INTRODUCTION

High moisture grains can be an economical feed source due to high grain yields and elimination of the cost for drying grain. Rather than simply a processing system, high moisture grain requires alteration in harvest and storage of the grain but by processing the grain into storage, it can eliminate processing of grain at the time of feeding. Other grains including sorghum and wheat have been utilized as high moisture, but corn is the principal grain harvested and stored in high moisture forms. High moisture corn (HMC) can be harvested and stored as whole shelled corn, the grain can be rolled or ground into storage, or larger sections of the plant can be harvested and ensiled to form high moisture ear corn with or without the husk. High moisture grain production has several agronomic and economic advantages. These include: harvest several weeks earlier than harvest for dry storage and this contributes to a decrease in field and harvest losses of 3 to 6 percent; elimination of drying costs; and a reduced commodity cost associated with seasonal grain prices and discounts equivalent to drying and elevator dockage charges. Disadvantages of harvesting high moisture grain include: loss of marketing flexibility compared to dry grain; additional equipment may be needed for harvesting, handling, and packing high moisture grain; storage facilities are needed for a large quantity of grain; harvest and ensiling can prove hectic; and storage losses can be large if the grain is not properly ensiled and removed from storage at an adequate rates.

Optimum Maturity and Harvest Moisture

Feed grains are considered physiologically mature when yield of dry matter is at the maximum point. Corn kernels continue to accumulate dry matter until moisture content decreases to about 35% although some hybrids may be mature at a moisture content near 40%. Postponing harvest to decrease moisture further will not increase yield of DM or energy per acre and often results in an increased field losses due to ear drop. For corn, kernels started to dent at about 50% moisture and are at a medium soft stage but not mature. Twelve to 16 days usually are needed to reduce kernel moisture from 50 to 40%. During this time, yield can increase at a rate of 0.25 to 0.75 bushel per acre per day.

The optimum moisture for corn and grain sorghum will allow easy harvest and low field loss but still adequate for proper fermentation and near maximum animal performance. The moisture content that best satisfies all these requirements occurs shortly after physiological maturity of the grain is reached. An acceptable range for grain moisture content is between 25 to 33 percent. Once grain reaches physiological maturity, corn grains will lose about 1/2 to 1% moisture per day in the field although a hard freeze will speed this drying process. Because sorghum grain is more exposed, rate of drying can be much faster than for corn grain. Field loss at harvest can be affected substantially by grain moisture content. Harvesting and handling becomes easier as moisture content falls, but delaying harvest increases ear drop or loss of grain from a sorghum head, and the prevalence of downed stalks will increase due to wind, stalk rot, and insect damage. These losses can be minimized by proper adjustment of harvest machinery and initiating harvest when grain is at or slightly above 30% moisture and completing harvest before moisture reaches 25%. If corn contains less than 25% moisture, spoilage losses increase (Mader and Erickson, 2007) and feed efficiency will suffer. If all grain is to be harvested within 5 points of moisture and moisture content decreases at a rate of 1% per day, a hybrid must be harvested within a short (5 day) time window. To extend harvest time, hybrids can be selected with early to later maturity dates and hybrids with slower field drying of the grain. Slow field drying of grain conflicts directly with that of producers of dry grain who prefer rapid field drying so that grain can be harvested earlier. To reduce the number of irrigations needed or to produce multiple crops in a season, some growers will plant and grow shorter growing season hybrids than normally produced in their region at some sacrifice in grain yield.
**High Moisture Grain Storage**

Two storage methods are used commonly for high moisture grains. Ground grain can be stored in bunker or trench silos whereas whole grains often is stored in upright oxygen limiting structures. Ground or coarsely rolled grain can also be stored in upright structures. Large bagging systems that have been primarily used for encasing silage can also be used to store high moisture grains. In addition, corn and sorghum can be harvested dry and reconstituted by adding water to allow the grain to ferment in any of these storage units. Because the dominant grain stored in a high moisture form is corn, the following discussion will relate mainly to corn grain.

Fermentation loss of DM for high moisture corn averages 3 to 4% of the initial dry matter ensiled, but loss can be 2 to 3 times this level if grain is ensiled at the wrong moisture for the type of structure being used. For storage in bunker silos, the preferred harvesting moisture is above 27 percent. Corn stored in bunkers should be ground or rolled and thoroughly packed into the silo. Since proper packing depends on the moisture and particle size, corn to be stored in a bunker silo can be coarsely ground with as much as 20 percent whole corn. However, as moisture of the corn decreases to near 25 percent, a finer grind may be necessary to achieve proper packing. Finer grinds also permit a feedout rate to be slower once the silo is opened. If the feeding rate is sufficiently fast (> 3 inches removed daily from the face of the bunker) to prevent deterioration as the grain is fed, a coarser grind is recommended.

Dry matter recovery of ensiled grains depends on the type of storage structure and form of the grain being stored (Table 1).

**Table 1.** Approximate dry matter fermentation and storage losses of high moisture corn

<table>
<thead>
<tr>
<th></th>
<th>Bunker corn silage</th>
<th>Bunker processed</th>
<th>Harvestore whole</th>
<th>Stave whole</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>8 – 25%</td>
<td>4 – 10%</td>
<td>4 – 12%</td>
<td>8 – 16%</td>
</tr>
<tr>
<td><strong>Fermentation</strong></td>
<td>5%</td>
<td>2%</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>10%</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
</tr>
</tbody>
</table>

For high moisture grain that is properly processed and packed in bunker silos, dry matter losses from fermentation will average about 2%, with an additional storage surface loss of 3 to 5%. Exclusion of oxygen is critical for efficient ensiling. Aerobic deterioration (mold growth, etc.) associated with whole grain storage and uncovered/unsealed processed grain storage units can result in total DM loss during storage of 10% in bunker silos and 10 to 15% in structures used to store whole corn. Bagging or covering large bunker silos with plastic often held down with tires can hold total DM loss to under 5% of the total dry matter ensiled.

Deterioration of the exposed face of a bunker of stored grain will occur with slow removal rates and extensive exposure (i.e., when grain is removed from longitudinal sections of the bunker silo at different times). Dry matter losses from the face will vary with firmness of pack, particle size, and moisture. Nevertheless, in aerobic stability studies, Young et al. (1982) ensiled HMC at 22 to 28% moisture and reported respective DM losses from untreated (no preservatives added) coarse rolled HMC (4 lb samples taken from stave silo) of 0.9, 1.3, 1.6, and 2.7% after 2, 5, 7, and 16 days of exposure to air in May and respective DM losses of 2.7, 3.1, 3.2, and 2.8% for samples exposed to air in July. Comparable losses were also found with rolled high moisture grain sorghum (Heidker et al., 1982). Loss of dry matter may underestimate energy loss during exposure to oxygen; in the Heidker et al. (1982) study, loss of lactate plus acetate after 3 days totaled 1.7% though dry matter loss was less than 1%. Presumably, this reflects loss of volatile compounds during determination of dry matter during oven drying. Clearly, the rate of deterioration and dry matter losses are influenced by ambient temperatures. However, peak dry matter losses appeared to be limited to approximately 3% of the dry matter after more than two weeks of exposure despite elevated temperatures. Orientation of the bunker face and exposure to direct sunlight would also influence surface moisture and dry matter losses. In addition, losses from the face of a well-packed bunker silo may be less than those found in a
small sample under laboratory conditions. However, other environmental influences, such as rain and wind, could increase the magnitude of these losses.

**High Moisture Grain Feeding Value**

Relative differences among various grain type and processing methods were outlined by Owens et al. (1997). In general, more extensive processing of grain reduces ADG. This reduction can be attributed largely to reduced dry matter intake (DMI). Reduced DMI of grain sources that are extensively processed and rapidly fermented has been attributed to an excessive rate of acid production in the rumen and subclinical acidosis that will increase day-to-day variation in DMI.

Feed to gain ratios generally are lower (improved) with high moisture ensiled grain when compared to dry rolled grain (Table 2). Metabolizable energy contents of the grain alone, without or with adjustment for final weight of test cattle, are greater for high moisture grain than dry rolled grains.

Table 2. Feed to gain (F/G) and metabolizable energy (ME, Mcal/lb) for feedlot cattle fed dry rolled vs high moisture corn and milo (Owens et al., 1997)

<table>
<thead>
<tr>
<th>Processing method</th>
<th>Corn F/G</th>
<th>Milo F/G</th>
<th>Corn ME, Mcal/lb</th>
<th>Milo ME, Mcal/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry roll</td>
<td>6.57</td>
<td>7.43</td>
<td>1.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.33</td>
</tr>
<tr>
<td>High moisture</td>
<td>6.43</td>
<td>7.12</td>
<td>1.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.35</td>
</tr>
<tr>
<td>Change, %</td>
<td>-2.13</td>
<td>-4.17</td>
<td>4.60 (6.84)*</td>
<td>1.36 (10.00)*</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Means within a column with different superscripts differ (<i>P</i> < 0.05).

*Adjusted for final weight.

On a body weight-adjusted ME basis, high-moisture corn and milo had 6.8% to 10.00% greater ME than dry-rolled corn and milo, respectively.

Performance of cattle fed high-moisture corn grain harvested and stored at various moisture contents and ground, rolled, or unprocessed (left whole) are shown in Table 3. Only the middle range in moisture content for whole corn was available; presumably, this represents grain stored in oxygen-limiting structures.

Table 3. Performance of cattle fed high moisture corn grain at various moisture contents and processed by various methods prior to storage (Owens et al., 1997)*

<table>
<thead>
<tr>
<th>Moisture content, %</th>
<th>Ground</th>
<th>Rolled</th>
<th>Whole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23 – 26</td>
<td>&gt;27</td>
<td>23 – 26</td>
</tr>
<tr>
<td>ADG, lb/d</td>
<td>2.91</td>
<td>2.80</td>
<td>2.23</td>
</tr>
<tr>
<td>DMI, lb/d</td>
<td>19.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.05</td>
</tr>
<tr>
<td>Feed/gain</td>
<td>7.2</td>
<td>6.5</td>
<td>8.6</td>
</tr>
<tr>
<td>ME, Mcal/lb</td>
<td>1.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.58&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.36</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Means in a row and processing type with different superscripts differ (<i>P</i> < 0.05).

Although the number of observations limits statistical power for comparison, ADG numerically was greater with the wettest rolled grain and with whole grain. The wetter corn grain resulted in lower DMI. To numerically maximize efficiency of feed use, lower moisture grain should be ground rather than rolled; overall, for optimum gain and efficiency, wetter grain is more desirable.

Regressions of daily gain and body weight-adjusted ME against the percentage of moisture of high moisture grain fed in all forms revealed that both ADG and ME should be maximum at about 40% moisture (Owens et al., 1997). Presumably, this increase in ME is a function of DM digestibility; digestibility tends to increase with moisture content.

The potential benefits of using high moisture corn stored in the whole form have been reported by Mader et al. (1991) and are summarized in Table 4.
Table 4. Performance of cattle fed high moisture corn (HMC) finishing diets (3 trial summary; Mader et al., 1991)

<table>
<thead>
<tr>
<th>Item</th>
<th>Dry whole corn</th>
<th>HMC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Whole</td>
</tr>
<tr>
<td>Daily gain, lb&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.18</td>
<td>3.13</td>
</tr>
<tr>
<td>Daily intake, lb&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.63</td>
<td>21.26</td>
</tr>
<tr>
<td>Feed/gain&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.90</td>
<td>6.90</td>
</tr>
</tbody>
</table>

<sup>a</sup>Standard error.
<sup>b</sup>Whole vs processed ($P < 0.05$).
<sup>c</sup>Ground vs rolled ($P < 0.10$).

Daily gain of cattle fed dry whole corn (DWC) was similar to performance of cattle fed whole high moisture corn (WHMC). Daily gains of cattle fed whole corn (DWC and WHMC) were greater than daily gains of cattle fed ground high moisture corn (GHMC) and rolled high moisture corn (RHMC). Feed intakes followed a similar pattern. As the percentage of processed corn in the diet increased, intakes tend to decrease. More desirable animal performance may be produced from WHMC than RHMC because of increased DMI and improved nitrogen utilization as a result of the lower organic acids and less soluble nitrogen associated with corn stored as WHMC.

Efficiency of feed conversion (feed to gain ratio) was similar among cattle groups fed whole corn. Because of lower gains for cattle fed GHMC, feed to gain ratios tended to be greater (worse) for cattle fed GHMC than for cattle fed RHMC. In this study, cattle fed GHMC tended to have more liver abscesses than other cattle groups. More highly processed grain sources including high moisture grains tend to increase the incidence of liver abscesses.

The increased incidence of liver abscesses may be attributed to a rapid ruminal digestion of the corn starch that will increase the likelihood of digestive disturbances and acidosis. Other research conducted at the University of Nebraska Northeast Research and Extension Center has shown that the decreased performance observed with ground HMC occurred primarily during the step-up or diet adjustment period, the very period when cattle most frequently develop acidosis. Once cattle were adapted to their high concentrate rations, performance was similar regardless of grain type fed. Numerically, the lowest feed to gain ratios were found with cattle fed RHMC that was stored whole in an oxygen limiting structure but rolled prior to feeding.

Limited data indicates that steers fed HMC stored whole and fed whole tended to gain faster and are approximately 5 percent more efficient than steers fed DRC in high concentrate finishing rations. In addition, rolling whole HMC prior to feeding resulted in a 1 to 2 percent improvement in feed efficiency over steers fed whole HMC (Mader and Erickson, 2007). However, storage losses of corn stored whole typically are greater than for corn stored in a bunker silo as GHMC. High moisture corn can also be stored whole by treating it with organic acids. Organic acids also can be used to treat HMC to be stored outside in areas where loss associated with rainfall will be low. Gains and feed efficiencies may be improved 1 to 3 percent over DRC when corn is treated with organic acids, but the cost of the acid and its application must be considered.

Performance benefits of ensiling grain can partially be attributed to enhancement of protein solubility and starch availability. Early reviews found that soluble N, as a % of total N in ground HMC, was increased from 16% on day 0 to 38% on day 56 of ensiling (Prigge, 1976). Prigge (1976) also reported that energy availability based on CO<sub>2</sub> products was increased by approximately 20%. Benton et al. (2005) reported in situ dry matter digestibilities (ISDMD) of 37.7 and 61.3%, for 24% and 30% moisture HMC, respectively, following 28 days of ensiling. The rates of change in ISDMD, 28 days post-ensiling, were 0.44 and 0.38%/day for the 24 and 30% moisture HMC. Degradable intake protein (DIP) as a percentage of crude protein were 41.6 and 68.1% for the 24 and 30% moisture HMC, respectively, while respective rates of change in
degradable intake protein, 28 days post-ensiling, were 0.51 and 0.44%/day. Although rates of change in ISDMD and DIP were greater for the lower moisture corn, the magnitude of initial post-ensiling levels of ISDMD and DIP were greater for the higher moisture corn. Clearly, a positive relationship between changes in ISDMD and DIP is apparent. In addition, changes in starch digestibility and protein solubility appear to continue throughout the period the grain is being stored in a fermentative state. Mahanna (2007) attributed these continuous increases in starch digestion and related changes in energy content of ensiled corn to “spring acidosis” which is assumed to be found more frequently in cattle fed grain ensiled for a long (> 6 months) period of time.

Cooper et al. (2002) also found greater DIP (67.1 vs 31.1%), greater rate of starch digestion (4.8 vs 3.0%/hr), and greater ruminal starch digestion (68.4 vs 52.0%) for HMC vs DRC. Interestingly, steam flaked corn had a numerical DIP level very similar to DRC but, as expected, a ruminal starch digestion very similar to HMC. In grain sorghum studies, Defoor et al. (2000) reported insoluble CP (% of total CP) to be 7.68 in 30% moisture ensiled (105 d) grain sorghum, and 9.03% for dry rolled grain sorghum. Starch availability (% of total) was enhanced with ensiling from 36.5% to 51.6%. Thus, ensiling ground grain sorghum increased protein solubility and starch availability in a manner similar to that found in HMC.

**RECONSTITUTION**

A summary of research conducted in South Dakota, Indiana and Nebraska has found little if any improvement in gain and feed efficiency from reconstituting corn when fed in high concentrate rations. With the extra cost incurred in drying corn and then reconstituting it, harvesting HMC from the field and storing it in its native form seems more logical and economical than reconstituting dry corn. Adding enough moisture for adequate fermentation can be a problem because a moisture content above 25% is desirable for proper reconstitution but is often difficult to achieve. Reconstitution of milo is much more beneficial than reconstituting corn. However, reconstitution of grains can add flexibility to the feeding operation because less inventory of grain needs to be maintained when compared with traditional HMC systems.

**Ground Ear Corn or Ground Snapped Corn**

Ground ear corn (corn and cob only) appears to have 6 to 10 percent greater feed value when stored as high moisture feed than when fed dry. This improvement may be due largely to increased palatability of the feed. Ear corn can be easily harvested by adjusting combine fan speed and concave clearance to retrieve the ground cob and corn. Hill et al. (1995) found that a diet consisting of ground high moisture ear corn diet produced steer performance equivalent to that from a high moisture ground corn diet that contained 8% alfalfa. Snapped ear corn is another type of ear corn that normally is harvested by attaching a corn combine head to a silage chopping unit. Either ear corn or snapped corn provides a relatively inexpensive roughage source in feedlot diets. Between 8 to 15% of the dry matter of high moisture ground ear corn is found in the cob depending on hybrid and stage of maturity at harvest whereas ground snapped ear corn may contain 20% or more roughage from the cob, husks, and other plant materials. This is likely to be more roughage than preferred to achieve a maximum rate and efficiency of gain in finishing rations. Thus, for optimal cattle performance, additional grain must be added to most ground ear corn or snapped ear corn rations once cattle are adapted to their finishing ration. For best results, cob pieces need to have a diameter less than 1/2 inch to assure good packing and adequate consumption when fed. Ear corn will require 25 to 35 percent more storage capacity than grain alone. Where storage capacity is limited or more expensive structures are used, the improvement in feed utilization and the feed value of the cob may not offset the additional cost of harvest and storage.

**SUMMARY**

Harvesting, processing and storing grain at moistures between 25 and 30% can provide a more economical energy source in feedlot diets than dry processed grain. However, care must be exercised to minimize fermentation and storage losses that can offset the economic gains associated with early harvesting. In general, covering bunker silos will hold storage dry matter loss to under 5%. In addition, harvesting the cob with the corn and storing the product as ensiled ear corn offers a viable and relatively inexpensive source of both energy and roughage source for feedlot cattle. Grain that is
properly ensiled not only has increased protein solubility and starch availability compared to dry grain, but both protein solubility and starch availability appear to continue to increase during storage.

LITERATURE CITED

QUESTIONS AND ANSWERS
Q: Where did your data come from that shows a higher feeding value of high moisture grain stored whole and rolled at feeding time versus high moisture grain rolled into storage?
A: Our data were published in the Journal of Animal Science in about 1984. That was a summary of three studies. I understand that your data does not support the idea that corn stored whole and rolled at feeding time had no greater value than corn rolled into storage. These are our results.

Q: For Terry, what is the energy value of fermented snapped ear corn in terms of an NE\textsubscript{g} value or its feeding value relative to corn?
A: Ear corn silage or fermented ear corn can be of three different types and feeding values. With the cob alone, you have a value relative to corn of about 94 to 95%, add husks and you drop this value by 5 to 8%. Snapped ear corn includes ear, the husk, and tops of some plants. One can calculate feeding value based on fiber or roughage content of the product. Snapped ear corn has about 25% roughage, the ear with the cob and the husk is about 20% roughage; the cob alone will provide about 10% roughage. You can put net energy values on the roughage to calculate net energy values from this and include associative effects as well, if you wish.