Preparation, Maintenance and utilisation of maize silage – a review.

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Abstract

Forage conservation has become an important tool for animal enterprises to ensure an adequate supply of quality feed throughout the year. This in turn contributes to stability in animal production and thus economic performance. Silage is often the preferred preserved fodder when animals are fed adjacent to the storage site. Plant species that are suitable for silage are those that have high dry matter yield per hectare and high digestibility, low buffer capacity and a high amount of water soluble carbohydrates. Whole plant corn has a range of 28 to 42 % of dry matter for about 2 weeks during grain filling, low buffer capacity and a high amount of water-soluble carbohydrates. These characteristics make maize an ideal silage crop. The preparation, storage and utilisation of silage can be divided in four phases - aerobic, respiration, stable and feed out phases. During these four phases losses of dry matter occur. These losses can be divided in unavoidable (i.e. those inherent in the process of production of silage) and avoidable (those that are the result of design and operational inefficiencies in harvest, storage and feed out). Factors that contribute to high quality of silage include harvesting the crop when the soluble carbohydrate (principally sugars) concentration in the crop is high, minimising respiration, achieving and maintaining an effective silage storage environment, maintaining anaerobic conditions during the stable phase, and minimising spoilage losses during the feed out phase. Additives can also be used to optimise the silage storage environment. Acceptance by animals of silage measured as dry matter intake is mainly related to quality of the material, particle length and feeding methods, its quality in storage and utilisation in animal production.

Introduction

Silage is forage preserved under anaerobic conditions, which has a moisture concentration of 50 to 85 %. Haylage requires dehydration before being stored in anaerobic conditions (Collins and Moore 1995) and contains 45% moisture. Due to its characteristics, whole plant corn is the nearly perfect silage crop. However, to achieve a high quality product, specific practices at each stage of the process must be followed.

The aim of this review is to summarise the steps involve in making maize silage, explain the physiological process that the forage undergoes, and highlight the practices that lead to a high quality end product.

Principles

Because it is difficult to transport, silage is used in the place it is made. It can be harvested at any time of the year, because it is less affected than hay by weather damage. Silage can preserve more nutrients per ha than hay because there is less field loss. More crops can be used for silage and silage is better suited as an ingredient for mixed rations for livestock than hay (National forage and grassland curriculum, 1996-98). The main disadvantages are that the process usually requires high machinery input and it can produce unpleasant odours (White *et al.*, 1999). Nevertheless it is less labour intensive than making hay (National forage and grassland curriculum, 1996-98).

According to O'Kiely (1998) plant species that are suitable for silage are those that have the following characteristics:

- High dry matter (DM) yield per hectare
- High digestibility
- High amount of Water soluble carbohydrates (WSC), such as glucose, fructose, sucrose and fructans
- Low buffering capacity (BC). The BC is defined as the equivalents of acid per unit DM needed to lower crop pH from 6 to 4. BC varies with grass species, and is usually higher in legumes, than in grasses or maize.

Maize silage has all the above mentioned characteristics (Bolsen, 1994). However, in order to achieve a high quality product specific practices at each stage of the process must be followed. The silage making process can be divided in the following units:

- Tillage
- Harvesting
- Storage
- Feed out phase

Tillage

Practices that tend to favour a high yield include conditioning of the ground, fertilizing, watering, drainage and control of weeds. Because these practices are common for all crops they are not covered in this paper.

Harvesting

It is very important to cut the forage at the right time in order to avoid losses during ensiling and to ensure a high quality product. From the physiological viewpoint, it is important to cut the forage when plant sugars are high, since this helps to feed bacteria. This brings better fermentation and increases the population of lactic acid bacteria, which in turn lowers the pH rapidly and provides greater useable energy (Bailey, 2000).

Cutting forage late in maturity reduces the digestibility of the forage, due to the changes in the chemical composition of the crop at different stages of maturity. After plants finished the growing period, structural components of the plant increase as a percentage of total DM, while components of the cell such as proteins, minerals and lipids decrease (White et al., 1999). Plant cells content is almost completely digestible, while the availability of plant cell walls varies depending on their composition and structure but tend to be less digestible than cell content. Additionally, as a plant advances in maturity, the leaf:stem ratio usually decreases (Buxton and Mertens, 1995).

On the other hand, cutting forage too early increases the losses due to seepage and low forage mass. Digestible DM yield and concentration of the crop peaks earlier than herbage mass (White et al., 1999). Therefore, farmers face a dilemma. They have to chose to harvest the forage early and lose silage mass or harvest late and lose digestibility.

This problem is not so serious with whole-plant corn, because it has an acceptable range (28 to 42%) of DM for about two weeks during the harvest season (Bolsen, 1995). It is also possible to use the maize kernel milk line to tell the ideal time to cut maize for silage. The line must be in the middle from the top to the butt. In this stage the plant have 68% moisture and the kernel 40% moisture. This line is the interface between the liquid endosperm and the solid endosperm portions of the kernel (Bolsen, 1995).

Chopping the forage properly is important not just because it helps to maintain the quality of the forage by reducing the pH faster (Seale, 1982), but also because particle length of the end product might negatively affect DM intake (Journet, 1995, Jambor, 2000). In order to avoid any effect of particle size in DM intake it is recommended to chop the forage at about 8 mm, because below this size there is not additional change of intake (Demarquilly, 1994).The fast acidification of the forage when is chopped properly could be explained, at least in part, by the increase in the lactic acid bacteria (LAB) population reported by Bolsen (1995).

In silage with 30% DM, organic nutrient digestibility increased with an increase in length of chop, whereas the DM intake tended to decrease. In silage with 40% DM, OM digestibility tended to decrease as chop length increased, while the silage intake tended to increase (Jambor, 2000). The decrease in digestibility of silage due to a decrease in the length of the particle is presumably a result of a higher rate of passage through the digestive system (McDonald *et al.*, 1991) while the decrease of OM digestibility of 40% DM silage might be related to the stage of maturity of the crop at the time of harvesting.

Storage

Storage practices are those that aim to minimise the activities of the plant enzymes and undesirable microorganisms, and encourage the dominance of lactic acid bacteria and include rapid filling, proper packing and effective sealing of the material (Bolsen, 1995) and the use of additives.
During storage stage and after the crop is harvested the forage undergoes a process that can be divided into three phases:

- Aerobic phase
- Fermentation phase
- Stable phase

(i) Aerobic phase

During the aerobic phase, the respiratory activity of the plant continues. Respiration is the process of oxidation of WSC. Respiration uses oxygen and produces carbon dioxide, water and heat.

When the plants are cut, chopped and crushed they release enzymes contained in cells. These enzymes, such as amylases and hemicelluloses, break down starch and hemicellulose. As a result of this process the amount of WSC in the ensiled material is increased (Bolsen, 1995). On the other hand, other enzymes such as proteases hydrolyse proteins to non-protein nitrogen (NPN), amino acids, peptides and ammonia (NH3). Heat produced in the process raises the temperature in the ensiled mass, which in turn increases the rate and extent of protein breakdown to soluble non-protein components. Temperatures above 42° C may cause Millard reactions, where sugars and amino acids are formed into polymers that are less digestible (Bolsen, 1995)

(ii) Fermentation phase

The respiration process uses up the oxygen that remains in the forage mass and anaerobic conditions are reached. Under this condition cell plants start to lyse, releasing sugars and plant enzymes, as a result more sugar is made available to LAB and more NPN components are produced.

On the other hand, the anaerobic conditions allow anaerobic bacteria to grow and reproduce rapidly. These bacteria are mainly LAB, enterobacteriaceae, yeast, molds and clostridial spores (McDonald et al., 1991). Between these microorganisms the most important to the ensiling process is the LAB. These bacteria ferment sugars to produce lactic acid which is the substance that preserves forage. LAB also produces ethanol, acetic acid and carbon dioxide.

Lactic acid production reduces pH. Low pH reduces the activity of proteolytic enzymes and stops the growth of some anaerobic bacteria such as *Enterobacteriaceae, Listeria, Bacillus spp. and clostridia* (McDonald et al., 1991). Low pH also increases the hydrolysis of polysaccharides such as hemicellulose.

The fermentation phase can last from 7 to 30 days. The time it takes is related to the percentage of moisture of the forage and is longer when the moisture is high. This phase is finished when fermentation of sugars by LAB ceases due either to low pH that stop LAB growth, or a lack of sugar (Bolsen, 1995).

Secondary fermentation is due to the growth of clostridial spores. Clostridia become active as soon as anaerobic conditions are reached, because they are normally inactive in the presence of oxygen. Clostridia can ferment sugar and organic acids, as well as freeing amino acids. These actions affect silage quality and increase losses in DM because the main product of this fermentation is butiric acid and it is a much weaker acid than lactic. This lead to a loss of 50% of ensiled DM and 20% of energy. Fermentation of amino acids by clostridia produces NH3, amines and volatile organic acids, which are of poor nutritional value, and also result in significant losses of DM .

If forage is ensiled between 30% to 35% DM or more, there will be little effluent, except in large tower or bunker silos. Below 30% DM, the amount of losses due to effluent is positively correlated with the moisture content of the plant and the pressure or packing in a silo (Pitt and Parlange, 1987). This effluent can become an environmental problem if it is not collected. After collection it can be used to feed cattle or as a fertiliser in the pastures (Bolsen, 1995).

(iii) Stable phase

This phase is characterised by little biological activity. If the fermentation phase is finished because of a lack of sugar, LAB may then ferment the sugars released by hemicellulose breakdown, leading to a continuing slow decrease of pH.

The losses during this phase are related to the permeability of the silo to air. Oxygen entering the silo increase the population of aerobic bacteria. This bacteria use as a substrate sugar, organic acids and proteins, leading to reduced nutrient digestibility and DM content, increased fibre content and production of heat (Ishler *et al.*, 2002).

Losses during the stable phase are due to oxygen entering the silo and depend on sealing techniques and physical properties of the cover. There have been attempts to measure the losses of DM due to spoilage of the surface. Ashbell et al, (1990) argued that the relation between the ash content in a silage sample and the losses of DM content can be expressed as follows:

Losses due to additional spoilage (%)= 1-((AF X OMS)/(AS X OMS)) x 100

Where AF is the percentage of ash in the face sample, OMF is the percentage of DM in the face sample, AS is the percentage of ash in the surface sample and OMS is the percentage of DM in

the surface sample. This relationship is based on the assumption that the DM content is reduced as spoilage occurs while the ash remain constant (Ashbell *et al.*, 1990).

Practices that help to minimise losses during storage phase

Reducing the time between harvesting the crop and closing the silo can minimize respiration losses (Bolsen, 1995). Losses of primary fermentation are related to the type of fermentation. There are two types of fermentation homofermentative and heterofermentative. The former produces lactic acid while the latter produces ethanol, acetic acid and carbon dioxide in addition to lactic acid. Homofermentative process results in little or no loss of DM and only small losses of energy. The heterofermentative process will result in losses in no more than 5%, and greater energy loss (McDonald et al., 1991).

Lactic acid is a stronger acid compared to acetic. Therefore the homofermentative process lead to a faster reduction in pH. Quickly lowering the pH reduces the activity of proteolytic enzymes and stops the growth of other bacteria. In this way DM losses are reduced by conserving proteins and using more efficiently the available sugar by the LAB due to the reduction in undesirable bacteria. *Lactobacillus acidophilus*, *Pediococcus acidilactici*, *Enterococcus faecalis*, *Lactobacilus lactis* and *Streptococcus bovis* are homofermentative bacteria of importance in the ensiling process (McDonald et al., 1991).

Additives may promote desirable fermentation and preservation or inhibit the detrimental process (Table 1). Additives that promote lactic acid bacteria can be divided into inoculants and substrate suppliers (National forage and grassland curriculum, 1996-98). Inoculants are specific species and desirable strains of LAB. Therefore they can help to reduce pH faster in the silage minimising the losses due to plant respiration and therefore reduce the risk of heat in slage. (Bolsen, 1995).

Substrate suppliers are another kind of stimulant additives. They aim to provide additional sugars quickly for fermentation in the silo (O'Kiely and Muck, 1998)., this group can be divided into enzymes and sugars (Ishler et al., 2002, National forage and grassland curriculum, 1996-98). Cell wall degrading enzymes are the most used type of enzyme additives, these include hemicellulases, xylanases, cellulases and pectinases, but there are other possibilities such as Starch-degrading enzymes. The principle advantage of enzymes is that they improve fermentation and breakdown of fibre. However, they increased effluent production in forage ensiled below 30 % of DM (Bolsen, 1995)

Sugars or carbohydrates such as molasses, sucrose, glucose, dextrose, beet pulp, citrus pulp, and whey are some examples of substrate suppliers (National forage and grassland curriculum, 1996-98).

Inhibitor additives are substances that slow down undesirable activity, such as clostridial fermentation. Table 1 shows the type and availability of these kinds of additives.

Table 1. Silage additives

Stimulants				Inhibitors	
Inoculants	Substrate suppliers		Aerobic	Acids	Other
Lactic acid	Enzymes	Sugar		Formic	Sulphur Dioxide
Bacteria	Cellulases	Molasses	Sulfates	Mineral	Sodium-
(*Lactobacilli*	Amylases	Sucrose	Caproic,	Lactic	Methabisulphite
Pediococci	Pectinases	Glucose	Sorbic,	Acetic	Formaldehyde
Streptococci)	Proteases	Dextrose	Acids	Benzoic	Paratoimaldehyde
Yeast	Xylanases	Beet pulp	Ammonia	Acrylic	
			Propionates	Citric	
			Urea	Sorbic	

Sources: Bolsen, 1995 and National forage and grassland curriculum 1996 - 98.

Feed out

Feed out starts when the silo is opened to be used for feeding animals. Oxygen penetrates the silo, and permits plant and microbial respiration to occur. These produce carbon dioxide, water and heat (O'Kiely and Muck, 1998). The rate at which oxygen enters the silo depends on the surface area exposed and the length of time the silage is expose to the air.

The length of time the silage is exposed to oxygen depends on two factors: the density of the silage mass and the feed out rate. There is a negative relation between the density of the material, and the distance from the face that oxygen can penetrate in the silage during the feed out phase. Density is influenced by the amount of packing, chop length and the moisture content of the ensiled material. Dried crops are more difficult to pack and leave more pores in the material. Higher rates of feed out decrease the damage oxygen can cause during this phase. Therefore, increasing the feed out rate of porous material is a way to reduce the possibility of heating and aerobic losses (Bolsen, 1995).

Loss during the feed out phase is due to aerobic microorganisms consuming carbohydrates; fermentation products such as lactic and acetic acid; and other soluble nutrients present in the silage. Microorganisms such as yeasts, moulds, enterobacteria and *Bacillus spp.* are present in the silage face and have an unlimited quantity of oxygen for their aerobic processes. This access to oxygen allows them to grow rapidly. When bacteria population reaches between 10^7 and 10^8 Colony Forming Units (CFU) per gram of silage, or moulds achieve a population of 10^6-10^7 CFU/gm of silage, the temperature of the silage start to increase. In addition, textural changes, discolouration and other factors reducing palatability and intake by animals may result due to aerobic activity (Weinberg and Muck, 1996).

As stated by Rich and White (2002), losses of dry matter during the feedout can be of the order of 30 – 70%, and these losses are from the most digestible part of the ensiled material.

In order to minimise the surface exposed to air, the face of the silo must be maintained as a smooth surface and as perpendicular to the floor and sides of the silo, as possible. Increasing the feed out rate can be useful in hot weather to avoid microbial population growth.

(i) Acceptance of the silage to animals

It has been stated that fermentation end products such as lactic, acetic and butyric acid negatively affect silage consumption (Journet, 1995). Addition of any of these acids or silo effluents to the silage results in up to 40% reduction of forage intake (Erdman, 1993). Silage intake is greater when the pH of the material is in a range of 4.5 to 7.0. If silage pH is outside this range the intake

can be reduced up to 15% (Erdman, 1993). The presence of butyric acid in the silage has been related to clostridium fermentation (White et al., 1999). The use of buffers has been recommended to raise the pH in order to improve food intake. However, raising the pH will make the silage more prone to spoilage (Mahanna, 1998).

High levels of ammonia-N can also reduce silage intake (White et al., 1999). Silage that spoils and heats in the silo may dramatically reduce dry matter intakes. Cows are reluctant to consume spoiled silage. This is especially true in total mixed rations where feed is continuously available for cattle and expected to stay fresh for extended periods of time (White et al., 1999). Silage intake by beef and dairy cows is greater with wilted silages than with unwilted. This has been related to the ammonia-N concentration of the unwilted material (Wright *et al.*, 2000).

The use of additives can improve the intake of silage. In a study with beef cattle it was determined that cattle offered the silage with an additive composed by ammonium hexamethanoate, ammonium hexapropionate and octanoic acid showed significantly higher daily DM intakes than those offered the silage without the additive (Agnew and Carson, 2000). Consequently, Dawson (1999) found that treatment of grass with formic acid before ensiling resulted in a proportional increase in silage intake of 0.08 compared with the bacterial inoculant-treated silage ($P<0.05$) (Dawson *et al.*, 1999). When cows are fed with different kinds of treated silages they expressed a marked preference for silage where fermentation process where restricted by the use of acids of enzymes. Keady, T.W. and Murphy, J.J (1998) found that cows ate more silage treated with a high amount of formic acid, followed by silage treated with enzymes than silage with a low level of formic acid or untreated.

(ii) Feeding conditions

Silage can be fed ad libitum but it can increase the wastage of material. On the other hand, giving small amount to the cattle in the feeder in order to reduce wastage of silage is labour intensive.

Chop length of the silage has been related to the performance of the animal. In an experiment with wilted and unwilted silage, harvested with either a double-chop harvester or a precision chop harvester, it was found that performance of lambs was greater with unwilted silage harvested with a precision chop harvester (Fitzgerald, 1996).

The use of additives has also been related to improve the performance of dairy cattle. In an experiment in steers and cows fed with formic acid treated silage or untreated silage, it was found that animals fed with treated silage have higher silage intake and daily bodyweight gain than with controls. It was also found that the content of water-soluble carbohydrates was higher and content of fermentation acids was lower in treated silage than in controls. This induced increased bodyweight gain and higher microbial protein synthesis in the rumen, resulting in higher milk protein production (Randby and Selmer Olsen, 1999).

Improvements in animal performance due to the use of inoculants have been variable. Nevertheless, it has been noticed that the improvement in live weight gain can be up to 25% and the improvements in milk production up to 40% with the use of inoculants. These improvements can be explained to some extent by the increase of DMD and DM recovery. It has also been suggested that some Lactobacillus may have a probiotic effect, and this effect can be strain specific, (Weinberg and Muck, 1996). This may therefore explain why the responses have been variable.

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