FACTORS AFFECTING CORN SILAGE QUALITY

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INTRODUCTION

Corn silage has been increasing in popularity as a forage. Growing corn for silage has a number of advantages relative to other forages: high yields, one harvest per season, high digestibility and high energy content.

Corn is also one of the easiest crops to ensile. It has a high sugar content and a low buffering capacity which generally lead to low pHs, typically 3.7 to 4.0. Consequently, one does not have to be concerned about clostridial silages or other poor fermentations. However, this ease of fermentation may cause some people to think that silage management is not that important with corn silage. That is not the case.

Key Concerns

There are four primary areas of concern in making corn silage. First, to obtain high quality corn silage, the corn must be harvested at the right stage of maturity. With this crop, the optimum harvest stage relative to ensiling concerns is also the optimum stage relative to feeding value. Second, the corn plant can accumulate high levels of nitrate under some circumstances, which may affect ensiling and feeding. Third, filling and storage practices can have a large effect on a highly digestible crop like corn silage. Finally, corn silage is susceptible to heating during feedout, especially in the summer.

Harvest Considerations

The timing of harvest is important in determining the yield and starting quality of corn silage. It will also determine if there are potential ensiling problems. The method most commonly used to determine when to harvest corn for silage is the maturity of the corn kernels. The effect of maturity on the yield, quality and dry matter content of corn silage is shown in Table 1. The maximum yield occurs around 3/4 milkline although there is little difference in yield at 1/2 and no milkline. Crude protein content declines with maturity as the kernels fill with starch and as more leaves begin to brown at and after the no milkline stage. The minimum fiber content occurs at approximately 1/2 milkline.

Typically the optimum time to harvest corn is when the kernels are at the 1/2 to 2/3 milkline stage. This is near the maximum yield and minimum fiber content, thus maximizing yield of digestible dry matter. It is also at a good dry matter content for ensiling, approximately 35% DM.

Consequences of harvesting early: Harvesting too early not only reduces yield but increases the likelihood of having silage effluent. The potential for effluent production is dependent on the dry matter content of the crop and the type of silo. For bunker and bag silos, silage effluent does not occur when the crop is above 30% DM. For small tower silos (<15 m), 35% DM is usually adequate to prevent effluent. In taller tower silos, the minimum dry matter content is approximately 40%.

The further below the minimum DM content, the greater the amount of effluent produced (Fig. 1). Silage effluent is high in soluble nutrients: sugars, soluble nitrogen and salts. Consequently, dry matter losses from effluent are removing the most highly digestible fractions of the silage. This, however, is not the only concern. If effluent drains into a stream or lake, environmental damage such as fish kills may result because of the high concentrations of nutrients in the effluent.

Consequences of harvesting late: The most obvious consequence is the reduction in quality and yield when the crop is overly mature. Also the kernels become harder, more may pass through the animal undigested. (Currently in the U.S. there is an increasing interest in adding kernel processors to harvesters to help break kernels and improve digestion. Such processors have been common in Europe for some time because of the types of corn grown there.)

Overly mature corn also affects ensiling. An overly dry crop is more difficult to compact and leads to a more porous silage that will be more susceptible to spoilage by microorganisms. As shown in Fig. 2, porosity or the fraction of air space in the silage at a given dry matter density increases significantly as dry matter content increases. The movement of air into silage is proportional to the porosity of the silage, and it appears that dry matter losses in a silo are approximately proportional to the amount of air entering the silage during storage and feedout. As a result, drier silages will be much more susceptible to spoilage losses and heating.

Is it possible to add water to an overly dry crop to bring the dry matter content down? Yes, but it may require much more water than you might expect. For example, if you have 1 t of corn silage at 45% DM, then you would need to add 286 l of water to make it 35% DM.

Moisture measurement: In years that are unusually wet or dry, estimating moisture content by kernel milkline may not be adequate. Also kernel milkline may not be reliable in some hybrids. One can use a commercial forage moisture tester or get a reasonable estimate using a gram balance and microwave oven.

Nitrates

High nitrate levels in a crop can be toxic to animals. When the crop is ensiled, some of the nitrates may be reduced by bacteria to nitrogen oxides, poisonous gases. This can cause potentially hazardous conditions particularly in tower silos.

Nitrate is the primary form of nitrogen by which the plant takes up nitrogen from the soil. Normally the nitrate is largely converted to proteins and other organic nitrogen compounds by the plant. However, under some circumstances, nitrate may accumulate in the plant, particularly the stalk and leaves. The two most common causes are excessive nitrogen fertilization and drought. In both of these cases, the corn takes up more nitrogen that it needs so that the excess remains as nitrate. Under drought conditions, nitrate concentrations tend to be highest shortly after a rainfall. Brief droughts are worse than prolonged drought conditions. Other nutrient deficiencies such as phosphorus, potassium and others may cause nitrate accumulation. If plant growth is limited by these, the plant may take up excess nitrogen relative to its needs.

Ensiling will reduce nitrate levels by approximately half. Enterobacteria and possibly other bacteria will use nitrate in place of oxygen once the silo becomes anaerobic. The nitrate is converted to nitrite and then nitric oxide (NO), which is a colorless gas. In air, the nitric oxide is converted to nitrogen dioxide (NO_2, a red-brown gas) and nitrogen tetroxide (N_2O_4, a yellow gas). All three gases are poisonous and cause serious lung damage, pneumonia and even death if concentrations are high enough. These gases are produced in the first week of ensiling and may be present around a silo for three or more weeks.

Normally the most danger is around tower silos. In bunkers or bags, air movement around the silos will quickly dilute the nitrogen oxide gases so that there is much less danger. Even so, you should be cautious if you should see yellow or brown gases coming from any silo or smell a bleach-like odor. In tower silos, the gases can collect above the silage because these gases are heavier than air. These gases have been known to drift down the silo chute into barns or silo feed rooms. Thus where chutes from tower silos come into an enclosed place, it is wise to have adequate ventilation in that area for the first month after making corn silage to dilute any nitrogen oxides. One should also make sure that these gases cannot seep into adjacent barns where there is also the potential for livestock to be harmed or killed.

If you need to enter a tower silo within 3-4 weeks of filling, then the run the forage blower for 15 to 20 minutes with the top silo door open before entering the silo to reduce nitrogen oxide levels. Also use a self-contained breathing apparatus when entering the silo within the first 3 weeks.

Filling and Storage Practices

Filling. As indicated in the earlier talk on alfalfa, one wants to fill a silo as quickly as possible. This minimizes the loss of sugars from respiration and also reduces the growth of spoilage microorganisms during the filling period. If large populations of spoilage microorganism develop during the filling period, it generally leads to silages that are likely to heat during feedout. This is particularly true for corn silage.

A second important factor in filling is obtaining a high density. The higher the density the greater is the silo capacity, reducing storage cost. Also important is the effect of density on the porosity of the silage as shown earlier in Fig. 2. By increasing density, one reduces the potential for DM losses from microbial spoilage.

In the tower silo, density at any location in the silo is primarily determined by the weight of crop added above that point and wall friction. This has led to standard tables predicting density with depth. However, the use of a distributor may promote more uniform filling, resulting in somewhat higher densities. In bag systems, densities are affected by the filling mechanism on the bagger and by the brake pressure of the tractor running the bagger. One should also make sure that filling produces a smooth, uniform tube of silage. This is important during feedout so that air cannot move rapidly back from the open end of the bag. In wrapped bales, density is determined by the baler type and the skill of the operator (primarily in round bales) in making a uniform bale.

In horizontal silos, the packing of silage by tractor or bulldozer is the primary determinant of silage density. As a result, dry matter densities in bunker silos are highly variable. We are currently carrying out a survey of bunker silo densities and filling practices in both corn and alfalfa silages. Based on 150 farm silos, the range in DM densities taken at approximately 1.2 m from the silo floor is 106 to 434 kg/m^3, and the average is 235 kg/m^3. The averages and ranges are very similar for both crops. In an earlier survey of 30 alfalfa silages in bunker silos, Ruppel et al. (1995) found that the weight of the packing tractor and the time spent packing were the most important factors in getting good densities. They suggest packing at a rate of 400 to 500 hour-kg tractor weight/tonne crop in order to get a high density. Preliminary evaluation of our data also indicates the importance of tractor weight and time per tonne as important factors in getting a good density. In addition, a two other factors appear to be important. One is how thinly a load is spread out over the bunker. The thinner the layer the greater the density obtained (Fig. 3). In general, the load should be spread out in a layer no thicker than 15 cm. Another is the height of the silo (Fig. 4). There does not appear to be much increase in density for silages that are greater than 4 m in height. However, we found that those who filled bunkers very high spent less time packing per tonne on average.

One thing that surprised us is that the use of dual wheels on tractors did not appear to reduce packing efficiency. Tractor weight was much more important than number of tires per tractor or tire pressure. For big silos, multiple tractors may be necessary to get a sufficient density. Use your rate of filling plus the 400 to 500 h-kg/tonne guideline to determine what tractor(s) you need to get a good density. For example, if your filling rate is 30 t/h, then you need a tractor weighing at least 30 * 400 or 12,000 kg (or multiple tractors adding up to 12,000 kg) packing continuously during filling in order to get a good density.

Another factor in filling a bunker silo is use of the progressive wedge technique (Fig. 5). This manner of spreading out loads reduces the surface area exposed to air relative to spreading the load out over the whole floor. This helps minimize respiration losses during filling. On the other hand, if the exposed area is reduced too much, i.e. too thick a layer is piled up, one cannot get a high density.

Storage. As with alfalfa silage, sealing the silo well is very important. It is perhaps even more important in corn silage because it is so susceptible to heating during feedout, which can reduce intake. Currently, plastic (polyethylene) provides the best seal and protection for the crop. In the case of bunker silos, the plastic needs to be securely anchored to the crop with used tires or by some other means. If the plastic billows in the wind, it can draw air into the silos like a bellows. It is not only important to seal the silo well but to periodically inspect the plastic whether you have bag, bale or bunker silos. If you find holes, patch them with a waterproof tape.

In the alfalfa silage talk, I mentioned the value of covering. That certainly applies to corn silage as well. However, farmers often wonder if there are not some good alternatives that would take less time. Unfortunately, there are not! Minson and Lancaster (1965) looked at 6 different silo coverings in 1 m deep bunkers (Table 2). None of the alternatives came close to the performance of plastic although several were better than no cover. Other alternatives such as spreading grain on the surface, applying molasses or molasses based products, etc. have been shown by others to be relatively ineffective as well. So for now, plastic is our best solution.

Feedout Practices

How you remove silage from silos can have a significant effect on DM losses and on how susceptible a silage is to heat in the silo or in the feedbunk. There are two issues: the rate of removal and the removal technique.

Removal rate. Losses during feedout are correlated with the time the silage is exposed to air prior to being removed. That time is dependent on 1) the porosity of the silage, which determines the rate at which air can move back from the face and 2) the feedout rate in cm/day. If, for example, air can move back 1 m from the face and you are removing 10 cm/day from the face, then the silage will be exposed to oxygen for 10 days prior to feeding. The longer that time is, the more likely you will have substantial DM losses during silo emptying and the more likely your silage will heat in the feedbunk.

Fig. 6 predicts the DM losses during feedout from a bunker silo for 35% DM silage at a wet density of 640 kg/m^3, fairly typical conditions under good management. At 15 cm/day removed from the whole face, DM losses during feedout are a modest 3%. Those losses increase geometrically at lower removal rates. One can predict the DM loss during feedout for your situation by taking the DM loss in Fig. 6 for your feedout rate and multiplying it by the ratio of the porosity of your silage with that for conditions in Fig. 6 (approximately 0.43, based on Fig. 2).

Typical recommendations for feedout rates in well managed silos are as follows: 5 to 10 cm/day for tower silos, 10 to 15 cm/day for bunker silos, 30+ cm/day for bag silos. The lower numbers should be fine in winter but may not be adequate in summer. The recommendation for bag silos is very tentative because there are questions still about the normal range of densities in bag silos. When planning to build a silo, one should design the silo to achieve a minimum of 10 cm/day for tower silos and 15 cm/day for bunker silos. This will prevent potential problems in actual use.

Removal technique. The best method to minimize DM loss at feedout from a bunker or bag silo would be one that resulted in a smooth surface such as those created by tower silo unloaders. This, however, might not be the most cost effective method.

We compared a device that milled a smooth face with a front-mounted bucket on a tractor for removing silage from a bunker silo. The milling device made only modest improvements in DM recovery (0.5 to 1.9%) on our own silos compared with doing a very good job with a bucket. We used a computer model to extend those results over a range of densities and feedout rates (Fig. 7). These results suggest that a specialized milling device provides more benefit when feedout rates are low and/or densities are low. Also there appears to be more advantage in hay crop silages. Even so, differences are not great when other aspects of silo management are handled well. An economic analysis indicated that the increases in net return for a 100-cow dairy were on the order of $400 to $750 per year for well-managed silos based on equivalent costs and labor for both devices. This would justify up to $6000 additional aquisition cost for such a milling device if labor were not affected.

It must be emphasized that this comparison is based on doing a very good job with a bucket. This means not leaving lots of loose silage at the bottom of the face overnight. It also means making the face relatively smooth. Ruppel (1997) has suggested a good way to remove silage from the face of a bunker (Fig. 8). This helps to make a relatively smooth face without opening deep cracks for air to move deep into the silo.

Another issue: do you need to remove material from across the whole face of the silo each day? No. What is important is that the average rate of removal from the whole face meets the recommendations above. For example if you use a block cutter to remove silage from a bunker, it will most likely take a deep cut, and it may take several days to work across the face. This is all right as long as the depth of your cut divided by the number of days to work across the whole face gives you a reasonable feedout rate.

Feedout problems. Corn silage is well known to have problems with heating, particularly during the summer. This can sometimes occur even when one has done everything well. The primary means of getting through this problem is to increase the feedout rate. In the U.S., farmers have sometimes applied propionic acid to stop spoilage at the face and cool the silage. This may make the silage cooler and more palatable, but it does not really solve the problem. Propionic acid at the face just allows oxygen to move deeper into the silo. So the key is increasing the removal rate and thus reducing the exposure time to oxygen.

In a bunker silo, one has the option of just feeding off one half of the silo, doubling the feedout rate. The remaining half will sustain substantial spoilage losses on the open surfaces, but you will most likely be able to feed cool silage. In a bag silo, you may try closing off the face as best as possible after your done unloading for the day.

If heating silage is a problem year after year, then you need to evaluate your management practices. Is your feedout rate good? If your feedout rate is low, consider putting a dividing wall in a bunker silo to increase your rate or reduce the height of silage in the silo to increase rate. Are you getting and keeping a good seal on the silo? Are cracks in the concrete walls developing that need repair? If you see more than several centimeters of spoilage, the seal can be improved. Are you getting a good density in your bunker or bag? Increasing density will be beneficial, but it will also reduce your feedout rate. So you may need to do more than just improve packing.

Additives

In the U.S., there are three types of additives that are used on corn silage: nonprotein nitrogen, inoculants and propionic acid. Each has a different purpose.

Nonprotein nitrogen. Three forms are used in the U.S.: anhydrous ammonia, aqua-ammonia and urea. As far as I am aware the U.S. may be the only country where ammonia is used. It is relatively hazardous to work with but is attractive in that it is less expensive than urea. There are two basic reasons for using a nonprotein nitrogen additive: increase the crude protein content of the silage and increase the bunk life (resistance to heating) of the silage.

In the silo, plant enzymes break urea into ammonia and carbon dioxide so that it produces similar effects to ammonia. Ammonia raises crop pH, and the combination of ammonia plus high pH kills many of the yeasts, molds and bacteria that cause heating and spoilage. If the silo remains well sealed, this should reduce the likelihood of heating. Because the initial pH of the crop is elevated, more fermentation occurs to reach a stable pH in corn silage. Also the lactic acid bacteria that survive tend to produce more acetic acid. Consequently, there are higher levels of fermentation products especially acetic acid, which can also help to improve the bunk life of a silage.

Ammonia should improve dry matter and fiber digestibilities mainly by breaking down hemicellulose in the plant cell wall. This should help improve animal performance. Research with anhydrous ammonia has yielded mixed results, perhaps because of the difficulty in getting a uniform application. Research with urea on corn has in general shown small but significant improvements in animal performance beyond what might be expected if urea were added to the silage at feeding.

Application rates are usually set to increase the crude protein content of the silage by approximately 5 percentage units.

Inoculants. Inoculants are sold in the U.S. for making corn silage as well as for making alfalfa and grass silages. The principle is the same: produce a fast and efficient fermentation that is high in lactic acid and low in acetic acid and ethanol.

While these products have been relatively effective in hay crop silages, a survey of recent research has shown that these products are successful in reducing pH approximately 40% of the time in corn silage (Muck and Kung, 1997). The reduced performance is likely due to the higher natural level of lactic acid bacteria on corn compared to that on alfalfa. Also, corn frequently has a very low pH without inoculation and a fermentation profile that may be naturally high in lactic acid.

Another problem with inoculants is that they sometimes cause silages to heat more rapidly than uninoculated silages. This is due to the reduction in acetic acid in the inoculated silages. This problem is much more prevalent in corn and small grain silages than in hay crop silages. As a result, inoculants are not as attractive a silage additive for corn silage. It must be noted that inoculant manufacturers are aware of the heating problem and are seeking bacterial strains that will more consistently improve silage bunk life.

Propionic acid. Propionic acid and propionic/acetic acid mixtures are sold primarily to improve the bunk life of corn silage. These acids, particularly propionic, can strongly inhibit the growth of yeasts and molds. These products are typically added at 0.2 to 1.0% of fresh weight. It is important to apply the products at or above the recommended rate. Applying under recommended rates can significantly reduce the effectiveness of these products.

Summary

Corn silage is a relatively easy crop to ensile because of its high sugar content and low buffering capacity. One keys to success is to harvest at the right stage, 1/2 to 2/3 milkline, where yields and quality are high and where moisture content is appropriate for good ensiling. Good silo management is also needed to minimize the exposure of the silage to air, particularly because corn silage is susceptible to heating. Steps that will help include: rapid filling, packing to a high density, sealing well, maintaining the seal, and feeding out at a sufficient rate to minimize oxygen exposure.

TABLE 1. Effect of harvest stage on yield and quality of corn silage (Weirsma and Carter, 1993).

Maturity Stage	Dry Matter, %	Dry Matter Yield, t/ha	Crude Protein, % DM	NDF*, % DM	Digestibility, % DM
Early Dent	27	12.5	9.9	48.0	79.0
1/2 Milkline	34	14.1	9.2	45.1	80.0
3/4 Milkline	37	14.3	8.9	47.3	79.6
No Milkline	40	14.1	8.4	47.3	78.6

* Neutral detergent fiber

TABLE 2 Effects of cover type on dry matter losses from 1.05 m deep bunker silos (Minson and Lancaster, 1965).

Cover Type	None	Roof	Sawdust	Soil	Limestone	Plastic
Visible Waste	5.6	10.0	4.2	6.3	5.8	0.8
Effluent	7.5	3.0	6.5	5.0	*	2.5
Gaseous	21.1	19.6	19.3	13.8	--	8.6
Total	34.2	32.6	30.0	25.1	23.6	11.9

* Leak caused effluent not to be collected

FIGURE 1. Silage effluent per tonne of crop from a bunker silo as affected by the dry matter of the crop (Bastiman, 1976).

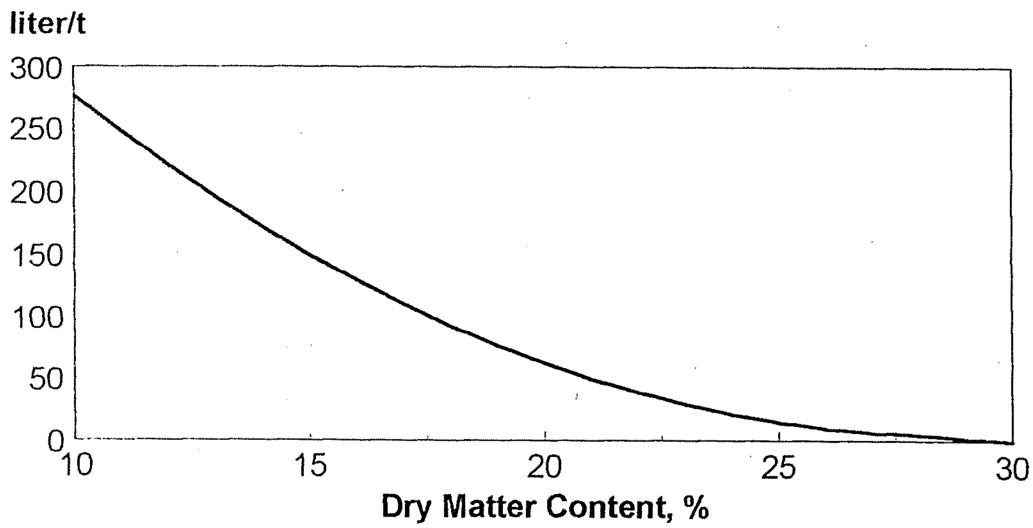


FIGURE 2. Porosity of silage as a function of dry matter density and dry matter content.

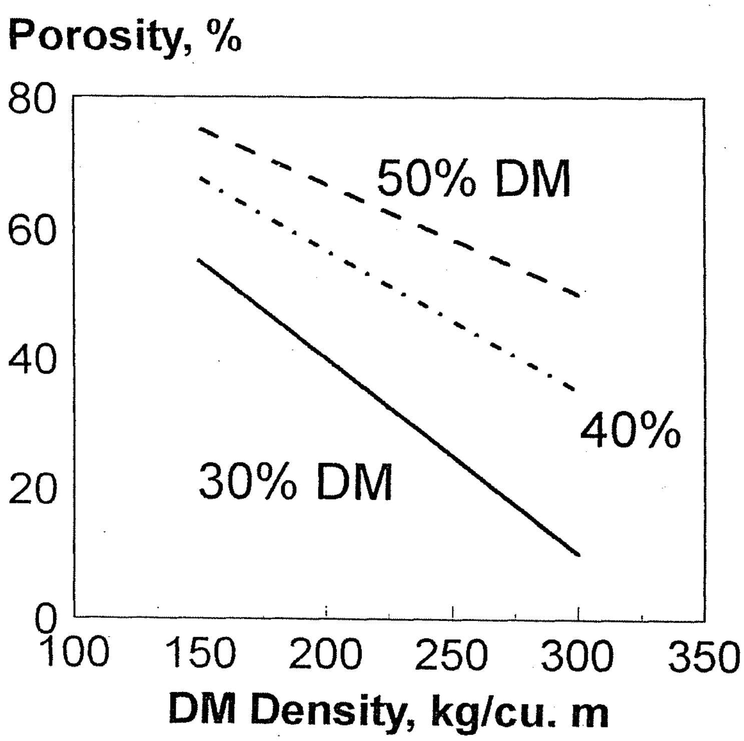


FIGURE 3. Dry matter densities in bunker silos as correlated with how thick a load is spread out during filling.

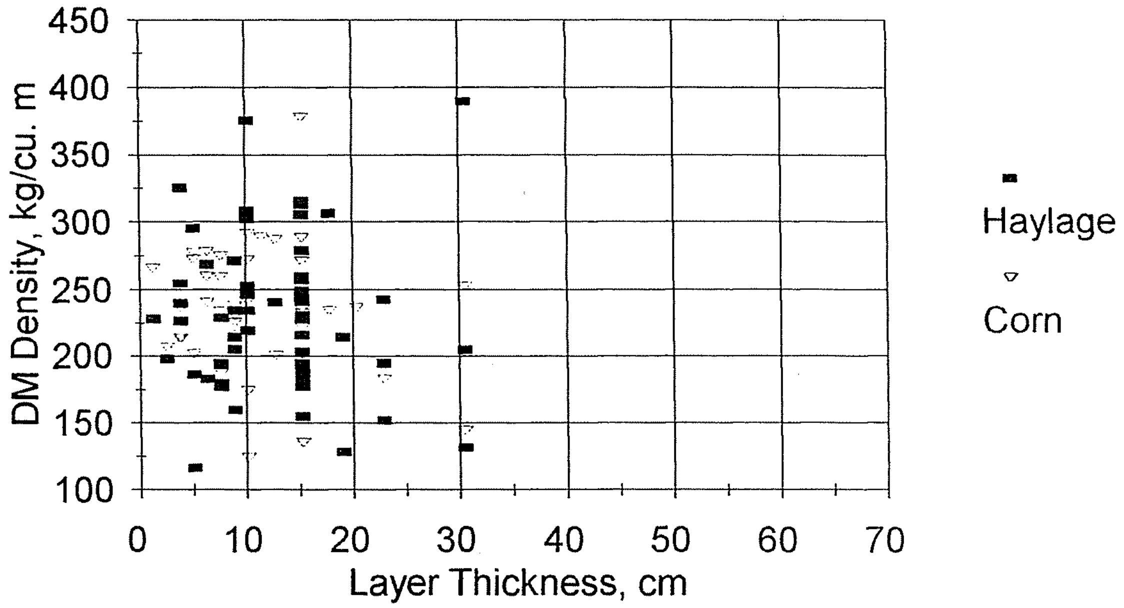


FIGURE 4. Dry matter densities in bunker silos as correlated with the maximum depth of silage in the silo.

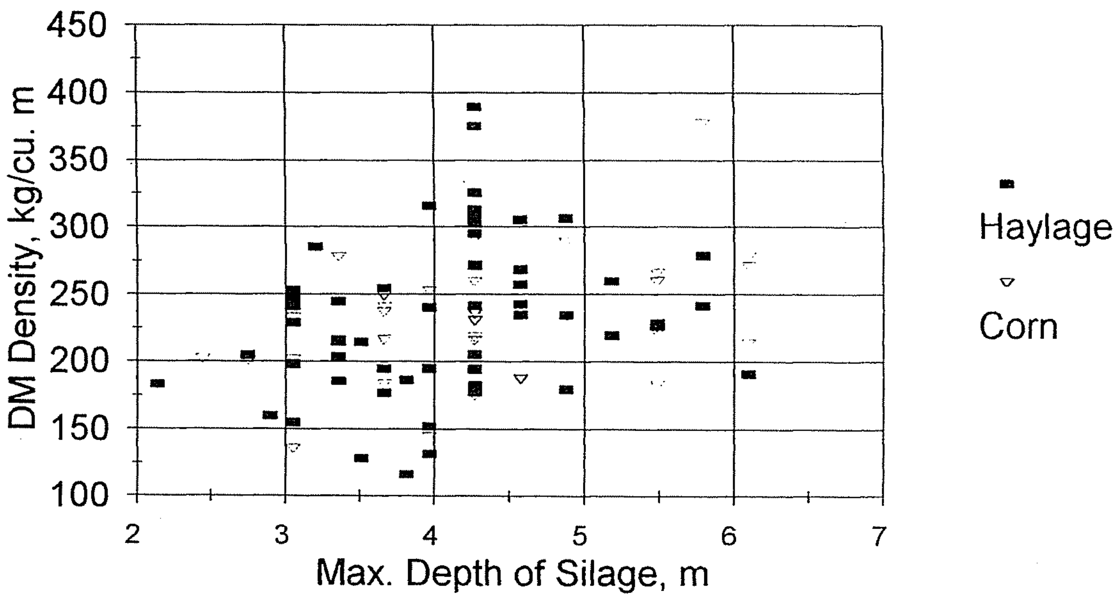


FIGURE 5. Comparison of the progressive wedge method of filling a bunker silo with other methods.

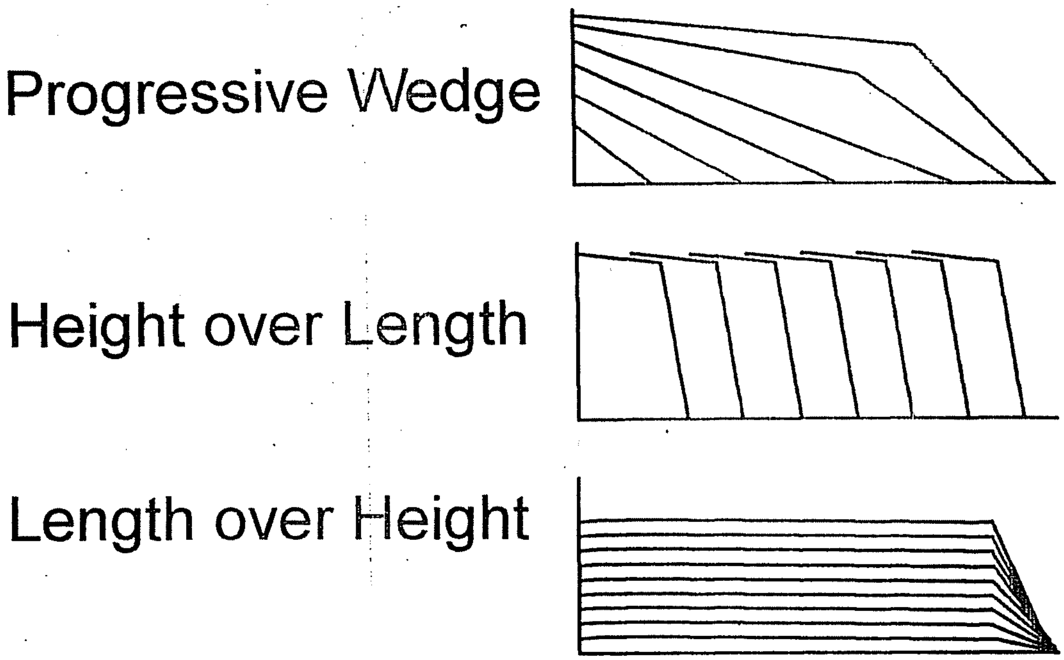
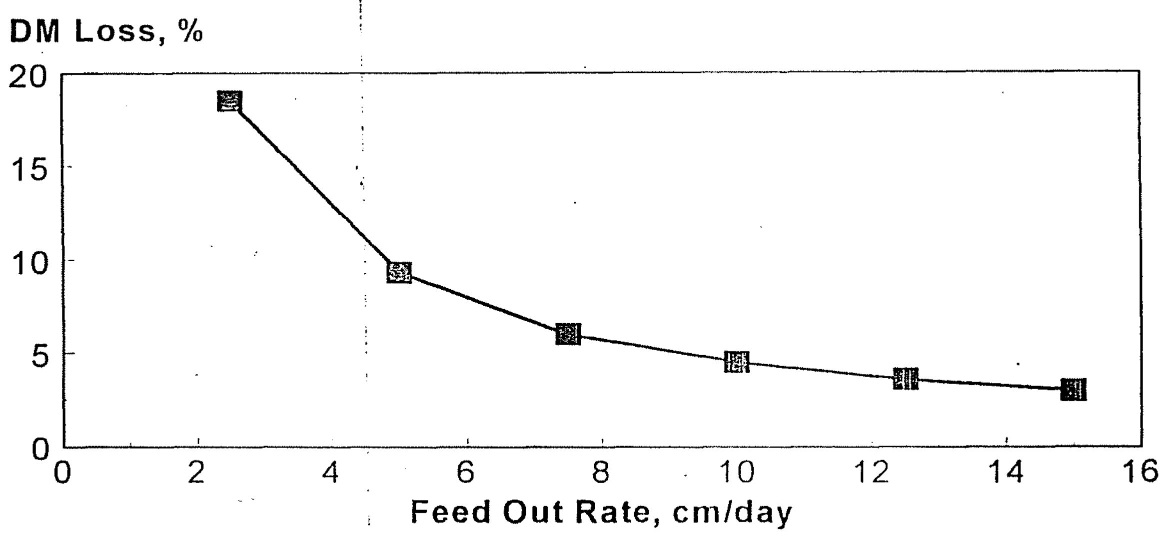
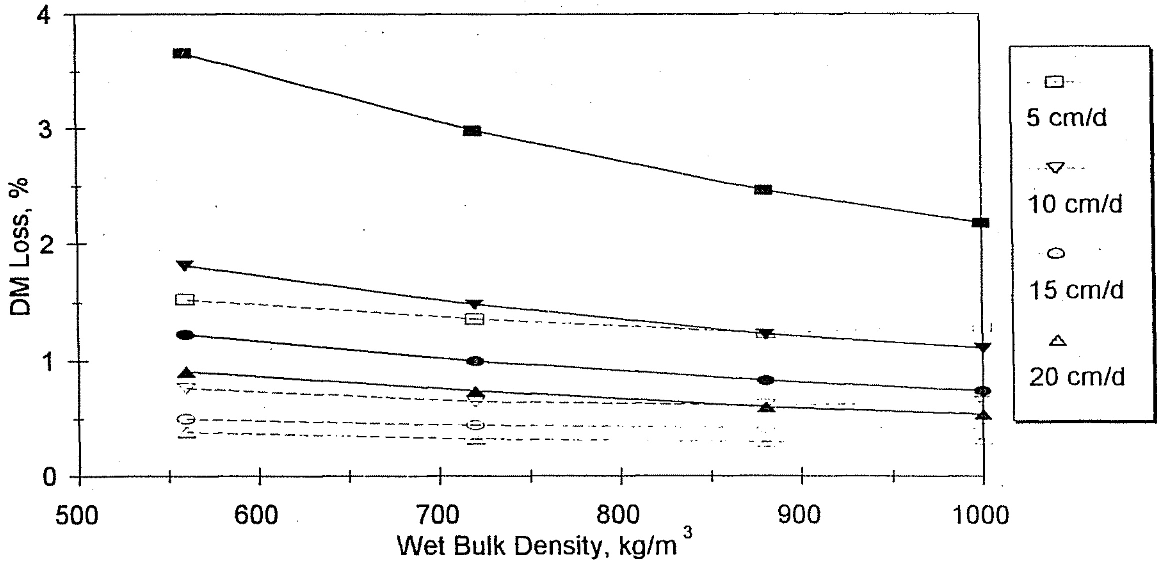


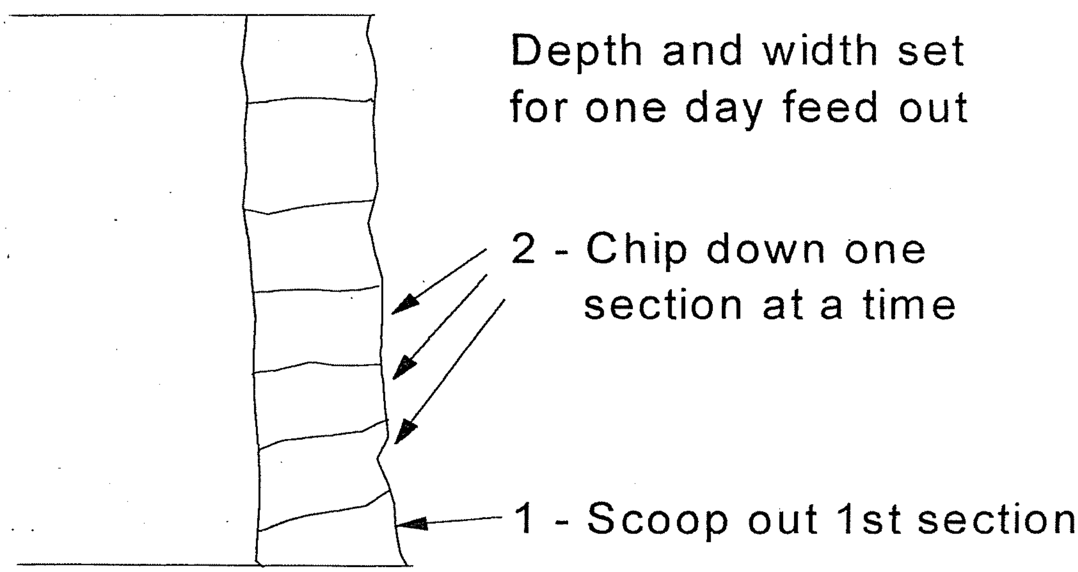
FIGURE 6. Loss of dry matter during feedout as a function of feedout rate based on silage at 35% DM and a wet density of 640 kg/m^3 (Pitt and Muck, 1993).



GURE 7. Differences in dry matter losses between a bucket unloader and a milling device for removing silage from a bunker silo as predicted by DAFOSYM. Solid symbols - alfalfa; open symbols - corn. (Muck and Rotz, 1996).



GURE 8. Bunker silo feedout technique to minimize fractures in a silage face (adapted from Ruppel, 1997).



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