Management and Storage Alternatives for Corn Silage

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Introduction

Whole-plant corn silage (*Zea mays L.*) continues to be a major forage and energy source in the North American cattle industry (16). In 2000, roughly 7.5% of the US corn acreage was harvest as silage, totaling just less than 2.4 million hectares (36). Corn silage is a palatable, consistent, yet versatile wet forage crop that requires less labor in production when compared to hay. Feed quality characteristics become dependant on a number of environmental and managerial factors, such as climate, harvesting DM content, maturity, mechanical processing, storage system, storage length, fill and feed-out rates, surface area exposure, additives used, etc. The purpose of this review is to summarize literature focusing on harvest, storage, and feed-out practices required to maximize the value of corn silage.

Harvest Management

A harvest management plan should be in place to ensure that the silage is harvested at the appropriate time to prevent unnecessary losses in DM and nutrient quality (17). Corn silage harvest can be completed in approximately two weeks, however feeding of the stored silage can take place for the remaining 50 weeks of the year. Therefore, poor planning at harvest and in storage may take a serious toll on productivity, animal health, and profitability all season long. Corn should be harvested for silage after the corn is well dented, but before the leaves turn brown and dry. Bal *et al.* (3) reported optimum maturity stage for corn harvest was 2/3 milk line (ML), with some flexibility between 1/4 and 2/3 ML. Quality and quantity measures are at their peak during this stage of development. Bal *et al.* (3) reported lowest digestibility of DM (58.0 vs. $\geq$64.9% DDM), organic matter (OM), protein, acid detergent fiber (ADF), and starch for corn silage harvested at black layer maturity, when compared to 2/3 ML. Corn silage cut late has brown/dead leaves and stalks, which in turn will sharply decrease total production per hectare and animal performance. Field losses from dry leaves can be as high as 30%, resulting in a 10% reduction in total DM stored. For each advancing day of forage maturity beyond 2/3 ML, approximately 1% more concentrate was needed to maintain milk production (8). Cleale and Bull (8) reported a 19 day delay in harvest resulted in a 40% reduction in the rate of disappearance of the potentially DDM.

Climatic factors may also contribute to maturity and storage concerns. Warm weather accelerates drying, thus narrowing the optimum maturity window. McGechan (22) reported that weather conditions alter grass sugar content up to 1%, changing buffering capacity and ensiling characteristics drastically. Additionally, Weinberg *et al.* (38) reported corn silage stored at elevated (37-41^{o}C) ambient temperatures resulted in unfavorable ensiling characteristics (higher pH and DM losses, and less lactic acid) and less aerobic stability when compared to silage stored at room temperature ($\leq$ 33^{o}C). Likewise, Ruppel *et al.* (31) found that an elevated temperature at filling was correlated to greater DM loss, change in non-starch carbohydrate (NSC), and greater pH and ammonia concentration.

Anaerobic Fermentation

Among environmental and management factors worthy of consideration in maintaining corn silage quality, Bolsen *et al.* (5) recognized the degree of anaerobiosis as the leading concern. Wet crops, stored directly or with minimal drying, can be preserved under anaerobic conditions in a silo (storage structure), through a four-phase process known as ensiling or anaerobic fermentation (27). In the pre-seal phase (day 1), fresh chopped forage cells continue to respire and aerobic/epiphytic bacteria (naturally occurring in forage) begin to breakdown water soluble carbohydrate (WSC) to yield carbon dioxide, water, and heat. Plant DM and WSC losses persist until anaerobic conditions are established. Respiration losses are considered to be unavoidable (27). Plant enzymes hydrolyze starch and hemicellulose to monosaccharides yielding extra sugar substrate for both aerobic and anaerobic bacteria. Plant enzymes also reduce feed value by metabolizing protein to non-protein nitrogen (NPN) under aerobic conditions (27).

As the oxygen supply trapped among the forage particles is metabolized, phase two, active fermentation begins (day 2). Active fermentation utilizes desirable bacteria to eliminate oxygen, reduce pH, and inhibit undesirable bacteria growth. Lactic acid producing bacteria (LAB) and acetic acid producing bacteria feed on WSC yielding their respective organic acids (day 3). LAB proliferation (day 4-7) yield adequate amounts of lactic acid to inevitably reduce the original pH (6.0) of the forage mass to a stable pH range of 3.8-4.5 (day 8-21) (4). Quantitatively, the amount of acid required to drop the original pH 6 to a stable pH 4 is dependant on the silages DM content and storage system. Once the stable phase is reached, pH inhibits all bacterial action ($>$ day 21) and preservation of the forage occurs until the feed out phase.

Physical characteristics of corn silage can lead to poor fermentation characteristics. If insufficient amounts of lactic acid are produced, butyric acid production becomes evident with a foul odor, usually associated with spoilage (24). Poorly fermented silage appears dark green, with a strong odor, slimy soft tissues, and will commonly have a pH $\geq$ 5. Overheated silage appears brown/black, with a caramel odor or slightly burned sugar odor due to Maillard reaction products. Properly heated silage appears light green or yellow, with a slight vinegar odor (acetic acid), firm plant tissues and a pH $<$ 4.5.

Temperature of the silage mass throughout ensiling becomes dependent on the efficiency of transition between aerobic to anaerobic environment. As cells respire and aerobic bacteria conduct proteolysis, temperatures of the mass steadily increase above ambient temperature. Silage mass temperatures above the normal range (10-40°C) have elevated proteolysis rates, resulting in increased NPN production (27). Bates (4) reported temperatures in the pre-seal phase increased from 21°C to 35°C within the first two days of ensiling. However, as anaerobic conditions developed, temperatures stabilize between 26.5-29.5°C by days 4-7.

Storage Dry Matter

Next to the rate of oxygen exclusion, forage characteristics (e.g. DM content, maturity, WSC content, forage type) at the time of ensiling are likely to be the predominant factor that dictates the final quality of corn silage. Recommendations for harvesting DM of whole plant corn silage range between 30-40% DM. Fermentative efficiency is greater for silages with low DM contents

(20-29% DM), however effluent losses are substantial. Corn silage with moisture contents greater than 70% are prone to excessive effluent or seepage losses due to the hydraulic pressure occurring in most storage systems. In the case of excessive moisture, seepage losses will peak by day 4 of ensiling. Effluent poses two problems, silage nutrient losses and pollution effects (20). Mahanna *et al*. (20) reported nutrient composition in lost effluent as 20% nitrogenous, 55% non-nitrogenous organic matter, and 25% mineral. Gordon (11) noted a 6.8-13% DM loss in seepage from silage ensiled at 77-82% moisture. Similarly, McGechan (22) indicated the DM loss associated with seepage averaged 5.8% (range 3.2-8.8%) in grass silage. However, corn silage produces less effluent than grass at similar DM, therefore seepage losses would likely be lower than this value. Mahanna *et al*. (20) also reported that silage seepage has 180 times greater biological oxygen demand (BOD) than that of domestic sewage. One thousand tons of silage reportedly has an equivalent BOD of a city with 250,000 people.

Silages with relatively high DM (> 40%) at ensiling have no effluent loss, but have less efficient rates of fermentation. High DM silages are often difficult to pack, resulting in trapped oxygen pockets within the mass, allowing greater plant cells respiration. A reduction in fermentation end products results with increasing silage DM level (6).

The ensiling process also emits several gaseous end products of fermentation. Gas concentrations, including NO_2, N_2O_4, NO, CO_2, NH_4, and CH_4, are highest 12-72 hours after ensiling, but can persist up to 10 days post-fill. These emissions are often overlooked in terms of total storage losses. Air tight or lowly ventilated storage systems present a concern for worker safety due to dangerous gas concentrations at ensiling.

Density and Particle Size

Silage mass density varies with storage system, but is often directly related to fermentative efficiency and total DM losses. Ruppel *et al*. (31) reported that optimal density and sealing reduces porosity or air infiltration, increases storage capacity and reduces capital investment. For optimal packing and ensiling characteristics, a bunker silo at 30-35% DM forage, requires a minimum density of 225-kg of DM/m^3. Darby and Jofriet (9) estimate upright tower silos to have 10% greater density when compared to horizontal silos, due to the hydraulic pressure of the silage mass. A study published by Ruppel *et al.* (31) indicated density of silage mass was directly correlated to DM loss. Silage packed at 160-kg DM/m^3 incurred a 20.2% DM loss after 180d storage, while 225, 260, 290, and 350-kg DM/m^3 sustained 16.8%, 15.1%, 13.4%, and 10.0%, respectively. The savings of increased DM recovery is worth the cost of extra packing time.

Packing is dependent on a number of managerial practices. First, forage delivery rate must be slow enough to ensure proper packing time. A delivery rate of 30-T/hr allows 1 to 4-minutes/T for packing, which is the minimum time to achieve the necessary packing density. Delivery rates exceeding 60-T/hr allow less than one minute per ton for packing silage, which is inadequate to meet minimum packing density. Secondly, heavy single wheeled tractors apply the greatest force to a given area to reduce trapped air pockets in horizontal silos. Consideration of an additional packing tractor may be necessary depending on bunker size and forage delivery rate. Another factor affecting packing density is layer thickness and packing method. Experts recommend thin even layers, 15 to 30-cm in depth, be frequently incorporated into the silage mass. Frequent packing ensures consistent fermentation throughout the storage structure. Ruppel (31) reported a 3% reduction in ADF and an 8% increase in nonstructural carbohydrate (NSC) when using the progressive wedge packing method. Finally, a greater silage depth can aid in packing density, as added gravitational force causes cell collapsing.

Greater packing intensity was associated with larger temperature rises above ambient temperature within the top surface layer of a horizontal silo (31). However, packing intensity was also positively correlated to better aerobic stability at the working face of the feed out phase. Similarly, McGuffey and Owens (24) noted that temperature was a good indicator of compaction. They reported lower temperatures in silage located at the bottom of the silo, indicating good compaction, while higher temperatures near the top surface indicating less compaction of the silage mass.

Jones *et al*. (17) recommend corn silage particle size to be chopped at 1 to 2-cm in theoretical length. Proper chop length is necessary to obtain uniform breakage of cobs and kernels with conventional harvesters. It is often necessary to chop finer than we would like and still maintain effective fiber. However un-cracked kernels tend to pass undigested through the GIT, and large pieces of cobs are prone to sorting in the feed bunk. Mechanical processing, such as chopping, bruising, rolling and kernel processing, help breakdown cell wall structure, aid in starch and fiber digestibility and fermentative efficiency (16, 22). Similarly, Bal *et al*. (2) reported that processing corn silage through a 1-mm roller clearance numerically increased dry matter intake (25.9 vs. 25.3-kg/d), milk production (46.0 vs. 44.8-kg/d), milk fat concentration (1.42 vs. 1.35-kg/d), and lowered GIT starch digestibility (99.3 vs. 95.1% DDM) over control silage.

Nutrient Losses

Nutrient losses are often worse than DM losses indicate, as WSC is metabolized. Ruppel *et al*. (31) reported DM losses ranging from 3-25%, but noted potentially 70% loss of digestible carbohydrate and up to 50% of soluble protein. Ruppel *et al*. (31) blamed these losses on surface area exposure allowing oxygen penetration, ineffective sealing of horizontal bunkers, and improper management at fill and feed-out phases. Pre-seal losses of 1-3% DM were reported, citing cell respiration and gaseous emissions as primary sources of loss. Total nutrient losses throughout the storage phase vary with storage system. Comparison of storage losses between storage system will be discussed later in this paper. However, differences in DM recovery exist in physical location within the forage mass. McLaughlin *et al.* (23) reported DM losses of 60% in the top 25-cm and 22% at 25 to 50-cm in horizontal silos. Ashbell and Kashanci (1) found DM losses at the surface and near walls of sealed bunker silos to be highest (76%), but lower in the center (16%).

Most producers dont understand that 2.5-cm of black forage may have been 5 to 8-cm of green high quality feed when placed into storage (14). This represents a 50-65% loss in DM. Additionally, there is often a transition zone (30 to 60-cm) of brown-gray forage below the black layer where a 20-30% of DM loss occurs.

Delays in Fill

Silo filling rate affects the establishment of anaerobic conditions, growth of LAB, substrate availability, DM losses and acid detergent insoluble fiber (ADIN) (31). Delays in silo fill postpones pH decline and lengthen microorganism activity, causing a decline in the relative feed value (RFV) of the silage at feed-out (27). In fact, slow fill rates extend the duration plant cells utilize WSC for energy, reducing available substrate for LAB metabolism. Extreme delays may leave WSC so low that lactic acid production is inadequate to attain the necessary pH drop required for preservation. Woolford (40) noted that >50% of the WSC can be lost within 24 hours of filling if the silo is slowly filled or inadequately sealed. Miller *et al.* (25) reported less DM (5.8% less) and protein loss and less NFE and ash content in rapidly filled silos. Additionally, prolonged cell respiration yields excessive heat, which may lead to Maillard product accumulation (ADIN) (27).

Other climate factors, such as rain during silo fill, can cause extended plant respiration, leaching of WSC, altered DM, and lower feed value. Addition of precipitation lowers silage buffering capacity and quantitatively increases the amount of organic acids needed to reach the stable pH phase.

Storage System Comparisons

Several factors, including herd size, capital investment, labor and feeding situation, access to equipment, amount of forage, and plans for future expansion, must be considered when selecting a silage storage system. Storage options for corn silage include oxygen limiting tower, concrete tower, horizontal pit, and silage bags. Capital cost is inversely related to DM losses for stored forage systems. Each option offers various advantages and disadvantages for a given scenario.

Upright tower silos typically reduced surface area expose to oxygen infiltration, thus reducing DM and nutrient losses over other alternatives. Towers are mechanized, easily accessible for feed out in good and bad weather conditions, and require very little land space, but they do require high initial investments and general maintenance. Towers silos are capable of ensiling forages 40-60% DM, with expected losses of 5-17% (21). Horizontal bunkers are economically attractive (25-50% of upright silo cost) and advantageous for storage of large amounts of ensiled feed, quick filling capacity with conventional equipment, and less energy for feed removal. McGuffey and Owens (24) reported that the quantity of organic acids in bunker silos was similar to that of gas tight silos, indicating typical fermentation occurred in both silos. However, bunker silos are prone to incur greater storage losses (15-30% DM loss) without proper management. Management options for reducing storage and feed-out losses will be discussed in a subsequent section. Bagged silage is very economical, allows great flexibility for expanding operations, and is easily fed out with modern equipment. Bags require greater space allotment for storage, as well as proper plastic disposal through the feeding period. Bags typically incur 17% DM loss, while round bale silage sustains approximately a 30% DM loss (21). Keller *et al.* (18) reported improved DM recovery and reduced mold with round bale silage as the number of layers of plastic increased.

Bunker Silo Management

While harvesting at the proper DM and meeting minimum bunker packing density are necessary in obtaining quality silage, they alone are not enough to ensure optimum recovery. It has been well documented that covering bunker silos with a plastic cover immediately after ensiling will reduce DM spoilage up to 30% in the uppermost 1-m. Oelberg *et al.* (28) compared fermentative conditions (pH 4.9 vs. 6.8) and DM recovery (total 96.2% vs. 68.0% DM) in the top (95.8% vs. 49.2% DM) and bottom (96.6% vs. 86.8% DM) portions of covered and uncovered bunker silos with alfalfa silage.

Plastics can vary in thickness, permeability, and anchoring/sealing technique (34). Savoie *et al*. (33) determined that plastic thickness of 0.01, 0.015, and 0.02-cm provide optimum storage protection for 3, 7, and 12 months, respectively. The cost of plastic sheeting increases linearly with thickness. Economic investment for plastic covering varies with color. Black plastic costs \$0.0023/m^2 or \$0.11/T, while white plastic (radiates more heat and is more UV resistant) costs \$0.003/m^2 or \$0.16/T. Regardless of price, the cost of losses and spoilage are 20 times greater than the cost of covering the bunker. According to Bolsen *et al*. (5) losses on a 12.2 x 30.5-m bunker exceed \$2000, while losses on a 30.5 x 76.2-m bunker exceed \$10,000.

Gordon (11) noted that sealing technique, as well as proper weighting of the plastic is critical in improving covering effectiveness. Adding weights to the plastic, such as tire centers (20-25/100ft^2), sawdust, sandbags, soil, or limestone, provides additional weight for packing surface material and also secures plastic into place. Mechanical failure of plastic coverings due to handling, wind, hail, rodents or birds can be costly. Thicker plastic is easier to handle and more resistant to tears and to oxygen infiltration (15). A puncture 1-cm in diameter will incur a monthly spoilage loss of 0.8%, 0.7%, or 0.6% DM for 0.01, 0.015, or 0.02-cm plastic, respectively. Specially designed tape is useful to repair punctures after the plastic is installed (15).

Many producers leave bunkers uncovered because of the belief that awkward plastic, tires, and labor intense covering arent worth the savings in spoilage. DM losses in the top 30 to 90-cm can exceed 60-70% and may comprise 15-25% of the corn silage in the bunker. Bolsen *et al.* (6) reported even a short (7 day) delay in sealing horizontal silos can reduce DM recovery and fermentative conditions. Sealed bunkers had greater DM and OM recovery in the top 67-cm, while unsealed was lowest, and delayed seal was intermediate.

Feed-Out Management

During the feed-out phase, silage becomes re-exposed to ambient air. While pH inhibits bacterial activity within anaerobic conditions, 15-30% of the bacteria remains present and active. Oxygen infiltration allows undesirable aerobic bacteria to proliferate if management strategies are not employed. Some silages begin to heat within hours of aerobic exposure, however some remain stable for several weeks (21). Cereal grains are less aerobically stable than legume silages because of their 10-fold greater concentration of WSC. Primary losses at feed-out result from yeast and other aerobic bacteria capable of metabolizing lactic acid, as well as molds, which feed on available WSC. Harrison (12) reported acetic acid, bacteria and yeast as most likely to cause aerobic deterioration in alfalfa silages at feed-out.

Pitt and Muck (30) determined the DM loss during feed-out of bunker silos as a function of removal rate. Bunker size should be designed to maintain a removal rate of 15.24 to 30.5-cm of silage across the entire face of exposed silage. However, during warm, humid weather removal of 45.8-cm may be necessary, especially corn silage, sorghum, or wheat silages. DM losses of 3% were incurred at the recommended 15.24-cm/d for 35% DM silage stored at a density of 225-kg/m^3 (30). DM losses decreased to less than 3% as silage density increased. Holmes and Muck (15) reported differences in feed-out losses with bunker flooring and management. Feed-out losses with good management ranged from 3-5% on a concrete floor, 4-6% on asphalt, 6-8% on macadam, and 8-20% with earthen floors, assuming good face management. With less than good management, losses increased an additional 7%, regardless of floor type. Additionally, any loose silage could start to heat as its exposed to oxygen, and should be fed with that day's ration. Experts recommend maintaining a smooth, clean and tightly packed face, perpendicular to the floor and sides. Ruppel *et al.* (31) assigned face scores to several commercial bunker silos. Bunkers with lower face scores had greater heat damage, and up to 10% greater concentrations of ADIN, due to oxygen penetration.

Aerobic stability is important because many (dairy) producers contract silage delivery for 2-4 days worth of feed (32). Silage removed, but not fed immediately, is exposed to air for an extended time period (15). This is of special concern in warm weather, as aerobic deterioration can occur rapidly during exposed conditions. Ohyama *et al*. (29) noted pH and temperature can be good indicators of deterioration in exposed silage. Spoiled silage should not be fed, due to the negative effects on animal performance. Molds produce toxins that may reduce cattle intake and negatively affect animal immune response. Spoiled silage creates an imbalance of nutrients within ingredients used to balance rations. A study conducted at Kansas State University indicated a linear decrease in DMI, CP digestibility and NDF digestibility in cattle consuming diets with increasing levels of spoiled corn silage (39).

Covering Alternatives

Covering bunker silos with plastic, while vastly improved over uncovered, is not 100% effective in reducing aerobic spoilage. The covering process requires much hand labor. Visual observation of the silo top frequently reveals a 5 to 20-cm layer of spoiled (black) feed (13). Producers consider this thin layer as a small loss, which can be sacrificed so as to avoid the labor of covering the bunker silo with plastic. Producers have sought less time consuming and less difficult alternatives. Research has shown that covering silage with a roof (32.6% DM loss), sawdust (30.0%), soil (25.1%), or ground limestone (23.6%) may provide some protection compared to no cover (34.2%) at all (13, 26). Other covering research such as candy, molasses, "nutri-shield", small grain sod, manure solids, small grain straw, or corn fodder, has shown no benefit over uncovered silage (13, 14). Watson (37) applied soybean soapstock (60-70% DM) to bunker silos at a rate of 30 to 40-kg/m^2 in an attempt to reduce spoilage and add nutritional value ($0.02/$cm^2$). Soapstock applied 1.3 to 2.5-cm in thickness showed excellent sealing properties, reducing spoilage from 42.4-T to 10.6-T in a 30.5 x 12.2-m bunker.

Common salt has been used in preservation of foods by inhibiting growth of harmful bacteria (12). Some strains of LAB are salt tolerant (7, 10, 35). Shockey and Borger (35) added NaCl, at a rate of 4-g/100-g to alfalfa silage and observed a reduction in the total number of clostridium bacteria. Cai *et al.* (7) added NaCl, at a rate of 40-g/kg to wet silage and observed a reduction in DM loss (7%), pH, total gas production and NH_3 levels. The addition of salt increased lactic acid and WSC concentrations, and also inhibited aerobic bacteria (clostridia) growth. Erickson (10) conducted a study in which they top-dressed 22.5-kg of NaCl/121-m^2 prior to sealing the bunker silo with 6-mil plastic. Salt-treated sections had reduced total aerobic bacteria counts, improved fermentation (lower pH), and improved feed quality (NDF). Un-salted sections had two times greater mycotoxin zearlenone (mold) content, in addition to greater clostridia counts.

The advantage of feeding these alternative covers is the goal producers would prefer over disposing of plastic covering. Several spray-on products have been developed and tested, but to date nothing has emerged as a successful product.

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