Additives

Britt and Huber (1975) reported that high concentrations of ammonia, but not urea, depressed lactic acid formation throughout the ensiling period. Kung et al. (2000) studied the effect of adding ammonia hydroxide to corn plants at ensiling. They found that ammoniation increased the pH to 9.10 at Day 0, whereas the pH of control silages was 6.52. The lactic acid concentration was lower in ammoniated silages (0.96% of DM) than in control silages (1.75% of DM) after 1 d of fermentation, due to a delayed growth of LAB. Concentrations of acetic acid were greater in ammoniated silages after 0.6, 6 and 60 d of ensiling. In the second experiment, Kung et al. (2000) studied the effect of adding buffered propionic acid (0.1, 0.2, and 0.3% of fresh forage) and ammonia-N (0.1, 0.2, and 0.3% of fresh forage) to corn plants at ensiling. They reported that ammoniated silages had a decreased ratio of lactic: acetic acid and an increased ammonia-N concentration. However, the effects of the propionic acid-based additive on silage fermentation were unremarkable.

Factors Affecting Aerobic Stability of Corn Silage

Yeasts

Yeasts are facultative, anaerobic, heterotrophic microorganisms and are considered undesirable in silages. Silage yeasts ferment sugars to ethanol and CO₂ under anaerobic conditions (Schlegel, 1987; McDonald et al., 1991). This decreases the amount of sugar available for lactic acid production and the ethanolic silage can taint the flavor of milk (Randby et al. 1999). Many yeasts species in silages degrade lactic acid to CO₂ and H₂O under aerobic conditions, thereby, causing a rise in silage pH, and promoting the growth of other spoilage organisms (McDonald et al., 1991). Woolford et al. (1982) reported that yeasts are essentially responsible for the aerobic instability of corn silage. Some authors reported that during the first weeks of ensiling, yeast populations can increase up to $10^7$ colony forming units per gram (cfu/g),
though prolonged storage will lead to a gradual decrease in yeast numbers (Jonsson and Pahlow, 1984; Middelhoven and Van Balen, 1988). The presence of oxygen enhances the growth of yeasts during storage, while high concentrations of formic or acetic acid reduce their growth (Driehuis and Van Wikselaar, 1996; Oude Elferink et al., 1999). Yeast counts greater than $10^5$ cfu/g are usually indicative of aerobic instability.

**Molds and Mycotoxins**

Molds are eukaryotic microorganisms that develop in silage when oxygen is present. Silage infested with mold, is usually easily identified by the large filamentous structures and colored spores that many species produce. Mold species that have regularly been isolated from silage belong to the genera *Penicillium*, *Fusarium*, *Aspergillus*, *Mucor*, *Bysschlamys*, *Absidia*, *Arthrinium* and *Trichoderma* (Woolford, 1984; Jonsson et al., 1990; Nout et al., 1993). Molds cause a reduction in feed value and palatability, and have a negative effect on human and animal health. Scudamore and Livesey (1998) reported that such mycotoxicoses range from digestive upsets, fertility problems and reduced immune function, to serious liver or kidney damage and abortions, depending on the type of and amount of toxin present in the silage. Some important mycotoxin-producing mold species are *Aspergillus fumigatus*, *Penicillium roqueforti*, and *Bysschlamys nivea*. *P. roqueforti* is acid tolerant, it can grow under low oxygen, high CO₂ conditions and it is the predominant mold species detected in different types of silages (Lacey, 1989; Nout et al., 1993; Auerbach et al., 1998). A silage that is heavily infested with molds does not necessarily contain high levels of mycotoxins and not all types of mycotoxins that a mold specie can produce are always present (Nout et al., 1993). It is possible to have visible molds without mycotoxins. Therefore, the visible mold-mycotoxin occurrence relationship is not clear.

Mycotoxins are now more frequently associated with crops like corn silage that include grain and stover fractions. Recently mycotoxins in corn silage have been implicated as the cause
of dairy herd health problems during years with near ideal growing conditions and record corn yields (Rankin and Grau, 2004).

Two species of *Aspergillus*, *Aspergillus flavus* and *A. fumigatus* and/or their mycotoxins, are reported regularly in silages. *Aspergillus flavus* is common in hot and dry regions where it colonizes corn plants in the field and produces aflatoxins and cyclopiazonic acid (Munkvold, 2003). Cyclopiazonic acid (CPA), which is also produced by Penicillium mold, is a potent specific inhibitor of the endoplasmic reticulum Ca$^{++}$-ATPase (Goeger et al., 1988). *Aspergillus fumigatus* is a thermotolerant fungus that is regularly isolated from silages. *A. fumigatus* produces several different mycotoxins including fumitremogens B and C, and gliotoxin (Cole et al., 1977).

Aflatoxins are a particular concern in dairy production because they can be passed into the milk of animals consuming contaminated feed (Masri et al., 1969). Therefore, the Food and Drug Administration stipulated that the concentration of aflatoxins in US should not exceed 20 ppb in feeds and 0.5 ppb in milk.

Molds within the genus Fusarium produce several classes of significant mycotoxins including the fumonisins, thichothecenes and zearalenone (D’Mello et al., 1999). Fumonisins are produced by Fusarium proliferatum and F. verticillioides as well as numerous other related Fusaria. These two species are extremely common on corn plants and cause ear and stalk rot diseases (Payne, 1999). In addition, these fungi are able to grow inside the corn plant without causing disease symptoms (Bacon and Hinton, 1996).

Maintenance of an anaerobic environment in the silo during the fermentation and storage phases and maintenance of aerobic stability of silage during the feedout phase are important in silage preservation (Bolsen et al., 1996). Failure to achieve such conditions may cause lower
recovery of nutrients, and the production of poor quality silage which can reduce DMI and animal performance (Chen et al., 1994). Aerobically unstable corn silage and high moisture corn is defined by heating, mold growth, or mustiness occurring a few cm to several m on the face or surface of the silo during feedout. Oxygen is the ultimate enemy of the ensiling process because most molds and yeasts are aerobic and require oxygen for growth. Thus any management practice that helps exclude oxygen from the silage mass is helpful. Such practices include harvesting at proper moisture concentrations, rapid filling, adequate packing, and covering with plastic. This exclusion of oxygen from the silage promotes rapid fermentation by anaerobic hetero and homofermentative bacteria, thereby reducing the growth of yeasts and molds during the initial stages of fermentation.

**Microbial Inoculants**

Higginbotham et al. (1998) examined the effect of microbial inoculants containing propionibacteria either alone or with *Pediococcus cerevisiae* and *P. cerevisiae* plus *L. plantarum*. They reported that the addition of microbial inoculants containing propionic acid bacteria did not affect the fermentation of corn silages; however, silages treated with propionic acid bacteria tended to heat more slowly and took a slightly longer time to reach their peak temperature. They concluded that the microbial inoculants evaluated did not prevent detrimental changes in quality when corn silage was exposed to air. However, propionic acid-based preservatives have been used to improve the aerobic stability of corn silages because of the antifungal nature of the acid (Britt et al., 1975; Leaver, 1975). Kung et al. (1998) reported substantial improvements (120 – 160 h) in the aerobic stability of corn silage treated with relatively low concentrations (0.1 to 0.2% of fresh forage weight) of several additives that contained buffered propionic acid as their primary active ingredient.
Lactobacillus buchneri recently has been approved by the Food and Drug Administration for use as inoculants in grass, corn, legume, and grain silages. This organism has been shown to dramatically improve aerobic stability of silages by inhibiting the growth of yeasts. The net result is that silages inoculated with *L. buchneri* are typically stable when exposed to air. When applied at the time of ensiling at the rate of $10^6$ cfu per gram of fresh material, *L. buchneri* has increased aerobic stability of high moisture corn, corn silage, alfalfa silage, and small-grain silages relative to untreated controls (Muck, 2001; Taylor and Kung, 2002; Kung et al., 2003; Kleinschmit et al., 2005). Although the precise mechanism has not yet been determined, the beneficial impact of *L. buchneri* appears to be related to the production of acetic acid which inhibits the growth of yeasts (Driehius, et al., 1999). Yeast and mold counts of *L. buchneri* inoculated silages are generally lower at feedout and do not increase as rapidly as in untreated controls exposed to air (Kung and Ranjit, 2001). As a result, the temperatures of silages inoculated with *L. buchneri* tend to remain similar to ambient temperature for several days, even in warm weather (Taylor et al., 2000). Inoculation with *L. buchneri* is the most beneficial under circumstances where problems with aerobic instability are expected. Corn silage, small-grain silages, and high-moisture corn are more susceptible to spoilage once exposed to air than legume silages and therefore the latter often respond more favorably to inoculation with *L. buchneri* (Muck, 1996).

Ranjit and Kung (2000) reported that silage inoculated with a moderate rate of *L. buchneri* ($1 \times 10^5$ cfu/g of forage) enhanced the aerobic stability of the corn silage, but the improvement was small (36 h). However, silage treated with $1 \times 10^6$ cfu/g of *L. buchneri* of fresh forage had (900 h) a very extensive heterolactic fermentation that resulted in a marked enhancement in aerobic stability. Nishino et al. (2004) reported that population of yeasts was lowered to about
$10^3$ cfu/g when *L. buchneri* was inoculated, and the stability of corn silage was greatly improved (48 h). Adesogan et al. (2005) reported that corn silage inoculated with *L. buchneri* had lower yeast counts and enhanced aerobic stability by (60.8 h).

**Ammoniation**

Moderate concentrations of ammonia (0.1 to 0.3%) have increased the concentrations of lactic and acetic acids (Muck and Kung, 1997), decreased proteolysis (Huber et al., 1979; Huber et al., 1980), improved DM recovery (Goering and Waldo, 1980), and improved the aerobic stability of corn silage (Britt and Huber, 1975; Soper and Owen, 1977). Many researchers have suggested that the addition of ammonia to silage improves aerobic stability because of its fungicidal properties (Depasquale and Montville, 1990). Kung et al. (2000) studied the effect of ammonia hydroxide (application rate of 0.30% N of fresh forage (35 g DM/100g) weight) on corn silage. They found that the number of enterobacteria were less than 2.00 log cfu/g after 4 d of ensiling in control silages but remained high (>5 log cfu/g) in ammoniated silages through 6 d of ensiling. The persistence of enterobacteria and subsequent growth of heterofermentative LAB may contribute to higher concentrations of acetic acid in ammoniated silages. The number of yeasts in control silages increased rapidly; however, the number of yeasts in ammoniated silages remained low for 144 h after aeration. Alii et al. (1983) reported that numbers of yeasts decreased immediately in high moisture corn after treatment with ammonia. Britt and Huber (1975) also reported that ammoniation decreased numbers of fungal colonies in corn silage within 30 min of initial treatment.

Ammoniation at moderate concentration (lower than 0.7%) decreased yeast and mold counts in corn silage; however, an undesirable product (4-methylimidazole) is formed under high concentrations of ammonia (Nishie et al., 1969). Greater concentration of ammonia in silages could form a reaction with sugars causing bovine bonkers (pupil dilatation, excessive salivation,
frequent urination and defecation, convulsions and ataxia). Ammoniation is not widespread in use because it is expensive, hazardous and corrosive on machinery and humans.

**Hemorrhagic Bowel Syndrome**

In the last ten years hemorrhagic bowel syndrome (HBS), also known as hemorrhagic jejunal syndrome (HJS), acute hemorrhagic enteritis, clostridial enterotoxaemia, overeating disease, and dead or bloody gut disease, has become a syndrome of great concern due to sudden death of both dairy and beef cattle in the US (Ondarza, 2006). Baker (2002) reported that HBS is responsible for 2% of the deaths of dairy animals in the US, and the disease seems to be more prevalent in cooler months (USDA, 2003).

Hemorrhagic Bowel Syndrome is characterized by sudden death of afflicted animals, often with little or no sign of health problems. Upon autopsy, animals show signs of severe bleeding in the small intestine. The cause of HBS is unknown; however, some evidence suggests that there are multiple causes. Several predisposing conditions may need to combine before the problem occurs (Ondarza, 2006). Analyses of diets, ages of cows, levels of milk production, a full spectrum of blood chemistry and biochemical assays failed to reveal a consistent clinical correlation to HBS (Dennison et al., 2002). Cows may show signs of abdominal pain and may have either constipation or bloody diarrhea. Early postmortem examination of cattle with HBS shows intestinal lesions with hemorrhages and clots that block the flow of ingested feed. Death is the result of the obstructed bowel, blood loss, and the resulting anemia.

Researchers have found a positive relationship between rumen acidosis, which facilitates the passage of more starch to the cow’s intestine, and HBS (Ondarza, 2006). Although many scientists have found *Clostridium perfringens* Type A in cows with HBS, Dennison et al. (2002) reported that it is unclear whether proliferation of *C. perfringens* is part of the primary disease process in cows with HBS or occurs as a secondary response. Evidence against *C. perfringens*
playing the primary etiologic role includes the observations that *C. perfringens* is ubiquitous (Jensen et al., 1989; Songer, 1996). Furthermore, immunization against *Clostridium* spp. does not appear to protect animals from HBS.

*Aspergillus fumigatus* has been proposed as the pathogenic agent associated with mycotic HBS in dairy cattle (Puntenney et al., 2003). This group of scientists has associated HBS with feeding moldy forage or grain due to higher concentrations of *Aspergillus fumigatus* in the blood of cows with HBS, though they did not show that moldy feeds directly cause HBS. Earlier work also suggested that *A. fumigatus* is a fairly common mold in both hay (Shadmi et al., 1974) and silage (Cole et al., 1977). Several studies have demonstrated potential for *Aspergillus* species to infect the ruminant gut at various sites and to cause enteric hemorrhage. Sheridan (1981) reported aspergillosis in the calf abomasum. In 1989, Jensen et al (1989) reported that *A. fumigatus* infected the terminal gastric compartments, particularly the omasum. Dairy producers in Florida have had increasing incidences of HBS in their herds and associated this with feeding of corn hybrids with high SG rankings.

**Variable Manure Syndrome**

Variable Manure Syndrome (VMS) also appears to be increasing in frequency in dairy herds particularly in the Southeastern US but occurs sporadically in other regions of the US (Kelbert, 2004). Variable Manure Syndrome or a drastic swing from normal to loose manure indicates rumen pH instability and subacute or clinical acidosis. Manure variation from day to day means the rumen has changed from being a continuous fermenter to a batch fermenter, which alters the bacterial profile significantly and kills digestive microbes that fuel a healthy digestive process. VMS leads to poor digestion, undigested feed in the manure, and less than optimum feed efficiency. Often VMS is found sporadically in a herd on the same day, without ration changes. The condition is often prevalent after corn is harvested under wet conditions.
Three out of the last four corn harvest seasons (2000, 2001, 2002 and 2003) in Florida have been wet (Kelbert, 2004). During the wet years, silage was typically harvested at below 32% DM and during the dry years silage was usually harvested above 32% DM. During these wet harvest years, if the harvest management or rain conditions resulted in a DM below 32% increased incidence of VMS occurred (Kelbert, 2004). VMS was not seen prior to 1998 when it was common to harvest corn earlier (<30% DM) rather than later to increase the level of sugars in the green chop silage. Since SG hybrids have become more widespread at the same time as the increased incidence of HBS and VMS, some Florida dairymen have believed that these problems are caused by SG corn hybrids.

**Stay-green Corn Hybrids**

Stay-green is the general term given to a plant variant in which senescence is delayed compared with a standard reference genotype. The SG phenotype can arise in one of four fundamentally distinct ways (Thomas and Smart, 1993). The first two classes are functionally SG and may occur after alteration of genes involved in the onset of senescence and the regulation of its rate of progress. However, SG in the remaining two classes is cosmetic, because the plants are green but lack photosynthetic competence. This may be due to a loss in photosynthetic capability that normally accompanies senescence combined with maintenance of leaf chlorophyll, or it may be related to premature death seen in herbarium specimens or frozen foods that retain greenness because they are rapidly killed at harvest (Thomas and Smart, 1993).

The SG ‘trait’ has been reported in corn (Tollenaar and Daynard, 1978; Ma and Dwyer, 1998; Rajcan and Tollenaar, 1999a, 1999b), and most of the current corn hybrids have some degrees of SG characteristic. However there is a limited understanding of the physiological processes underlying the development of this trait in such hybrids. Selection for improved resistance to disease and reduced leaf senescence at high plant densities (Cavalieri and Smith,
has led to the introduction of SG cultivars of corn with an extended period of plant maturation post flowering (Havilah and Kaiser, 1994). Senescence during kernel filling is related to the quantity of light received by the leaves and N availability via remobilization to actively growing kernels of maize (Borras et al., 2003). During senescence, leaves lose their greenness as a result of a decline in chlorophyll concentration, providing a clear visual symptom of leaf senescence. Delayed appearance of visual symptoms of leaf senescence or SG has been associated with the improved performance of more recent corn hybrids in the US (Crosbie, 1982; Tollenaar, 1991; Duvick, 1997).

In sorghum (*Sorghum bicolor* L.), SG was viewed as a consequence of the balance between N-demand by the grain and N-supply during grain filling (Borrell et al., 2001). Borrell et al. (2001) suggested that roots of the SG sorghum maintain greater capacity to extract N from the soil compared with the non-SG hybrids during kernel filling. Rajcan and Tollenaar (1999) also suggested that SG corn hybrids have greater N uptake during grain filling than non-SG hybrids. Ma and Dwyer (1998) found a 20% greater N uptake during grain fill in a SG hybrid than in a non-SG hybrid, but there were no indications of greater N allocation to the kernels of the SG corn.

Green leaf area at physiological maturity has proved to be an excellent indicator of SG, and has been used successfully to select drought-resistant sorghums in the US (Rosenow et al., 1983). The duration of leaf senescence is a function of the timing of the onset of senescence and the timing of physiological maturity.

The progress of leaf senescence during the grain-filling period may vary as a result of water and nitrogen stress (Wolfe et al., 1988; Uhart and Andrade, 1995) and or changes in the source-to-sink ratio, that is, the ratio between assimilate supply and the potential of the grain to

Rajcan and Tollenaar (1999) proposed that leaf senescence in a recent corn hybrid was delayed because of an improvement in the ratio of assimilate supply (i.e., source) to assimilate demand (i.e., sink) during kernel filling. They also found that total N uptake in above ground portions were 10 and 18% greater in the SG hybrid than an older, non-SG hybrid under low and high soil N conditions, respectively. However, Sudebi and Ma (2005) reported that three corn hybrids contrasting in leaf number and stay-greenness grown with a precisely controlled N supply did not differ in N acquisition, partitioning, and remobilization to different plant parts at physiological maturity. The SG hybrid remained green at physiological maturity only when there was an unrestricted N supply, indicating that SG is a trait that is exhibited only under adequate N availability.

During post-anthesis drought, genotypes possessing the SG trait maintain more photosynthetically active leaves than those that do not (Rosenow et al., 1983). Differences in rates of DM accumulation, as well as in radiation-use efficiency, were largest from 3 wk post-silking to physiological maturity and appeared to be associated with more rapid leaf senescence in the old hybrids (Tollenaar, 1991; Tollenaar and Aguilera, 1992). Fakorede and Mock (1980) reported that improved corn hybrids produce more DM because they remain photosynthetically active during mid-to late grain filling.

Corn silage hybrids with the SG characteristic, grown at relatively high plant populations, may show improved disease resistance compared with conventional hybrids. This benefit may,
however be outweighed by lower whole plant DM in SG cultivars than other cultivars as a result of their higher proportion of green leaf (Havilah and Kaiser, 1994).

Wilkinson and Hill (2003) examined the benefits of the SG characteristic on crop yield and DM distribution. They found a lower proportion of ear in SG hybrids than in the conventional (C) cultivars and noted that this may have limited whole-plant yield by providing less ‘sink’ for photosynthate as the crop progressed through the later stages of growth. It is notable that yield of DM was only higher in C cultivars than SG cultivars in the warmest of the four environments, indicating that environmental effects on yield are likely to be greater than SG effects, particularly in marginal areas for the growth of forage corn.

Havilah and Kaiser (1994) reported that the SG characteristic reduced the DM concentration of the corn plant after the crop had reached a milk line score of 2.5 on a scale of 0 (all milk in grain) to 5 (no milk in grain). This 2.5 or half milk line stage is considered to be the optimal maturity stage for harvesting forage corn for silage (Holland et al., 1990; Havilah and Kaiser, 1991; Davies and Wilkinson, 1993; Johnson et al., 1999). However, Roth and Lauer (1997) found a wide range in whole-plant DM concentration (from 280 to 500 g of DM kg⁻¹ fresh weight) and hence maturities at milk line score equivalent to 2.5. The SG characteristic further invalidates the use of the milk line for predicting harvest dates for corn forage destined for ensiling.

In situations of relatively low late-season temperatures, without the occurrence of frosts to kill the leaves, the starch in the endosperm of SG hybrids may become progressively harder with advancing grain maturity while the stover (leaf and stem) remains too wet for ensiling (Wilkinson et al., 1998). This can lead to lower grain digestibility and production of significant amounts of effluent during the ensiling period. Any advantage in crop yield due to the SG
characteristic may be offset by increased loss of water-soluble carbohydrates (WSC) as carbon dioxide during the more extensive fermentation of the wetter crop in the silo (Wilkinson et al., 1998).

There is very little information in the literature on the influence of the SG characteristic on the nutritive value of corn silage and the health and performance of dairy cows. Both of the animal studies in the literature that involved feeding of SG hybrids did not compare such hybrids to conventional hybrids.

The objectives of this study were the following:

- To determine the optimum maturity stage for harvesting SG corn varieties destined for silage production, and to determine if there are differences in the fermentation and aerobic stability of hybrids with contrasting SG rankings.
- To determine the effects of SG ranking, maturity of corn hybrids and simulated rainfall on the health, feed intake and milk production of dairy cows.
CHAPTER 3
EFFECT OF MATURITY AT HARVEST OF CORN HYBRIDS DIFFERING IN STAY-GREEN RANKING ON THE QUALITY OF CORN SILAGE

Introduction

Corn silage has been used across the US as a source of energy and digestible fiber for dairy cattle. Florida dairy producers have been concerned about a possible link between reduced milk yield, digestive upsets and Hemorrhagic Bowel Syndrome in cattle consuming corn silage with high stay-green (SG) rankings. Such hybrids form the bulk of silage hybrids currently sold in the US.

Thomas and Smart (1993) characterized a SG trait (i.e., the phenotypes that exhibit delayed senescence) as having greater water and chlorophyll concentration in the leaves at maturity. Therefore, high SG rankings are genetically correlated with high stalk and leaf moisture concentrations (Bekavac et al., 1998). Four classes of SG have been identified by Thomas and Smart (1993). The first two classes are functionally SG and may occur after alteration of genes involved in the onset of senescence and the regulation of its rate of progress. However, SG in the remaining two classes is cosmetic because the plants are green but lack photosynthetic competence. This may be due to a loss in photosynthetic capability that normally accompanies senescence combined with maintenance of leaf chlorophyll, or it may be related to premature death seen in herbarium specimens or frozen foods that retain greenness because they are rapidly killed at harvest.

Selection for improved resistance to diseases and reduced leaf senescence at high plant densities led to introduction of corn hybrids with high SG rankings. The SG ranking is assigned to corn hybrids to reflect greater retention of green leaf, improved health and greater lodging resistance late in the growing season, typically beyond the black layer stage. The dry-down rates of the ear and stover of such SG hybrids is asynchronous. The ears mature faster than the stalks
and leaves, therefore the leaves remain green and immature while the ear turns brown and the kernels ripen.

Wiersma et al. (1993) and Coors et al. (1997) demonstrated that corn forage harvested at immature stages (soft dent) was lower in quality than that harvested between ½ and ¾ kernel milk line. Such results led to the widely held notion that corn intended for ensiling should be harvested at the ½ kernel milk line stage to optimize nutritive value. Many modern corn hybrids released since the research of Wiersma et al. (1993) have the SG characteristic. This trait maintains the integrity of the plant longer into the fall improving combine-ability. However, the presence of this characteristic implies that the traditional relationship between whole plant silage moisture and kernel milk line may no longer hold because it probably results in silages that have milk lines that are more advanced relative to whole-plant maturity (Bagg, 2001). Therefore, research is needed to determine the optimal maturity at harvest for optimizing the nutritive value of corn hybrids with high SG rankings. The objective of this study was to determine the optimum maturity stage for harvesting corn varieties destined for silage production, and to determine if there are differences in the nutritive value, fermentation and aerobic stability of hybrids with contrasting SG rankings.

**Materials and Methods**

**Plot Trial**

**Planting and establishment.** Two varieties of corn with high (HSG) SG rankings (Pioneer 31Y43 (Pioneer Hi-Bred International, Des Moines, Iowa) and Croplan Genetics 827 (Croplan Genetics, St. Paul, MN) were compared with two varieties with average (ASG) SG rankings (Pioneer 32D99, Croplan Genetics 799). Each of the four varieties was grown on 2 March, 2004 in four replicated 1 x 6 m plots within each of four blocks at the Plant Science Research and Education Center, Citra, FL. The relative maturity of the hybrids was 117 ± 0.8 d.
**Fractionation and ensiling.** Corn plants within a 1 x 2 m area of each plot were harvested at 25 (Maturity 1), 32 (Maturity 2) and 37 (Maturity 3) g DM/100g on 11 and 26 June and 2 July 2004 respectively. A one-row forage harvester and a cutting height of 20 cm were used at each harvest. The harvested forage from each plot was weighed and divided into thirds, one third for botanical fractionation (ear vs. stover), a second third for chemical analysis and the last third for ensiling. The ear and stover fractions and the whole plant sample reserved for chemical analysis were chopped (2 cm) and representatively subsampled (0.2 kg) for DM analysis (105ºC for 24 h). Representative samples (6.5 kg) of the herbage reserved for ensiling were placed in polythene bags within quadruplicate 20-L mini-silos (one silo per plot) and sealed.Weights of the empty and full silos were recorded, and silos were then stored for 107 d at ambient temperature (25ºC) in a covered barn.

**Chemical analysis.** Dried whole plant, stover and ear samples were ground to pass through a 1-mm screen in a Wiley Mill (A. H. Thomas, Philadelphia, PA) and analyzed. Ash concentration was determined in a muffle furnace at 550ºC for 6 h. Starch was determined using the procedure of Holm et al. (1986). The anthrone reaction assay (Ministry of Agriculture Fisheries and Food, 1986) was used to quantify water-soluble carbohydrates (WSC). Concentration of total N was determined by rapid combustion using a macro elemental N analyzer (Hanau, Germany) and used to compute CP concentrations (CP = N x 6.25). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined using an ANKOM Fiber Analyzer (ANKOM Technology, Macedon, NY) and the method of Van Soest et al. (1991). The in vitro apparent DM digestibility (IVDMD) was measured using an adaptation of the Tilley and Terry (1963) procedure for ANKOM Daisy II Incubators (ANKOM Technology, Macedon, NY). The
rumen fluid was obtained from two nonlactating, fistulated cows fed a diet consisting of soybean meal (400 g/day) and bermudagrass hay (*Cynodon dactylon*) in ad libitum amounts.

For the ensiled forage samples, final silo weights were recorded at silo opening and silages from each treatment were subsampled for DM determination (450 g), silage juice extraction (20 g), microbial analysis (400 g), chemical analysis (800 g) and aerobic stability (1 kg wet weight). Samples destined for microbial analyses (yeast and mold counts) were placed in an icebox, and dispatched the same day to the American Bacteriological and Chemical Research Corporation, Gainesville, FL. Aerobic stability was measured by placing thermocouple wires at the center of a bag containing 1 kg of silage within an open-top polystyrene box. The silages were covered with two layers of cheesecloth to prevent drying. The thermocouple wires were connected to data loggers (Campbell Scientific Inc., North Logan, UT) that recorded silage and ambient temperature every 30 min for 5 d. Aerobic stability was denoted by the hours taken for a 2°C rise in silage temperature above ambient temperature (23°C). Silage DM concentration was determined at 60°C in a forced air oven for 48 h. Ash concentration was determined in a muffle furnace at 550°C for 6 h. Silage juice was obtained by blending 20 g of silage with 200 ml of distilled water for 30 s at high speed and filtering the slurry through 2 layers of cheesecloth. The pH was measured at opening and after aerobic stability with a pH meter (Accumet, model HP-71, Fisher Scientific, Pittsburgh, PA). The filtrate was centrifuged at 4°C and 21,500 x g for 20 min and the supernatant was frozen (-20°C) in 20 ml vials for subsequent analysis of volatile fatty acid (VFA) and ammonia-N (NH₃-N). Organic acids were measured using the method of Muck and Dickerson (1998) and a High Performance Liquid Chromatography (HPLC) system (Hitachi, FL 7485, Tokyo, Japan) coupled to a UV detector (Spectroflow 757, ABI Analytical Kratos Division, Ramsey, NJ) set at 210 nm. Ammonia-N was determined using an adaptation
for the Technicon auto analyzer (Technicon, Tarrytown, NY) of the Noel and Hambleton (1976) procedure. Dried silage samples were ground (1-mm screen) and analyzed for WSC, starch, CP, NDF, ADF, and IVDMD using the same procedures used for dried unensiled plant fractions.

**Statistical Analysis**

The experimental design was a split plot in which the whole plot was hybrid company x SG ranking and the subplot was maturity at harvest. The data were analyzed using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC) and the following model:

\[ Y_{ijkl} = \mu + C_i + SG_j + M_k + B_l + E_{ijkl} \]

where

- \( \mu \) = overall mean
- \( C \) = Effect of Company
- \( SG \) = Effect of Stay-green
- \( M \) = Effect of Maturity
- \( B \) = Effect of Block
- \( E \) = Experimental error

Least squares means and SE were reported. Polynomial contrasts were used to test the effect of maturity (25, 32 and 37 g DM/100g) on nutritive value and yield. The coefficients for the contrasts were generated with the IML procedure of SAS. All interactions were examined: stay-green x maturity, stay-green x company, maturity x company, and stay-green x maturity x company. Significance was declared at \( P < 0.05 \), and tendencies at \( P < 0.10 \).

**Results and Discussion**

All statements about nutritional differences in the hybrids from the two companies relate to the performance of the hybrids under the test conditions and may not reflect quality differences.
between other hybrids from these companies, or differences between the tested hybrids under different growth conditions.

**Yield and Chemical Composition of the Unensiled Whole Plant Samples**

High SG hybrids had greater DM yield than ASG hybrids at Maturity 1 (17.8 vs. 14.1 t DM/ha), but this trend was reversed at Maturity 3 (15.6 vs. 20.4 t DM/ha; Table 3-1). Wilkinson and Hill (2003) found similar yields of conventional and SG corn hybrids harvested at 25.8 to 43.5 g DM/100 g and attributed this to earlier flowering in the conventional hybrids, which increased the time available for ear development and grain filling between flowering and harvest.

Whole plant DM, ash, starch and CP concentrations were unaffected by SG ranking. Unlike Croplan Genetics hybrids, Pioneer HSG hybrids had greater DM and starch concentrations and IVDMD, and lower concentrations of ADF and NDF than their ASG hybrids (SG x source interaction, \( P < 0.05 \)). Wilkinson and Hill (2003) reported that whole plant DM concentration was similar between SG and conventional (C) cultivars. However, Sudebi and Ma (2005) found that a leafy hybrid had a greater \( (P < 0.05) \) whole plant DM concentration than a SG hybrid. Sudebi and Ma (2005) also found that SG ranking did not affect whole plant CP concentration at physiological maturity. They reported that SG hybrids do not require more N than the conventional hybrids to remain green at maturity. This contrasts with previous field studies in which SG hybrids had greater total N uptake than conventional hybrids (Ma and Dwyer, 1998; Rajcan and Tollenaar, 1999; Borrell and Hammer, 2000; Borrell et al., 2001).

Neutral and acid detergent fiber concentrations were lower, whereas IVDMD was greater in Croplan Genetics ASG vs. HSG hybrids. However, Pioneer hybrids had contrasting results (SG x source interaction, \( P < 0.05 \)). Nevertheless, IVDMD results for both hybrids reflected their respective ADF and NDF concentrations.
Maturity had a quadratic effect \((P < 0.001)\) on DM yield and IVDMD \((P < 0.05)\), and a linear effect on yield of digestible DM \((P < 0.01)\), though the rate of change of DM yield and yield of digestible DM with maturity depended on hybrid source \((\text{Maturity} \times \text{source interaction}, P < 0.01)\). Whole plant DM and starch concentrations increased linearly \((P < 0.001)\) with maturity, whereas CP, NDF and ADF concentrations decreased linearly \((P < 0.001)\) at rates that largely depended on hybrid source \((\text{Maturity} \times \text{source interaction}, P < 0.07)\). These changes reflect the transition from vegetative to reproductive growth in the plants. Ash concentration changed quadratically with maturity at rates that differed with hybrid source \((\text{Maturity} \times \text{source interaction}, P = 0.05)\). Changes in WSC concentration with maturity depended on hybrid source and SG \((\text{SG} \times \text{maturity} \times \text{source interaction}, P = 0.032)\). Average SG hybrids had lower yield of digestible DM than HSG hybrids at Maturity 1 \((8.2 \text{ vs. } 10.1 \text{ t of digestible DM/ha})\), but greater yields at Maturity 2 \((9.0 \text{ vs. } 8.2 \text{ t of digestible DM/ha})\) and Maturity 3 \((11.9 \text{ vs. } 8.5 \text{ t digestible DM/ha})\) \((\text{SG} \times \text{Maturity interaction}, P < 0.001)\).

**Chemical Composition of the Unensiled Stover Samples**

The stover of ASG hybrids had greater \((P < 0.05)\) DM concentrations (Table 3-2) than HSG hybrids \((258 \text{ vs. } 239 \text{ g/kg})\) though the difference tended to be more pronounced in Croplan Genetics hybrids \((\text{SG} \times \text{source interaction}, P = 0.09)\). The lower DM concentration of HSG hybrids agrees with the statement that SG hybrids typically have more moisture in leaves than conventional hybrids. The results also agree with the work of Sudebi and Ma (2005) who found that a leafy hybrid had greater \((P < 0.05)\) stover DM concentration than a SG hybrid.

Unlike that of Croplan Genetics hybrids, the stover of Pioneer ASG hybrids had less WSC than their HSG hybrids \((\text{SG} \times \text{maturity interaction}, P = 0.011)\). The stover of HSG hybrids from both sources had greater \((P < 0.05)\) CP concentrations than ASG hybrids \((86 \text{ vs. } 74 \text{ g/kg of DM})\), but the difference tended to be more pronounced for Croplan Genetics hybrids than Pioneer
hybrids (SG x maturity interaction, $P = 0.068$). These results may be due to greater proportion of chlorophyll in hybrids with higher SG rankings due to greater green leaf proportion. Sudebi and Ma (2005) also found that a leafy hybrid had lower N concentrations in roots and leaves than SG. The greater total N accumulation by the SG hybrids was possibly due to the fact that they remained green after physiological maturity such that they took up N for a longer period of time than early-senescing hybrids (Sudebi and Ma, 2005; Borrell et al., 2005). Another reason for the greater CP concentration of HSG hybrids is they exhibit greater retention of chloroplast proteins than conventional hybrids (Borrell et al., 2001).

Unlike that of Pioneer hybrids, the stover of Croplan Genetics HSG hybrids tended ($P = 0.08$) to have greater NDF concentration (692 vs. 679 g/kg of DM) and lower ($P = 0.08$) ADF concentration (376 vs. 387 g/kg of DM) than that of ASG hybrids, indicating a tendency for greater hemicellulose concentrations in the stover of HSG hybrids (SG x source interaction, $P < 0.05$). Therefore, the NDF, ADF and IVDMD results obtained on the stover from each hybrid source are consistent with those obtained from the corresponding whole plants. Stover DM increased linearly ($P < 0.05$), and ash concentration tended to increase linearly ($P = 0.06$) with maturity. Concentrations of CP and IVDMD decreased linearly ($P < 0.001$) with maturity, whereas concentrations of WSC, NDF and ADF were unaffected. The stover of Croplan Genetics hybrids had greater ($P < 0.05$) ash concentration (52 vs. 45 g/kg of DM) and lower WSC concentration (153 vs. 120 g/kg of DM) than those of Pioneer hybrids.

**Chemical Composition of the Unensiled Ear Samples**

In agreement with Wilkinson and Hill (2003) and Ettle and Schwarz (2003), ear WSC concentration decreased linearly ($P < 0.001$) with increasing maturity, whereas DM concentration increased linearly ($P < 0.001$).
Unlike Croplan Genetics hybrids, Pioneer HSG hybrids had greater DM and CP concentrations in the ear than their ASG hybrids (SG x source interaction, $P < 0.05$; Table 3-3). High SG hybrids also had greater ($P < 0.01$) ear ash concentration than ASG hybrids (20 vs. 18 g/kg DM) but ear WSC concentrations were similar among hybrids. The results from the Pioneer hybrids support those of Ettle and Schwarz (2003) and Wilkinson and Hill (2003) who noted that SG corn hybrids had greater ear DM concentration than fast dry down and conventional hybrids, respectively. The CP results contrast with others showing similar N allocation (Ma and Dwyer, 1998) or N concentration (Sudebi and Ma, 2005) in the kernels of SG and conventional hybrids.

Chemical Composition of Corn Silage Samples

As reported by Ettle and Schwarz (2003), Croplan Genetics HSG hybrids had lower starch concentrations than ASG hybrids (Table 3-4). However, a reverse trend was detected among Pioneer hybrids (SG x source interaction, $P < 0.001$). Since corn maturation is typically accompanied by increasing starch deposition (Wilkinson and Phipps, 1979), HSG hybrids should have greater starch concentration than ASG hybrids. The contrasting trend for the Croplan Genetics hybrids is partly attributable to fiber concentration differences between hybrids. Neutral and acid detergent fiber concentrations tended ($P = 0.01$) to be greater in Croplan Genetics HSG vs. ASG hybrids, but an opposite trend was evident among Pioneer hybrids (SG x source interaction, $P < 0.001$). Consequently, as in the unensiled whole plant and unensiled stover, the IVDMD of ensiled HSG hybrids from Croplan Genetics tended to be lower than those of their ASG hybrids, but this trend was not detected among Pioneer hybrids (SG x source interaction, $P = 0.07$). Ettle and Schwarz (2003) noted that their dry down variety had greater ($P < 0.05$) IVDMD than their SG variety. The lower IVDMD values found in Croplan Genetics HSG hybrids are probably attributable to their greater NDF and ADF concentrations. The faster
rate of ear maturation in such HSG hybrids could have also resulted in more mature, less
digestible kernels. Lower starch and IVDMD in such HSG vs. ASG silages indicates that
nutritive value was lower in the former. This contradicts finding of similar digestibility between
HSG and conventional hybrids by Australian researchers (Havilah and Kaiser, 1994), possibly
due to differences in the prevailing temperature and humidity during the growth of the hybrids.
Kernel processing may be beneficial for improving energy availability from the Croplan
Genetics HSG hybrids.

Water-soluble carbohydrate concentration was greater \((P < 0.05)\) in HSG (7.1 vs. 6.4 g/kg
of DM) than ASG hybrids, and CP concentration tended to be greater \((P = 0.08)\) in HSG than
ASG hybrids (96 vs. 90 g/kg of DM). The latter disagrees with Ettle and Schwarz (2003), who
reported that a fast dry down variety had greater CP concentration than a SG variety. The higher
CP concentration of the HSG hybrids agrees with observations of higher leaf N concentrations in
SG sorghum hybrids (Borrell and Hammer, 2000). This is probably related to greater retention
of chloroplast proteins and greater capacity for N uptake in SG hybrids (Borrell et al., 2001).

Dry matter and starch concentrations increased linearly \((P < 0.001)\) with increasing
maturity, while WSC, CP, NDF and ADF concentrations decreased linearly \((P < 0.001)\), but
maturity did not affect IVDMD. Others have also noted that IVDMD and in situ degradability of
corn silage remained unchanged within the range of maturities examined in this study, and
attributed this to transition from vegetative to reproductive growth (Bal et al., 2000).

**Fermentation Indices of Corn Silage Samples**

The pH (Table 3-5) of all silages was in the range of 3.71 to 3.81, which reflects good
fermentation. Pioneer HSG hybrids had slightly less acidic pH than their ASG hybrids (3.80 vs.
3.73) but Croplan Genetics HSG hybrids had more acidic pH their ASG hybrids (3.73 vs. 3.77;
SG x source interaction, \(P = 0.015\)). Nevertheless, the differences were practically insignificant.
The concentrations of NH$_3$-N and most organic acids were similar in HSG and ASG hybrids and butyric acid was not detected in the silages. Ettle and Schwarz (2003) reported that dry down and SG varieties had similar pH though the dry down variety had greater ($P < 0.01$) lactic acid concentration but lower ($P < 0.01$) acetic acid concentration than the SG variety.

Silage pH increased linearly ($P < 0.01$) and ammonia-N concentration changed quadratically ($P < 0.05$) with maturity. The pH result agrees with Ettle and Schwarz (2003) and was partly due to linear ($P < 0.001$) decreases in concentrations of lactic and acetic acids with maturity. Changes in NH$_3$N and propionic acid concentration with maturity depended on hybrid source and SG (SG x maturity x source interaction, $P < 0.05$). Mold counts were not sufficient ($1 \times 10^5$ log cfu/g) to cause spoilage but yeast counts were sufficient to cause rapid deterioration of the silage. Yeast and mold counts changed with maturity in a manner that depended on hybrid source and SG (SG x maturity x source interaction, $P < 0.01$). Nevertheless, aerobic stability was not affected by maturity because there were sufficient numbers of yeasts to cause rapid spoilage at all maturities.

**Conclusions**

Effects of SG ranking on the nutritive value of the hybrids were affected by hybrid source. In contrast to Croplan Genetics hybrids, Pioneer HSG hybrids had greater ear and whole-plant DM concentrations than their ASG hybrids; though stover DM concentration was lower in HSG vs. ASG hybrids from both sources. Unlike Pioneer hybrids, Croplan Genetics HSG hybrids had greater NDF and ADF concentrations and lower IVDMD in the unensiled whole-plant, the stover, and the silage than the ASG hybrids, indicating that nutritive value was lower in Croplan Genetics HSG vs. ASG hybrids. However, silage fermentation and aerobic stability were largely unaffected by SG ranking of hybrids from both sources. This work therefore suggests that in some corn hybrids, high SG rankings may be associated with a different moisture distribution.
and lower nutritive value relative to conventional hybrids. However, effects of SG ranking were not consistent across the two hybrid sources examined. There was no evidence that the fermentation and aerobic stability of corn silage was adversely affected by the SG ranking of corn hybrids.

As the hybrids matured, DM yield, yield of digestible DM, starch, DM concentration, and yeast counts increased, fiber components, CP and WSC decreased, whereas IVDMD was unchanged. However, these maturity-related changes differed with hybrid source and SG ranking. It is concluded that the best combination of DM yield, nutritive value, fermentation quality and yeast counts were obtained when the corn hybrids were harvested at 32 g DM/100g.
Table 3-1. Yield and chemical composition of unensiled whole plants from corn hybrids differing in stay-green (SG) ranking, maturity and source.

<table>
<thead>
<tr>
<th>Maturity¹</th>
<th>High SG</th>
<th>Average SG</th>
<th>SE</th>
<th>SG</th>
<th>Maturity Source²</th>
<th>SG*M</th>
<th>SG*C</th>
<th>m*C</th>
<th>SG<em>m</em>c</th>
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ns = not significant, P > 0.10; L = Linear effect, P < 0.05; Q = Quadratic effect, P < 0.05

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL)Genetics, St. Paul, MN
³ WSC = Water-soluble carbohydrate
<table>
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<th>Maturity¹</th>
<th>High SG</th>
<th>Average SG</th>
<th>SE</th>
<th>SG Maturity (m)</th>
<th>Source²</th>
<th>SG*m</th>
<th>SG*c</th>
<th>m*c</th>
<th>SG<em>m</em>c</th>
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ns = not significant, P > 0.10; L = Linear effect, P < 0.05; Q = Quadratic effect, P < 0.05

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN
³ WSC = Water-soluble carbohydrate
Table 3-2. Chemical composition of unensiled stovers from corn hybrids differing in stay-green (SG) ranking, maturity and source.

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<th>Average SG</th>
<th>SE</th>
<th>SG</th>
<th>Maturity (m)</th>
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<th>SG*m</th>
<th>SG*c</th>
<th>m*c</th>
<th>SG<em>m</em>c</th>
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ns = not significant, P > 0.10; L = Linear effect, P < 0.05; Q = Quadratic effect, P < 0.05

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL)Genetics, St. Paul, MN
³ WSC = Water-soluble carbohydrate
Table 3-2. Continued

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<th>Maturity¹</th>
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<th>Maturity (m)</th>
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<th>m*c</th>
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ns = not significant, $P > 0.10$; L = Linear effect, $P < 0.05$; Q = Quadratic effect, $P < 0.05$

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.

² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN
### Table 3-3. Chemical composition of unensiled ears from corn hybrids differing in stay-green (SG) ranking, maturity and source.

<table>
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<th>Maturity¹</th>
<th>High SG</th>
<th>Average SG</th>
<th>SE</th>
<th>P value</th>
<th>SG</th>
<th>Maturity (m)</th>
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<th>SG*c</th>
<th>m*c</th>
<th>SG<em>m</em>c</th>
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<tr>
<td>DM, g/kg</td>
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<td>318</td>
<td>230</td>
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<td>306</td>
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<td>&lt;.001, L</td>
<td>ns</td>
<td>ns</td>
<td>0.012</td>
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<td></td>
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</tr>
<tr>
<td>WSC³, g/kg DM</td>
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<td>99</td>
<td>108</td>
<td>116</td>
<td>111</td>
<td>11.4</td>
<td>ns</td>
<td>&lt;.001, L</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>76</td>
<td>73</td>
<td>52</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>CP, g/kg DM</td>
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<td>64</td>
<td>92</td>
<td>79</td>
<td>7.3</td>
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<td>ns</td>
<td>0.007</td>
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<td>0.017</td>
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<tr>
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<td>96</td>
<td>80</td>
<td>85</td>
<td>93</td>
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<td>90</td>
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</table>

ns = not significant, P > 0.10; L = Linear effect, P < 0.05; Q = Quadratic effect, P < 0.05

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.

² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN

³ WSC = Water-soluble carbohydrate
Table 3-4. Chemical composition of corn silages made from hybrids differing in stay-green (SG) ranking, maturity and source.

<table>
<thead>
<tr>
<th>Maturity¹</th>
<th>High SG</th>
<th>Average SG</th>
<th>SE</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maturity</td>
<td>Source²</td>
<td>SG*</td>
<td>SG*c</td>
</tr>
<tr>
<td></td>
<td>PN31Y43 CPL827</td>
<td>PN32D99 CPL799</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM at</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>harvest,</td>
<td>1 267 220</td>
<td>258 265 17.8</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td>g/kg</td>
<td>2 306 322</td>
<td>290 352</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td></td>
<td>3 384 348</td>
<td>383 374</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td>Starch,</td>
<td>1 169 143</td>
<td>153 216 15.5</td>
<td>0.001</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td>g/kg DM</td>
<td>2 283 244</td>
<td>264 355</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td></td>
<td>3 320 308</td>
<td>297 373</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td>WSC³,</td>
<td>1 9.7 11.7</td>
<td>10.2 9.9 0.6</td>
<td>0.019</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td>g/kg DM</td>
<td>2 5.5 4.2</td>
<td>5.0 4.4</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
<tr>
<td></td>
<td>3 5.6 5.7</td>
<td>3.9 5.0</td>
<td>ns</td>
<td>&lt;.001, L</td>
</tr>
</tbody>
</table>

ns = not significant, P > 0.10; L = Linear effect, P < 0.05; Q = Quadratic effect, P < 0.05

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL)Genetics, St. Paul, MN
³ WSC = Water-soluble carbohydrate
Table 3-4.  Continued

| Maturity¹ | High SG | Average SG | SE | P value | SG | Maturity (m) | Source² (c) | SG*m | SG*c | m*c | SG*m*c |
|-----------|---------|------------|----|---------|----|--------------|-------------|-------|-------|------|--------|-------|
|           | PN31Y43| PN32D99    |    |         | 0.086 | <.001, L     | ns          | ns    | ns    | ns   | ns     | ns    |
|           | CPL827  | CPL799     |    |         | 0.068 | <.001, L     | 0.034       | ns    | <.001 | ns   | ns     | ns    |
| CP,       |         |            |    |         | 0.082 | <.001, L     | 0.002       | ns    | <.001 | ns   | ns     | ns    |
| g/kg DM   | 1       | 111        | 104| 100     | 98   | 5.6          |             |       |       |      |        |       |
|           | 2       | 96         | 90 | 88      | 89   |              |             |       |       |      |        |       |
|           | 3       | 88         | 84 | 81      | 82   |              |             |       |       |      |        |       |
| NDF,      |         |            |    |         | 0.070 | ns           | ns          | ns    | 0.07  | ns   | ns     |       |
| g/kg DM   | 1       | 509        | 536| 544     | 474  | 14.8         |             |       |       |      |        |       |
|           | 2       | 420        | 446| 449     | 382  |              |             |       |       |      |        |       |
|           | 3       | 424        | 450| 450     | 370  |              |             |       |       |      |        |       |
| ADF,      |         |            |    |         |       |              |             |       |       |      |        |       |
| g/kg DM   | 1       | 292        | 297| 318     | 257  | 8.5          |             |       |       |      |        |       |
|           | 2       | 219        | 246| 264     | 196  |              |             |       |       |      |        |       |
|           | 3       | 226        | 252| 244     | 187  |              |             |       |       |      |        |       |
| IVDMD,    |         |            |    |         |       |              |             |       |       |      |        |       |
| g/kg DM   | 1       | 610        | 587| 660     | 627  | 22.9         |             |       |       |      |        |       |
|           | 2       | 640        | 610| 617     | 676  |              |             |       |       |      |        |       |
|           | 3       | 631        | 590| 605     | 654  |              |             |       |       |      |        |       |

ns = not significant, $P > 0.10$; L = Linear effect, $P < 0.05$; Q = Quadratic effect, $P < 0.05$

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN
Table 3-5. Fermentation indices of corn silages made from hybrids differing in stay-green (SG) ranking, maturity and source.

<table>
<thead>
<tr>
<th>Maturity¹</th>
<th>High SG</th>
<th>Average SG</th>
<th>SE</th>
<th>SG</th>
<th>Maturity (m)</th>
<th>Source²</th>
<th>SG*m</th>
<th>SG*c</th>
<th>m*c</th>
<th>SG<em>m</em>c</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>PN31Y43</td>
<td>PN32D99</td>
<td></td>
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<tr>
<td></td>
<td>CPL827</td>
<td>CPL799</td>
<td></td>
<td></td>
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<td></td>
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<td>3.8</td>
<td>3.7</td>
<td>3.7</td>
<td>3.7</td>
<td>0.03</td>
<td>0.09</td>
<td>0.003,L</td>
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<td>ns</td>
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<td>2</td>
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<td>3.8</td>
<td>3.7</td>
<td>3.7</td>
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<td>3.7</td>
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<td>NH₃-N, g/kg</td>
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<td>118</td>
<td>137</td>
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<td>0.02, Q</td>
<td>0.114</td>
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<td>131</td>
<td>109</td>
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<tr>
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<td>Propionic acid, g/kg DM</td>
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<td>7.4</td>
<td>5.7</td>
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<td>3.1</td>
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</table>

ns = not significant, $P > 0.10$; L = Linear effect, $P < 0.05$; Q = Quadratic effect, $P < 0.05$

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.

² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN
Table 3-5. Continued

<table>
<thead>
<tr>
<th>Maturity¹</th>
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<th>Average SG</th>
<th>SE</th>
<th>SG</th>
<th>Maturity ²</th>
<th>Source²</th>
<th>SG*m</th>
<th>SG*c</th>
<th>m*c</th>
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<td>ns</td>
<td>ns</td>
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<td>&lt;.001</td>
<td>0.001, L</td>
<td>0.105</td>
<td>0.03</td>
<td>ns</td>
<td>0.03</td>
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<tr>
<td>Yeasts,</td>
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<td>7.18</td>
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<td>25.0</td>
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</table>

ns = not significant, $P > 0.10$; L = Linear effect, $P < 0.05$; Q = Quadratic effect, $P < 0.05$

¹ Maturity 1, 2 and 3 = 25, 32 and 37 g DM/100g at harvest, respectively.
² Source = Pioneer (PN) Hi-Bred International, Des Moines, Iowa and Croplan (CPL) Genetics, St. Paul, MN.
CHAPTER 4
EFFECT OF STAY-GREEN RANKING, MATURITY AND MOISTURE CONCENTRATION
OF CORN SILAGE ON THE HEALTH AND PRODUCTIVITY OF LACTATING DAIRY
COWS

Introduction

Silage producers in Georgia and Florida have been concerned that ensiling corn hybrids with high stay-green (SG) rankings has led to increased incidences of digestive upsets, Variable Manure Syndrome and Hemorrhagic Bowel Syndrome in their cattle in recent years. These problems may be partly due to excessive moisture levels in corn plants harvested at previously recommended maturity stages (⅓ to ⅔ milk line) for optimizing corn yield, nutritive value and dairy cow performance (Bal et al., 1997; Moss et al., 2001).

The SG characteristic typically occurs in variants with delayed leaf senescence due to partial or complete inhibition of deconstruction of the photosynthetic apparatus during leaf senescence. Although the SG phenotype is superficially similar in all crop species and genotypes, the genetic and physiological basis is diverse. Sorghum genotypes with the SG trait continue to fill their grain normally under drought (Rosenow and Clark, 1981) and exhibit increased resistance to charcoal rot (Rosenow, 1984) and lodging (Henzell et al., 1984; Woodfin et al., 1988). Corn silage hybrids with the SG characteristic, grown at relatively high plant populations, may show improved disease resistance compared with conventional hybrids. This benefit may, however, be outweighed by lower whole plant DM in SG cultivars than in conventional cultivars as a result of their higher proportion of green leaf (Havilah and Kaiser, 1994).

The SG trait is beneficial for grain growers because it confers lodging and disease resistance on the plant thus facilitating combining. However, this trait presents problems for silage producers because it causes asynchronous maturity and dry down rates in the ear and the stover. The
presence of the characteristic implies that the traditional relationship between whole plant silage moisture concentration and kernel milk line may no longer be valid, and this may be the reason why farmers are observing increased seepage from silo when using kernel milk line to predict when to harvest SG corn destined for silage (Lauer, 1998). The SG characteristic hinders prediction of corn harvest dates with the kernel milk line because kernels get very mature while whole plant DM remains under 305 g/kg of DM (Thomas, 2001).

Harvesting forages when they are too wet or too dry makes the silage susceptible to effluent losses and respiration losses, respectively (Barnett, 1954). Crops ensiled with excess moisture are often poorly fermented due to proliferation of butyric acid-producing clostridia. Delaying harvests of SG hybrids to allow the stover to dry can predispose to disease infestation. It is also difficult to ensile crops with excessive DM concentrations because they are difficult to consolidate adequately in the silo, and the residual oxygen in the silo hinders the fermentation. There is very little information in the literature on how the SG characteristic affects the performance of cattle and whether rainfall at harvest or ensiling increases problems associated with SG hybrids. The aim of this study was to determine the effects of corn hybrid SG ranking, maturity and water addition at ensiling on health, feed intake and milk production of dairy cows.

**Materials and Methods**

Two experiments were carried out at the Dairy Research Unit of the University of Florida from October to November 2005 to evaluate how the SG ranking of corn hybrids affects the performance of dairy cows. In the first experiment, 30 lactating Holstein cows in mid-lactation (92 ± 18 days in milk) were allocated randomly to five dietary treatments for two, 28-d periods. Each period consisted of 14 d for adaptation to a new diet and 14 d for sample collection. Near isogenic corn hybrids with high SG (Croplan Genetics 691) and low SG (Croplan Genetics 737) ranking were grown side by side on a 25-acre field at the Dairy Research Unit, University of Florida. Both
varieties were planted on 6 April, 2005, harvested on 12 July, 2005 at 26 g DM/100g (Maturity 1) and packed into 32-ton, 2.4-m wide Ag-Bags with a Versa Bagger (model ID 1012; Versa Corp., Astoria, OR). A further treatment involved adding 15 l of water per ton of silage to the high SG hybrid during packing with a hose pipe to simulate rainfall. The quantity of water added was the maximum amount possible that allowed normal operation of the bagger. Both hybrids also were harvested on 19 July, 2005 at 35 g DM/100g (Maturity 2) and packed into Ag-Bags. The forages were ensiled for 84 d (Maturity 1) and 77 d (Maturity 2) before the bags were opened.

**Diets**

For both experiments, the TMR contained corn silage, alfalfa hay and concentrate mixed at 35, 10 and 55% of dietary DM respectively (Table 4.1). The dietary treatments evaluated were the following: 1) Low stay-green hybrid (LSG) harvested at 26 g DM/100g, 2) High stay-green hybrid (HSG) harvested at 26 g DM/100g, 3) High stay-green hybrid harvested at 35 g DM/100g, 4) Low stay-green hybrid harvested at 35 g DM/100g, 5) High stay-green hybrid (HSG wet) harvested at 26 g DM/100g and irrigated. Cows were fed individually twice daily (at 0700 and 1330 h), using Calan gates (American Calan Inc., Northwood, NH). Feed refusals were collected daily at 0600 h. Cows were trained to use Calan gates for 10 d before the beginning of the trial. Diets were mixed prior to feeding using 250-kg Calan Data Rangers (American Calan Inc., Northwood, NH).

**Sample Collection and Analysis**

In Experiment 1, cows were balanced for parity, milk production and days in milk (DIM) and assigned to each treatment at the beginning of Period 1. At the end of Period 1, cows were randomly assigned to another treatment such that no cow was on the same treatment as it was in Period 1 and no treatment in Period 2 had more than 2 cows from the same treatment in Period 1. Cows were milked thrice daily at 0200, 1000 and 1800 h and milk production (MP) was measured for the last 14 d of each period. Milk samples were collected from 2 consecutive milkings on 2 d
during each week in the last 14 d of each period, preserved with potassium dichromate and stored at 4°C. Milk samples were analyzed by Southeast Milk lab (Belleview, FL) for concentration of fat, true protein and SCC using a Bentley 2000 Near Infrared Reflectance Spectrophotometer (Bentley Instruments Inc., Chaska, MN). Feed efficiency was calculated as kg of milk/kg of DMI. Body weight was measured for 3 consecutive days after the 1000 h milking at the beginning and end of each period. Rectal temperature and the number of ruminal contractions in 2 min period were measured at 1900 h on the last 5 d of each period. Manure was scored using a 1 to 4 scale, where 1 was dry manure, 2 was normal manure, 3 was loose manure and 4 was diarrhea. Blood samples (10 ml) were taken using vacutainers (BD Vacutainer. Franklin Lakes, NJ) containing sodium heparin by caudal arteriovenipuncture on the last day of each period. Samples were centrifuged at 2500 x g for 20 min and the plasma was frozen at -20°C. Concentration of plasma glucose (Glc) was determined using a Technicon Autoanalyzer II (Bran-Luebbe, Elinsford, NY) and a method modified from Gochman and Schmidt (1972). Blood urea nitrogen was determined using an autoanalyzer method (Technicon Industrial systems Autoanalyzer II; Industrial method # 339-01; Tarrytown, NY), which is a modification of the carbamido-diacetyl reaction, described by Coulombe and Favreau (1963). Plasma concentration of BHBA was determined using the procedure described by Williamson et al. (1962). Chromic oxide (Cr₂O₃) was used as an external marker for determination of apparent digestibility. Chromic oxide powder (Fisher Scientific, Fairlawn, NJ) was weighed into gelatin capsules (Jorgensen Lab. Loveland, CO) and dosed twice daily with a balling gun (10 g/dose at 0700 and 1900 h) for 10 consecutive d in each experimental period. Fecal samples (approximately 150 g) were collected during the last 5 d of each period at the time of dosing. Feces were dried to constant weight at 60°C in a convection oven, ground to pass through a 1-mm screen in a Wiley mill and a composite sample was made from all 10 fecal
samples per cow per period. Chromium concentration in feces was determined using a Perkin Elmer 5000 (Wellesley, MA) Atomic Absorption Spectrometer, according to the procedure described by Williams et al. (1962). Apparent digestibility of DM, CP, ADF, and NDF were calculated by the marker ratio technique (Schneider and Flatt, 1975).

Two representative samples of the concentrate, each forage and the TMR were collected during each week of each collection period and composited, sub-sampled and analyzed for CP, NDF, ADF, water-soluble carbohydrates (WSC) and starch. Concentration of N was determined by rapid combustion using Macro elemental N analyzer (Elementar, Hanau, Germany). The NDF and ADF concentrations were determined using an ANKOM Fiber Analyzer (ANKOM Technology, Macedon, NY). The anthrone reaction assay (Ministry of Agriculture, Fisheries and Food, 1986) was used to quantify WSC. Each corn silage also was analyzed for aerobic stability by placing thermocouple wires at the center of a bag containing 1 kg of silage, within an open-top polystyrene box. The silages were covered with 2 layers of cheesecloth to prevent drying. The thermocouple wires were connected to data loggers (Campbell Scientific Inc., North Logan, UT) that recorded the temperature every 30 min for 10 d. Aerobic stability was denoted by the time taken (h) for a 2°C rise in silage temperature above ambient temperature (23°C).

In Experiment 2, 5 ruminally-fistulated lactating cows were used to evaluate the effect of the dietary treatments on ruminal pH, VFA concentration and ammonia-N concentration, during 3 consecutive 15-d periods. Each period consisted of 14 d of adaptation and 1 d of ruminal fluid collection. Ruminal fluid was collected (200 ml) by aspiration and filtered through two layers of cheesecloth at 0, 2, 4, 6, 8, 10 and 12 h after feeding on the last day of each period. The pH was measured within 20 min collection using a pH meter (Accumet, model HP-71, Fisher Scientific, Pittsburg, PA). The ruminal fluid was acidified with 3 ml/sample of H₂SO₄ (50% v/v). Samples
were centrifuged at 12,000 x g for 20 min, after which the supernatant was collected and frozen (-20°C) in 20-ml vials. Volatile fatty acids were measured using the method of Muck and Dickerson (1988) and a High Performance Liquid Chromatograph (Hitachi®, FL 7485, Tokyo, Japan) coupled to a UV Detector (Spectroflow 757, ABI Analytical Kratos Division, Ramsey, NJ) set at 210 nm. The column used was a Bio-Rad Aminex HPX-87H (Bio-Rad Laboratories, Hercules, CA 9454) column with 0.015M sulfuric acid mobile phase and a flow rate of 0.7 ml/min at 45°C. Ammonia N was determined with a Technicon Auto analyzer (Technicon, Tarrytown, NY, USA) and an adaptation of the Noel and Hambleton (1976) procedure.

**Statistical Analysis**

Both experiments involved cross-over designs and the data were analyzed with the Proc Mixed Procedure of SAS (2002). The model used for analyzing the results from Experiment 1 was:

\[ Y_{ijk} = \mu + T_i + P_j + C_k + R_l + E_{ijkl} \]

where

- \( \mu \): general mean
- \( T_i \): treatment effect (fixed effect)
- \( P_j \): period effect (fixed)
- \( C_k \): cow effect (random effect)
- \( R_l \): residual effect
- \( E_{ijkl} \): experimental error

The model used for analyzing rumen VFA and ammonia-N data in Experiment 2 was

\[ Y_{ijk} = \mu + T_i + P_j + H_k + C_l + E_{ijkl} \]

where

- \( \mu \): general mean
The covariance structure used was AR (1), and a slice statement was used to detect differences among treatments at each incubation time. Significance was declared at $P < 0.05$ and tendencies at $P < 0.15$.

Results and Discussion

Chemical Composition of Corn Silage

The ingredient and chemical composition of the TMR is shown in Table 4-1. The silages had similar DM concentration at silo opening (Table 4-2), though LSG silages had numerically higher values than HSG silages. Starch concentration was greater for HSG than LSG at Maturity 1 but lower at Maturity 2. Yeast and mold counts were greater and aerobic stability was lower in the HSG silage vs. the LSG silage at Maturity 1, but not at Maturity 2. Adding moisture to the HSG hybrid increased yeast and mold counts and decreased CP, NDF and ADF concentrations. These results suggest that higher SG ranking was associated with more yeast and mold growth and spoilage when corn was harvested at 26 g DM/100g, or when water addition increased the moisture concentration of corn harvested at 26 g DM/100g.
Voluntary Intake

Dry matter intake was similar across diets (Table 4-3) but intake of starch tended ($P = 0.09$) to be lower for cows fed the HSG diet. Adding moisture to the Maturity 1 HSG hybrid resulted in increased ($P = 0.05$) starch intake (5.8 vs. 6.7 kg/d) and a tendency for increased CP intake ($P = 0.014$). Intakes of CP, NDF and ADF were lower ($P < 0.05$) in cows fed the HSG diet than those fed the LSG diet, but these differences tended to be more pronounced in the Maturity 1 silage than the Maturity 2 silage (SG x maturity interaction, $P < 0.01$). Ettle and Schwarz (2003) found that corn silage variety had no effect on feed intake, but daily intake of crude fiber was considerably less (2.7 kg per cow) for a variety with rapid kernel dry down (DD) compared to a SG variety (3.0 kg per cow), possibly due to a lower concentration of fiber in the DD variety.

Intakes of DM (DMI) and starch were not affected by maturity, while intake of NDF and ADF decreased ($P < 0.05$) with maturity. Phipps et al. (2000) reported that DMI of dairy cows was lower when they consumed corn silage harvested at 39% DM compared to 26 or 29% DM. Forouzmand et al. (2005) reported that intakes of DM, CP, NDF and ADF were lower when silage had 37.7% DM (Black layer stage; BL) compared to 26.8% DM (½ milk line; ML) or 30.5% DM (⅓ ML). However, Ettle and Schwarz (2003) reported that total DMI and DMI of corn silage harvested at 30 to 32% DM (16.5 and 10.5 kg of DM per cow, respectively) were lower ($P < 0.05$) than the corresponding intakes in corn silage harvested at 38 to 42% DM (17.8 and 11.8 kg of DM per cow, respectively). Bal et al. (1997) found no differences in DMI in corn silages with DM at harvest ranging from 30.1 to 42%. These discrepancies in maturity effects on DMI probably reflect varietal differences in the experimental silages particularly differences in the concentration and digestibility of NDF.

Cows fed LSG hybrids had greater ($P < 0.01$) DM, NDF and CP digestibilities than those fed HSG hybrids, and the difference in NDF digestibility was more pronounced at Maturity 1
(Maturity x SG interaction, $P=0.03$). Starch digestibility was unaffected by SG ranking. Ettle and Schwarz (2003) reported that their DD variety had greater ($P<0.05$) digestibility of OMD than a SG variety. The poorer DM digestibilities of the HSG hybrids were largely due to lower digestibility of NDF and CP in HSG hybrids.

Apparent DM and CP digestibilities were not affected by maturity. Bal et al. (1997) reported that DMD was similar for cows fed corn silage harvested at 30.1, 32.4 and 35.1% DM. Ettle and Schwarz (2003) also reported that stage of maturity (30 to 32% DM and 38 to 42% DM) did not affect OM digestibility. Starch digestibility decreased ($P<0.05$) with maturity and tended to be greater in HSG vs. LSG at Maturity 1 though not at Maturity 2 (SG x maturity interaction, $P=0.12$). Bal et al. (1997) also reported a decline in starch digestibility with maturity. The decline in starch digestibility could be related to lower efficiency of postruminal starch digestion or more whole kernel passage from the rumen of cows fed the more mature silage (Harrison et al., 1996). Adding moisture to the Maturity 1 HSG hybrid increased ($P<0.05$) CP digestibility (62.3 vs. 65.2%), possibly due to provision of adequate moisture for microbial digestion.

**Milk Production and Composition**

Milk production and the concentration of milk constituents were largely unaffected by SG ranking. There was a tendency ($P=0.12$) for greater milk production in cows fed Maturity 1 vs. Maturity 2 diets (Table 4-4). Ettle and Schwarz (2003) reported similar milk yields for DD and SG varieties. Phipps et al. (2000) also reported that cows fed corn silage harvested at 29 to 30% DM had greater milk yield than cows fed corn silage harvested at 39% DM. Bal et al. (1997) noted greater ($P<0.07$) milk yield when cows were fed corn silage harvested at 35% DM rather than 30% DM (33.4 vs. 32.4 kg/d). The latter study examined a narrower maturity range than that explored in this study or those of Phipps et al. 2000, possibly due to varietal differences in NDF digestibility.
Cows fed HSG hybrids had lower milk fat concentration (3.5%) than those fed LSG hybrids (3.8%) when the hybrids were harvested at Maturity 1, but the reverse occurred in hybrids harvested at Maturity 2 (SG x maturity interaction, \( P = 0.04 \)). There was a tendency (\( P = 0.08 \)) for milk fat yield to decrease with maturity. Johnson et al. (2002) reported that milk fat yield was lower (\( P < 0.02 \)) in corn harvested at 38.2% DM compared to that harvested at 27.1 and 33.3% DM, and milk fat concentration was lower (\( P < 0.04 \)) for cows fed corn silage of 38.2% DM compared to those fed silage at 27.1% DM. A similar decline in milk fat concentration with increasing maturity was reported also by Phipps et al. (2000) and Forouzmand et al. (2005). In contrast, Bal et al. (1997) reported that milk fat concentration and milk fat production were not affected by maturity. The maturity-related decreases in milk fat concentration and yield in this study are not attributable to differences in fiber concentration of the hybrids at the two maturities, since ADF and NDF concentrations decreased with maturity.

Milk protein and milk protein yield were not affected by maturity. Johnson et al. (1999) also found that milk protein concentration was not affected by maturity. However, Bal et al. (1997) reported that milk protein production was greater (\( P < 0.05 \)) for cows fed corn silage harvested at 35.1% DM than that harvested at 30.1% DM (ED), 32.4% DM (¼ ML) or 42% DM (BL stage). They suggested that this was due to the higher starch concentration and digestibility of corn silage harvested at 35.1% DM.

Efficiency of feed conversion into milk tended (\( P = 0.14 \)) to improve with corn silage maturity. This agrees with Forouzmand et al. (2005) who reported that cows fed corn silage harvested at 37.7% DM were more efficient (\( P < 0.05 \)) than those cows fed corn silage harvested at 26.8 or 30.5% DM. Adding moisture to the HSG hybrid did not affect milk production, milk constituent yield or concentration or feed efficiency.
Body Weight and Plasma Metabolites

Mean BW was unaffected by SG ranking or maturity, but BW gain increased with maturity of corn plants and it was lower in cows fed LSG vs. HSG diets (Table 4-5). The latter was probably because cows fed HSG diets partitioned more nutrients to BW gain. Ettle and Schwarz (2003) also reported that BW was not affected by variety or maturity. Concentrations of plasma glucose were not affected by SG ranking, but tended to increase ($P = 0.09$) with maturity. This increase was in part due to the greater concentration of starch in the more mature hybrid. Plasma BUN and BHBA concentrations were not affected by SG ranking or maturity.

Rumen Parameters and Health Indices

Rectal temperature was greater in cows fed HSG ($P < 0.05$) vs. LSG (38.1 vs. 38.0 °C), but the values were within the normal physiological range. Rumenal contraction rate and manure score were not affected by SG ranking but they increased with maturity (Table 4-6). Ruminal pH tended to slightly increase with maturity ($P = 0.09$) reflecting the increased ruminal contraction rate with maturity. Ruminal pH decreased progressively ($P < 0.001$) after feeding (Figure 4-1) but only fell below 6 in cows fed the LSG, Maturity 1 diet.

Ruminal NH$_3$-N concentration was lower ($P < 0.01$) in cows fed LSG hybrids than in cows fed HSG hybrids, though this tended to be more evident in cows fed Maturity 1 vs. Maturity 2 diets (Figure 4-2) (SG x maturity interaction, $P = 0.06$). This suggests that there was enhanced absorption or uptake of ammonia-N by the ruminal microbes on the LSG diet probably due to greater fermentable metabolizable energy availability. Ruminal NH$_3$-N concentration decreased with maturity in cows fed HSG hybrids (27.9 vs. 20.9 mg/dl), but was unchanged with maturity in cows fed LSG hybrids (19.0 vs. 19.1 mg/dl) (SG x maturity interaction, $P = 0.06$). Adding moisture to the HSG hybrid reduced ($P < 0.05$) the concentration of ammonia-N.
Ruminal concentration of lactic acid was not affected by SG ranking or maturity, but adding moisture to the Maturity 1 HSG hybrid reduced \( P < 0.05 \) the concentration of lactic acid. Ruminal concentration of acetic acid (Figure 4-3) was not affected by SG ranking or moisture addition. However, acetic acid concentrations decreased \( P < 0.001 \) with hybrid maturity, partly due to decreases in fiber concentration with maturity. Ruminal concentration of propionic acid (Figure 4-4) decreased with maturity in cows fed LSG hybrids (19.1 vs. 18.3 molar %), but increased with maturity in cows fed HSG hybrids (18.3 vs. 20.2 molar %) (SG x maturity interaction, \( P < 0.001 \)). Adding moisture to the Maturity 1 HSG hybrid increased \( P = 0.05 \) the concentration of propionic acid reflecting the greater starch intake in cows fed the HSG wet diet.

Ruminal concentration of iso-butyric acid increased with maturity in cows fed LSG hybrids (3.1 vs. 4.9 molar %), but was similar at both maturities in cows fed HSG hybrids (3.5 vs. 3.7 molar %) (SG x maturity interaction, \( P < 0.05 \)). Ruminal concentration of butyric acid (Figure 4-5) decreased with maturity in cows fed LSG hybrids (12.7 vs. 11.1 molar %), but was similar at both maturities in cows fed HSG hybrids (12.4 vs. 12.4 molar %) (SG x maturity interaction, \( P < 0.01 \)). Adding moisture to the HSG hybrids tended \( P = 0.09 \) to decrease butyric acid concentration. Ruminal concentration of iso-valeric and 2-methyl butyric acids were not affected by SG ranking but the iso-valeric and 2-methyl butyric acids concentrations increased with maturity in cows fed LSG hybrids (3.8 vs. 5.1 molar %) and not HSG hybrids (4.6 vs. 4.5 molar %) (SG x maturity interaction, \( P < 0.05 \)). Cows fed LSG hybrids had greater \( P < 0.01 \) ruminal concentration of valeric acid than cows fed HSG hybrids. Concentration of valeric acid was not affected by maturity or moisture addition.

Ruminal fluid acetate: propionate ratio (Figure 4-6) was lower in cows fed LSG hybrids (3.0 vs. 3.2) at Maturity 1 than HSG hybrids, but this ratio was greater in cows fed LSG hybrids (3.1 vs.
vs. 2.6) at Maturity 2 than HSG hybrids (SG x maturity interaction, $P < 0.001$). This indicates that the efficiency of rumen fermentation was greater in cows fed LSG hybrids at Maturity 1 but it was greater in cows fed HSG hybrids at Maturity 2.

Total VFA concentration was lower ($P < 0.01$) in cows fed HSG hybrids than cows fed LSG hybrids at both maturities. However, total VFA concentration decreased with maturity in cows fed LSG hybrids (99.5 vs. 75.2 mM) but cows fed HSG hybrids had similar values at both maturities (67.6 mM) (SG x maturity interaction, $P < 0.05$). Adding moisture to Maturity 1 HSG hybrids increased ($P < 0.001$) total VFA concentration which indicates that the extent of fermentation was increased by this treatment (Figure 4-7). This may have resulted from the greater CP and starch intake and CP digestibility that occurred when moisture was added to the Maturity 1 HSG diet. Apparent digestibility is often proportional to ruminal total VFA concentration. The disparity between these measures in this study may reflect greater post ruminal digestion of the HSG(wet) diet.

**Conclusions**

This study shows that the effect of maturity on several performance attributes of the cows was influenced by the SG ranking of the hybrids. Nevertheless, harvesting corn silage at 35 instead of 26 g DM/100g tended to decrease milk yield and milk fat yield, but increased manure score, rumen contractions and BW gain, and tended to increase rumen pH, plasma glucose concentration and the efficiency of feed utilization for milk production. This suggests that corn silage should be harvested at 35 instead of 26 g DM/100g to optimize rumen health and improve the efficiency of feed conversion into milk.

Feeding a hybrid that had a higher SG ranking resulted in lower apparent DM and CP digestibilities, greater BW gain, greater though physiologically normal rectal temperature; but did not adversely affect other health measures or milk production by the cows. No incidence of
digestive upset, diarrhea or Hemorrhagic Bowel Syndrome occurred in the cows. Therefore no
direct link between high SG rankings in corn silages and the incidence of these problems was
found in this study.

Addition of moisture to HSG hybrids to simulate rainfall at harvest increased CP and starch
intake, CP digestibility and total VFA concentrations in ruminal fluid. However, moisture addition
was also associated with greater numbers of yeasts and molds decreased aerobic stability
indicating the importance of harvesting and ensiling corn under dry conditions.
Table 4-1. Ingredient and chemical composition of the diets

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>g/100g of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn silage</td>
<td>35.0</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>10.0</td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td>4.4</td>
</tr>
<tr>
<td>Citrus pulp</td>
<td>4.8</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>4.7</td>
</tr>
<tr>
<td>Soy Plus</td>
<td>4.2</td>
</tr>
<tr>
<td>Corn meal</td>
<td>17.3</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>4.2</td>
</tr>
<tr>
<td>Whole cottonseed</td>
<td>9.2</td>
</tr>
<tr>
<td>Molasses</td>
<td>2.8</td>
</tr>
<tr>
<td>Mineral mix¹</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Chemical composition

<table>
<thead>
<tr>
<th>Maturity at harvest</th>
<th>Maturity 1 LSG²</th>
<th>Maturity 1 HSG³</th>
<th>Maturity 1 HSG(wet)⁴</th>
<th>Maturity 2 LSG²</th>
<th>Maturity 2 HSG³</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, g/100g of DM</td>
<td>51.5</td>
<td>51.0</td>
<td>50.0</td>
<td>59.7</td>
<td>59.7</td>
<td>0.14</td>
</tr>
<tr>
<td>Starch, g/100g of DM</td>
<td>22.5</td>
<td>23.1</td>
<td>24.0</td>
<td>24.9</td>
<td>24.0</td>
<td>0.09</td>
</tr>
<tr>
<td>CP, g/100g of DM</td>
<td>18.7</td>
<td>18.7</td>
<td>18.6</td>
<td>18.5</td>
<td>18.6</td>
<td>0.01</td>
</tr>
<tr>
<td>NDF, g/100g of DM</td>
<td>32.2</td>
<td>31.9</td>
<td>30.8</td>
<td>30.3</td>
<td>30.7</td>
<td>0.09</td>
</tr>
<tr>
<td>ADF, g/100g of DM</td>
<td>21.1</td>
<td>21.2</td>
<td>20.4</td>
<td>19.9</td>
<td>20.1</td>
<td>0.07</td>
</tr>
</tbody>
</table>

¹ Mineral mix contained 24.75% CP, 9.9% Ca, 1.1% P, 7.15% K, 2.75% Mg, 8.25% Na, 1448 mg/kg of Mn, 445 mg/kg of Cu, 1552 mg/kg of Zn, 8.54 mg/kg of Se, and 15.5 mg/kg of I. 147,756 IU of vitamin A/kg, and 717 IU of vitamin E/kg (DM basis).
² Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest
³ LSG = Low stay-green hybrid
⁴ HSG = High stay-green hybrid
⁴ HSG (wet) = HSG hybrid wetted with 15 L of water/ton of forage at ensiling
Table 4-2. Chemical composition of corn silages differing in maturity, SG ranking and moisture treatment at ensiling (n=4)

<table>
<thead>
<tr>
<th></th>
<th>Maturity 1</th>
<th>Maturity 2</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSG¹</td>
<td>HSG²</td>
<td>HSG(wet)³</td>
</tr>
<tr>
<td>DM at silo opening, g/kg</td>
<td>303</td>
<td>289</td>
<td>295</td>
</tr>
<tr>
<td>Ash, g/kg DM</td>
<td>41</td>
<td>39</td>
<td>33</td>
</tr>
<tr>
<td>Starch, g/kg DM</td>
<td>291</td>
<td>332</td>
<td>333</td>
</tr>
<tr>
<td>WSC⁴, g/kg DM</td>
<td>9.5</td>
<td>9.5</td>
<td>9.8</td>
</tr>
<tr>
<td>CP, g/kg DM</td>
<td>89</td>
<td>90</td>
<td>87</td>
</tr>
<tr>
<td>NDF, g/kg DM</td>
<td>458</td>
<td>449</td>
<td>400</td>
</tr>
<tr>
<td>ADF, g/kg DM</td>
<td>271</td>
<td>275</td>
<td>243</td>
</tr>
<tr>
<td>Yeast, log cfu⁵/g</td>
<td>1.00</td>
<td>3.38</td>
<td>6.11</td>
</tr>
<tr>
<td>Mold, log cfu⁵/g</td>
<td>1.45</td>
<td>2.45</td>
<td>6.30</td>
</tr>
<tr>
<td>Aerobic stability⁶, h</td>
<td>18.3</td>
<td>7.3</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest

¹ LSG = Low stay-green hybrid
² HSG = High stay-green hybrid
³ HSG (wet) = HSG hybrid wetted with 15 l of water/ton of forage at ensiling.
⁴ WSC = Water soluble carbohydrate
⁵ cfu = colony forming units
⁶ Aerobic stability = Number of hours that elapsed before silage temperature exceeded ambient temperature by > 2°C.
### Table 4-3. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green (SG) rankings on feed intake and digestibility of lactating dairy cows.

<table>
<thead>
<tr>
<th></th>
<th>Maturity 1</th>
<th>Maturity 2</th>
<th>SE</th>
<th>Effects (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSG(^1)</td>
<td>HSG(^2)</td>
<td>HSG(wet)(^3)</td>
<td>LSG(^1)</td>
</tr>
<tr>
<td>Intake, kg/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>29.8</td>
<td>26.3</td>
<td>27.3</td>
<td>26.7</td>
</tr>
<tr>
<td>Starch</td>
<td>6.6</td>
<td>5.8</td>
<td>6.7</td>
<td>6.5</td>
</tr>
<tr>
<td>CP</td>
<td>5.6</td>
<td>4.7</td>
<td>5.1</td>
<td>4.9</td>
</tr>
<tr>
<td>NDF</td>
<td>9.6</td>
<td>8.0</td>
<td>8.4</td>
<td>8.0</td>
</tr>
<tr>
<td>ADF</td>
<td>6.3</td>
<td>5.3</td>
<td>5.6</td>
<td>5.3</td>
</tr>
<tr>
<td>Digestibility, g/100g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>68.4</td>
<td>61.6</td>
<td>63.9</td>
<td>68.4</td>
</tr>
<tr>
<td>NDF</td>
<td>60.1</td>
<td>49.2</td>
<td>47.0</td>
<td>54.6</td>
</tr>
<tr>
<td>CP</td>
<td>69.1</td>
<td>62.3</td>
<td>65.2</td>
<td>68.7</td>
</tr>
<tr>
<td>Starch</td>
<td>98.1</td>
<td>98.5</td>
<td>98.4</td>
<td>97.9</td>
</tr>
</tbody>
</table>

\(^1\) Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest
\(^2\) ns = not significant, P > 0.15
\(^3\) LSG = Low stay-green hybrid
\(^4\) HSG = High stay-green hybrid
\(^5\) HSG (wet) = HSG hybrid wetted with 15 l of water/ton of forage at ensiling
Table 4-4. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green (SG) rankings on milk production and composition from lactating dairy cows.

<table>
<thead>
<tr>
<th></th>
<th>Maturity 1</th>
<th></th>
<th>Maturity 2</th>
<th></th>
<th>SE</th>
<th>Effects ($P$ value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSG(^1)</td>
<td>HSG(^2)</td>
<td>HSG(wet)(^3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>36.9</td>
<td>37.5</td>
<td>37.5</td>
<td>36.2</td>
<td>36.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Milk fat, g/100g</td>
<td>3.79</td>
<td>3.49</td>
<td>3.71</td>
<td>3.33</td>
<td>3.54</td>
<td>0.1</td>
</tr>
<tr>
<td>Milk protein, g/100g</td>
<td>2.93</td>
<td>2.91</td>
<td>2.90</td>
<td>2.95</td>
<td>2.90</td>
<td>0.0</td>
</tr>
<tr>
<td>Milk fat, kg/d</td>
<td>1.40</td>
<td>1.33</td>
<td>1.33</td>
<td>1.28</td>
<td>1.28</td>
<td>0.1</td>
</tr>
<tr>
<td>Milk protein, kg/d</td>
<td>1.08</td>
<td>1.12</td>
<td>1.09</td>
<td>1.08</td>
<td>1.09</td>
<td>0.0</td>
</tr>
<tr>
<td>SCC, 10(^3) cells/ml</td>
<td>578</td>
<td>634</td>
<td>477</td>
<td>567</td>
<td>347</td>
<td>197</td>
</tr>
<tr>
<td>Feed efficiency, kg milk/kg DMI</td>
<td>1.25</td>
<td>1.38</td>
<td>1.40</td>
<td>1.39</td>
<td>1.42</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest
ns = not significant, $P > 0.15$

\(^1\) LSG = Low stay-green hybrid
\(^2\) HSG = High stay-green hybrid
\(^3\) HSG (wet) = HSG hybrid wetted with 15 l of water/ton of forage at ensiling
Table 4-5. Effect of maturity and moisture addition to corn silages with contrasting stay-green (SG) rankings on body weight and plasma metabolites in lactating dairy cows.

<table>
<thead>
<tr>
<th></th>
<th>Maturity 1</th>
<th>Maturity 2</th>
<th>SE</th>
<th>Effects (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSG¹</td>
<td>HSG²</td>
<td>HSG(wet)³</td>
<td>LSG¹</td>
</tr>
<tr>
<td>BW, kg</td>
<td>628</td>
<td>638</td>
<td>638</td>
<td>634</td>
</tr>
<tr>
<td>BW gain, kg/d</td>
<td>0.30</td>
<td>0.61</td>
<td>0.74</td>
<td>0.62</td>
</tr>
<tr>
<td>Plasma BUN, mg/dl</td>
<td>19.4</td>
<td>19.4</td>
<td>19.1</td>
<td>18.8</td>
</tr>
<tr>
<td>Plasma glucose, mg/dl</td>
<td>64.4</td>
<td>66.1</td>
<td>66.6</td>
<td>66.9</td>
</tr>
<tr>
<td>β-Hydroxybutyrate, mmol/l</td>
<td>0.25</td>
<td>0.29</td>
<td>0.29</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest
ns = not significant, P > 0.15
¹ LSG = Low stay-green hybrid
² HSG = High stay-green hybrid
³ HSG (wet) = HSG hybrid wetted with 15 l of water/ton of forage at ensiling
Table 4-6. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green (SG) rankings on rumen parameters and health indices of lactating dairy cows.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maturity 1</th>
<th>Maturity 2</th>
<th>SE</th>
<th>Effects (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSG(^1)</td>
<td>HSG(^2)</td>
<td>HSG(wet)(^3)</td>
<td></td>
</tr>
<tr>
<td>Rectal temperature, ºC</td>
<td>38.06</td>
<td>38.11</td>
<td>38.00</td>
<td>0.1</td>
</tr>
<tr>
<td>Rumen contractions, /min</td>
<td>2.21</td>
<td>2.22</td>
<td>2.14</td>
<td>0.1</td>
</tr>
<tr>
<td>Manure score(^4)</td>
<td>2.48</td>
<td>2.53</td>
<td>2.68</td>
<td>0.14</td>
</tr>
<tr>
<td>pH</td>
<td>5.9</td>
<td>6.0</td>
<td>6.1</td>
<td>0.1</td>
</tr>
<tr>
<td>NH(_3)-N, mg/dl</td>
<td>19.0</td>
<td>27.9</td>
<td>21.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Lactic acid, molar %</td>
<td>1.7</td>
<td>1.9</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Acetic acid, molar %</td>
<td>58.1</td>
<td>57.8</td>
<td>57.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Propionic acid, molar %</td>
<td>19.1</td>
<td>18.3</td>
<td>19.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Iso Butyric acid, molar %</td>
<td>3.1</td>
<td>3.5</td>
<td>3.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Butyric acid, molar %</td>
<td>12.7</td>
<td>12.4</td>
<td>11.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Iso Valeric acid and 2-methyl butyric acids, molar %</td>
<td>3.8</td>
<td>4.6</td>
<td>4.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Valeric acid, molar %</td>
<td>2.6</td>
<td>2.2</td>
<td>2.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Acetate: Propionate</td>
<td>3.0</td>
<td>3.2</td>
<td>3.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Total VFA, mM</td>
<td>99.5</td>
<td>67.6</td>
<td>112.4</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Maturity 1 = 26 g DM/100g at harvest, Maturity 2 = 35 g DM/100g at harvest
ns = not significant, P > 0.15

1 LSG = Low stay-green hybrid
2 HSG = High stay-green hybrid
3 HSG (wet) = HSG hybrid wetted with 15 l of water/ton of forage at ensiling
4 Manure was scored on a scale of 1 to 4; 1 = dry, 2 = normal, 3 = loose, 4 = diarrhea
Figure 4-1. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal fluid pH. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-2. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal NH$_3$-N concentration. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-3. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal acetic acid molar percentage. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling/ton, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-4. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal propionic acid molar percentage. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water /ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-5. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal butyric acid molar percentage. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-6. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal acetic: propionic acid ratio. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
Figure 4-7. Effect of maturity at harvest and moisture addition to corn silages with contrasting stay-green rankings on ruminal total VFA concentration. LSG = Low stay-green hybrid, HSG = High stay-green hybrid, HSG (wet) = HSG wetted with 15 L of water/ton of forage at ensiling, Mat 1 = 26 g DM/100g at harvest, Mat 2 = 35 g DM/100g at harvest.
CHAPTER 5
GENERAL SUMMARY

A series of studies were conducted to determine the maturity at which the nutritive value of stay-green (SG) corn hybrids is optimized and to investigate whether corn hybrids with high SG rankings cause Variable Manure Syndrome (VMS) and Hemorrhagic Bowel Syndrome (HBS) in dairy cows. The SG characteristic is desirable for corn grain production because it confers resistance to lodging and disease infestation to corn plants. However, this characteristic is undesirable for silage producers because it results in asynchronous drying rates in the ear and stover, which may invalidate the use of the milk line for accurate prediction of harvest dates. Several dairy producers in Florida have associated increased incidence of HBS in their cows in recent years with intake of SG corn hybrids. Therefore there is a need for research into optimal maturity at harvest of such hybrids and the existence of a link between HBS and SG corn intake.

The objective of Experiment 1 was to determine the optimum maturity stage for harvesting SG corn varieties for silage production, and to determine if there are differences in the fermentation and aerobic stability of hybrids with contrasting SG rankings. Two varieties of corn with high (HSG) SG rankings (Pioneer 31Y43, Croplan Genetics 827) were compared with two varieties with average (ASG) stay-green rankings (Pioneer 32D99, Croplan Genetics 799). These varieties were grown on 1 x 6 m plots and harvested at 25 (Maturity 1), 32 (Maturity 2) and 37 (Maturity 3) g DM/100g. The harvested forage was divided into three portions, one each for botanical fractionation (ear vs. stover), whole plant chemical analysis and ensiling. Representative samples (6.5 kg) of the herbage reserved for ensiling were placed in polythene bags in quadruplicate within 20-l mini silos and sealed. Silos were stored for at least 107 d at ambient temperature (25°C) in a covered barn.
The stover of ASG hybrids had greater DM concentrations and lower CP concentrations than those of HSG hybrids from both sources, though these differences tended to be more pronounced in Croplan Genetics hybrids. These results reflect the greater green leaf and stem proportion in HSG hybrids. Unlike those of Pioneer hybrids, the stover, whole plant and silage from Croplan Genetics HSG hybrids had greater NDF and ADF concentrations and lower starch concentration and IVDMD than the corresponding ASG hybrids. Thus, the higher SG ranking was associated with poorer nutritive value in Croplan Genetics hybrids. Therefore this study indicates that hybrids from different companies may have different nutritional attributes. The SG attribute may affect the moisture distribution of some corn hybrids, whereas it affects the nutritive value of others. However, the fermentation and aerobic stability of ASG and HSG hybrids were largely similar, therefore the SG attribute did not adversely affect silage quality in this study.

As the hybrids matured, DM yield, yield of digestible DM, starch, DM concentration, and yeast counts increased, whereas fiber components, CP and WSC decreased, consequently IVDMD was unchanged. However, the nature of these maturity-related changes differed with hybrid source and SG ranking. It is concluded that the best combination of DM yield, nutritive value, fermentation quality and yeast counts was obtained when the corn hybrids were harvested at 32 g DM/100g.

The objective of Experiment 2 was to determine the effects of SG ranking, maturity and simulated rainfall on the quality of corn silage and health, feed intake and milk production of dairy cows. The near isogenic hybrids used were Croplan Genetics 691 (high stay-green, HSG) and Croplan Genetics 737 (low stay-green, LSG). The hybrids were harvested at 26 g DM/100g (Maturity 1) and 35 g DM/100g (Maturity 2) and packed into 2.4-m wide, 32-ton Ag-Bags. A further treatment involved adding 15 l of water per ton of silage to forage harvested at Maturity 1
to simulate rainfall at harvest. The water was added with a hosepipe during packing. Thirty lactating Holstein cows in mid-lactation (92 days in milk (DIM)) were allocated randomly to the five silages for two, 28-d periods. The silages formed part of a TMR consisting of corn silage, alfalfa hay and concentrate mixed at 35, 10 and 55 g/100g (DM basis) respectively. Dry matter intake, digestibility, milk production and composition, blood and ruminal function parameters were measured.

Intake of starch, CP, NDF and ADF were lower in cows fed HSG vs. LSG hybrids, though the differences in CP and fiber intakes were more pronounced in cows fed Maturity 1 vs. Maturity 2 diets. The digestibilities of DM, NDF and CP were also lower in cows fed HSG vs. LSG hybrids, though the difference in NDF digestibility was more pronounced at Maturity 1. Cows fed HSG diets also had greater rectal temperature and BW gain. However, milk production and the concentration of milk constituents were largely unaffected by SG ranking. These results suggest that the higher SG ranking was associated with lower feed digestibility and intake but it did not adversely affect the health of the cows.

Milk production tended to be greater in cows fed Maturity 1 vs. Maturity 2 diets. Cows fed HSG hybrids had lower milk fat concentration than those fed LSG hybrids harvested at Maturity 1, but the reverse occurred in hybrids harvested at Maturity 2. There was a tendency for milk fat yield to decrease with maturity. Milk protein concentration and yield were not affected by maturity. However, manure score, rumen contractions BW gain, ruminal pH, plasma glucose concentration and the efficiency of feed conversion into milk improved or tended to improve with corn silage maturity. This suggests that corn silage should be harvested at 35 instead of 26 g DM/100g to optimize rumen health and improve the efficiency of feed conversion into milk.
Adding water to the Maturity 1, HSG hybrid reduced ruminal ammonia-N concentration but increased starch intake, CP digestibility and ruminal VFA concentration, and tended to increase CP intake. This suggests that water addition improved dietary protein and energy utilization, probably because the added water provided more conducive conditions for enzymatic nutrient hydrolysis. However water addition was associated with greater yeast and mold counts and poorer silage aerobic stability, reflecting the importance of harvesting and ensiling corn silage under dry conditions.

These experiments did not demonstrate a direct link between HSG corn hybrids and VMS and HBS. Indeed several researchers now consider HBS to be caused by multiple factors including bad silage management practices such as inadequate packing, harvesting or ensiling while it is raining, harvesting crops too early or feeding excess levels of readily fermentable carbohydrates, etc. Although this work has not shown a direct link between HBS and SG, it confirms the finding that higher SG rankings are associated with poorer nutritive values in hybrids from Croplan Genetics.

More work is needed to investigate the causes of HBS in dairy cows and the role of SG hybrids in the etiology of the disease. Such studies should:

(i) Compare SG hybrids to traditional non-SG hybrids.

(ii) Examine diurnal fluctuations in body temperature of cows fed such diets.

(iii) Monitor levels of indices of the immune status of the cows.

(iv) Examine the existence of an interaction between dietary concentrate level, SG ranking and moisture at ensiling.

(v) Sample silages and blood samples for \textit{A. fumigatus} and \textit{C. perfringens} counts.
LIST OF REFERENCES


Hammes, D.J. 1997. Developing markets for optimum EG high oil corn. Pages 1-10 in Proc. Annu. III. Corn Breeders School, 33rd. Dept. Of Crop Sciences, Univ. of Illinois, Urbana-Champaign, IL.


BIOGRAPHICAL SKETCH

Kathy Gisela Arriola was born on September 18, 1973, in San Francisco, California. The youngest of four children, she grew up mostly in Lima, Peru. She graduated with honors from Liceo Naval Teniente Clavero High School in 1990 and she earned her B.S. in animal science from the Universidad Nacional Agraria La Molina, Peru in 1998. While at the Agraria La Molina she earned pre-professional experience in the Investigation Program for swine, beef and dairy cattle. After working for one year as a consultant for dairy farmers, she moved to Florida in 2000 and worked. In 2004, Kathy was accepted into the M.S. program in the Department of Animal Sciences at the University of Florida (UF) under the guidance of Dr. Adegbola Adesogan. While pursuing her M.S. in ruminant nutrition she was given the opportunity to assist in several projects related to her field. Kathy was involved in the Animal Science Graduate Student Association and she was an active member of Gamma Sigma Delta.