Silage Production from Tropical Forages

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Key Points

1. The determination of overall DM recovery is important in tropical grass silage systems
2. Silage fermentation profile and aerobic stability: trends and additional effects
3. Combinations of chemical and microbial additives might be useful for control of losses
4. Fermentation products should be considered in order to better predict animal performance
5. A critical points database would be a helpful management tool for the development of a set of HACCP principles for the production and utilisation of tropical grass silages

Keywords: tropical grass silage, effluent, gases, silo losses, aerobic stability

Introduction

In the tropics, silage production supplies feed for the dry (winter) season, when forage growth rates do not match the nutritional demands of the animal. In the warm season, the yield of tropical forages (mainly grasses) is high but the high moisture content and low soluble carbohydrate pool may limit the uptake of ensilage as a conservation technique for such forages. The success of the ensiling process is dependent on many factors, including some associated with forage quality and feed safety. Uncontrolled growth of microorganisms leads to heating of silage with consequent nutritional losses and potential risks to animal health. Occasionally, recommended management practices related to animal health issues, such as the application of silage additives or mechanical processing, are used in the field (Chin, 2002).

Silages made from tropical forages are prone to increased losses across different stages of the ensiling process. Such losses decrease the net output of edible silage and are more marked in legume silages. To maximise the overall efficiency of silage production and utilisation, all sources of loss should be identified and their consequences quantified. Historically however, fermentation patterns and in-silo losses have been more extensively studied than field losses (Nussio *et al.*, 2000; Balsalobre *et al.*, 2001a; Reis & Coan, 2001). This review suggests a rationale for integrated systems of tropical forage silage production, mainly focused on the use of the warm-season C4 grasses specially studied in South America.

Harvesting related losses

The initial losses in the ensiling process occur during forage harvesting and chopping. Igarasi (2002) used a pull type double-chop forage harvester fitted with flail knives and cutter head to ensile unwilted "Tanzania" guineagrass (*Panicum maximum* Jacq cv Tanzania) and found harvesting losses of 3.2% and 5.3% of the total available forage in winter and summer, respectively. Wilting the forage for 5 hours increased harvesting losses to 12.2% and 20% during winter and summer respectively thereby calling into question the benefits of forage wilting. To evaluate ensiling losses with Tifton 85 (*Cynodon dactylon*), Castro (2002) used a self propelled precision-chop harvester provided with multi-rotary drum mower. The forage was harvested at a dry matter of 25% and was allowed to wilt to 35, 45, 55 and 65% DM. Harvesting losses were reduced from 6 to 3% with the increase in forage DM content.

Opposing trends between harvesting losses and wilting losses might be explained by forage species, but are mainly due to differences in the design of the harvesting equipment.

In silo losses

Moisture control and substrate availability for fermentation

Techniques that reduce water activity, such as wilting or the use of absorbent substrates as additives, may promote absorption of free water. Since tropical grasses have a high moisture content and a low soluble carbohydrate pool at harvesting time (Vilela, 1998), the addition of soluble carbohydrate sources may reduce losses from undesired fermentation. Recent data from Igarasi (2002) indicated lower water activity in tropical grasses than in temperate grasses at the same moisture level, possibly as a result of a higher ionic charge in the cell content. Accordingly, it might be possible to successfully control undesirable microorganisms, such as Clostridium, even when DM contents are slightly below 30%.

Some absorbents, such as finely ground grain or citrus pulp, may simultaneously increase both the soluble sugar concentrations and dry matter content of the ensiled product. However, these absorbents act differently to control the free water content of the product. Even though the use of absorbents with higher NDF content reduces silage bulk density, the water retention capacity of the silage may be increased (Jones & Jones, 1996; Giger-Reverdin, 2000).

Aguiar *et al*. (2001) cited by Sollenberger *et al.* (2004) observed lower levels of ammonia-N with a 10% addition of pelleted citrus pulp to ensiled “Tanzania” guineagrass, when compared to the control silage. Surplus soluble carbohydrate associated with the higher DM content probably lowered the activity of proteolytic enzymes due to the rapid pH drop in the silage. A lower moisture content, resulting from citrus pulp addition, also improves the fermentation pattern, as observed by Balsalobre *et al*. (2001a). However, in silage wilted to a DM content similar to that observed with the addition of citrus pulp, the pH was higher, suggesting that the addition of soluble sugars might have promoted the additional drop in pH. Igarasi (2002) ensiled “Tanzania” guineagrass with citrus pulp included at between 5 and 10% and noted better fermentative characteristics (pH, ammonia-N), higher DM and improved TDN (digestible energy) recovery as a result of lower losses of gas and effluent. These quality characteristics contrasted with a lower aerobic stability after opening of the silo and with an increase in TDN relative cost, mainly for summer harvested forage.

Evangelista *et al*. (2001) included wheat meal or pelleted citrus pulp at 0, 5, 10 or 15% when ensiling Coastal Bermuda grass (*Cynodon spp*) at 7 or 9 weeks of vegetative re-growth and observed no additive effects on silage pH values at 7 weeks of growth. However, all wheat meal and citrus pulp inclusion levels resulted in a more rapid pH drop in forages harvested at 9 weeks re-growth. As expected, silage DM content increased in line with additive inclusion rate. This was more noticeable in forage harvested at 9 weeks re-growth. With both harvesting intervals, increasing additions of wilted sugarcane (sacharina) or finely ground maize meal were associated with an increase in silage ammonia-N content, indicating more protein degradation with both additives (Lima *et al*., 2001).

Pedreira *et al*. (2001) observed higher ammonia-N concentrations in silages with unaltered moisture contents probably due to a greater degree of proteolysis by plant enzymes or through *Clostridium* activity. Addition of pelleted citrus pulp affected the pH and led to lower ammonia-N values, presumably because of lower *Clostridium* activity, even though the crude protein content and the other cell wall constituents were reduced as a result of the low NDF, ADF and CP concentrations in citrus pulp. Vilela *et al.* (2001) wilted hybrid Paraíso (Elephantgrass and Pearl millet) for 0, 6 and 12 hours, and found lower ammonia-N contents in the wilted silages. However, wilting may reduce soluble carbohydrates and consequently lactic acid, because of cell respiratory activity. Wilting may also increase silage ash content due to an increase in soil contamination from raking. These observations suggest a combined effect of a loss of cell contents through silage effluent losses and carbohydrate disappearance during the wilting process, resulting in lower energy availability and increased ash concentration (Balsalobre *et al*., 2001a).

Souza *et al.* (2001) evaluated elephantgrass silage of 14.5% DM ensiled with ground coffee hulls as an absorbent and observed a lower effluent yield and pH values close to 3.9. Another benefit was the maintenance of silage CP content close to that of the fresh forage. Many additives reduce the CP content through a dilution effect. Quadros *et al.* (2003) added increased amounts of coffee hulls to elephantgrass (up to 20% on a fresh weight basis) and noticed better silage fermentation profiles and silage DM digestibility when coffee hulls were added at rates from 5% to 10%. Ferrari & Lavezzo (2001) used cassava meal as an additive in elephantgrass silages and found increased DM and total soluble carbohydrate contents. However, ammonia-N and butyric acid concentrations suggested that these silages were inferior. Fermentation of “Tanzania” guineagrass silage was changed by citrus pulp addition and there was an interaction with particle size reduction (Balsalobre *et al*., 2001b).

Bulk density: particle size and packing

Among the factors that affect silage bulk density are: weight and pressure applied at packing, packing duration, layer thickness between loads, filling rate, forage DM content and mean particle size (Ruppel *et al*., 1995; Mayne, 1999; Holmes & Muck, 1999; Balsalobre *et al*., 2001a). Silage bulk density determines the amount of residual gas in voids in the forage mass. In situations where the reduction of particle size is limited by equipment design, it represents the main restrictive factor to an increase in silage bulk density. The study of Ruppel (1992) cited by Holmes & Muck (1999), showed DM losses of 202 and 100 g/kg for silage bulk densities of 160 and 360 kg/MS/m^3, respectively, demonstrating the benefits in terms of loss reduction that can be achieved with increased bulk density. In a field survey by Igarasi (2002), the average bulk densities of *Panicum* and *Brachiaria* silages on farms was 141.9 kg DM/m^3 (from 86.7 to 230 kg MS/m^3) with 93% of the samples below 200 kg DM/m^3 and 21% below 100 kg DM/m^3. Evaluating “Tanzania” guineagrass silages, Igarasi (2002) observed mean silage densities around 150 kg DM/m^3 in samples of about 25% DM and with satisfactory fermentation. The maximum estimated bulk density of 159.5 kg DM/m^3 was observed with a wilted forage containing 33.3% DM. Particle size reduction may improve fermentation due to better packing and increased surface contact area between substrate and microorganism, with a resultant greater access to cellular contents. McDonald *et al.* (1991) pointed out that when particle size is smaller than 20-30 mm, positive effects on the availability of soluble carbohydrates may be noticed and, consequently, lactic acid bacteria may be stimulated. However, the literature is still unclear about the benefits of reducing particle size on grass silage fermentation. According to Mayne (1999), the positive effects of particle size reduction on the fermentation process were more generally observed in higher DM content forages.

Forage chopping can alter silage fermentation patterns through altering the extent of plant tissue damage. Electrical conductivity is a useful indicator of the extent of mechanical processing (Kraus *et al*., 1997) and can help assess the degree of cell disruption and variations in cell content exchange due to chopping and shredding of forage by equipment of different design. Cell wall rupture may improve homogeneity, creating a liquid film surrounding the grass particles and can lead to more uniform growth conditions for the lactic acid producing bacteria (Pauly, 1999). In spite of this, Pauly (1999) questioned the benefits of mechanical processing for the loss of cell contents in effluent and in facilitating fermentation. The author implied that possible advantages might be due to the establishment of anaerobic conditions in a shorter period of time. Additionally, larger particle sizes could lead to a slower pH drop and higher DM losses, mainly of water soluble carbohydrates and protein (Woolford, 1972). Mari (2003) reported a higher bulk density with smaller particles in “palisadegrass” (*Brachiaria brizantha* A. Rich, Stapf) silage. Igarasi (2002) studied “Tanzania” guineagrass silages and observed that electrical conductivity increased from 1694 to 1823 mS/cm with a reduction in particle size, the effect being more noticeable in wilted forages (from 1774 to 1985 mS/cm). Smaller particle size increased silage bulk density, improved aerobic stability after unloading and produced a faster pH drop and gave higher DM recovery. A reduction in particle size did not alter gaseous or effluent yield and left the recovery and relative cost of TDN unchanged.

Forage particle size reduction may be an alternative way in which to minimise Clostridium fermentation, by promoting greater packing density and closer substrate contact with the fermenting bacteria, leading to a higher lactate yield and a faster pH drop. However, in silages with low DM content, particle size reduction may increase water activity and effluent losses. In this way, it could result in the same overall DM loss, but through a different mechanism, demonstrating mutual, negative, relationships between effluent and gaseous losses. However, in higher DM content silage, total losses are diminished as a result of the higher osmotic pressure associated with the significant reduction in water activity. In this situation, by promoting particle size reduction, effluent yield is minimised (Balsalobre *et al*., 2001b).

Effluent

There are some models that attempt to quantify silage effluent yield (Haigh, 1999). However, they use only forage DM as a factor in their prediction and do not consider other factors such as silo type and size, packing density, chopping type and use of additives. According to these models, DM values of between 28.5 and 30% would be necessary to eliminate effluent yield. From Figure 1, the exponential regression equation to predict effluent yield from “Tanzania” guineagrass silage revealed a trend for lower effluent (38.3 to 9.3 l/t) when DM increased from 20 to 30% (Igarasi, 2002). Even though the model proposed by Haigh (1999) predicts effluent yield based on DM content in a negative correlation, only in few cases the trend was significant. . As a result, it can be assumed that other parameters besides forage DM content may be correlated with effluent losses. More intensive packing (for higher silage bulk density) might increase effluent yield, dependent on plant DM. Although effluent losses are frequently measured, they are not always the most important source of loss. The composition of the effluent allows a more realistic evaluation and varies with DM content and with the type of additive used. In perennial ryegrass silages with a DM content between 16 and 19.5%, effluent DM contents were between 7 and 8.5% (Jones *et al*., 1990). Evaluating elephantgrass (*Pennisetum purpureum*) silage with low DM content (13%) and made under different packing densities (356 to 791 kg/m^3), Loures (2000) observed that the effluent yield and DM content were both increased with greater silage packing pressure.

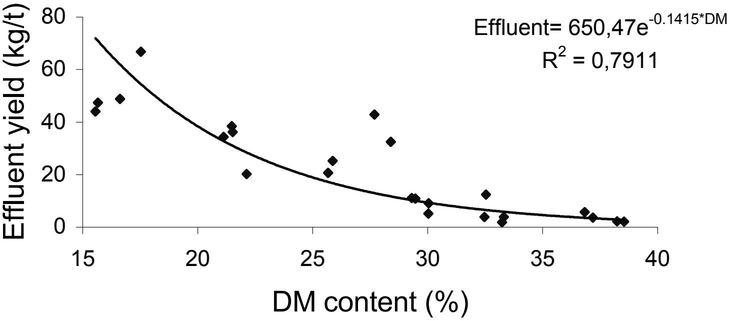

Figure 1 Prediction equation for effluent yield (kg/t of fresh forage) based on DM content in Tanzania grass silage; Source: IGARASI (2002)

Both wilting and addition of citrus pulp to "Tanzania" guineagrass, harvested and re-chopped at three different particle sizes, resulted in lower effluent losses compared to a control silage. However, the effect due to wilting was greater than that of citrus pulp addition, suggesting that even under similar DM, the water activity and probably the location of this water in the plant tissue is important for effluent yield (Balsalobre, 2001b). According to Aguiar *et al.* (2001) cited by Sollenberger *et al.* (2004), the addition of citrus pulp to tropical grass prior to ensilage or wilting of the forage reduced effluent yield from 40-50 l/t to less than 10 l/t.

In general, as particle size is reduced, a better fermentation pattern is obtained, and there are lower total DM losses, despite a trend towards greater effluent production. The ratio of losses through effluent in relation to total losses is increased, as particle size becomes smaller.

Gases

Wilted silages made from tropical grasses require careful control of packing and gaseous losses in order to obtain a satisfactory fermentation profile which is itself strongly affected by the wilting period. In general, increasing DM content increases silage pH and decreases acetic and propionic acid yield and produces lower ammonia-N (Castro, 2002). For wet silages, excessive moisture at ensiling may lead to even higher DM losses in the form of gases, often arising from undesirable fermentation by *Clostridium.* In this scenario, energy losses are also high (McDonald *et al.*, 1991). Heterolactic bacteria also produce CO_2 and alcohols and these also contribute significantly to the greater DM losses from wet silages.

In "Tanzania" guineagrass silages of low DM content (20%), there was a significant reduction in gaseous losses as the particle size was reduced (as evaluated by the percentage retained on a 1.9 cm sieve). However, a compensatory increase in effluent DM losses was also observed, resulting in unchanged overall losses averaging 27% (Balsalobre *et al.*, 2001b). In such silages, made with grass of similar mean chop length, addition of 5 and 10% of pelleted citrus pulp raised the DM contents to 23 and 28%, respectively, but still allowed effluent losses. However, in both cases there were significant reductions in gaseous losses, as well in the overall DM. In the 28% DM silage (containing 10% citrus pulp), mean particle size fell from 80 to 10% of material retained by an 1.9 cm sieve and resulted in a drop in overall DM losses, from 18.18% to 13.75% (Balsalobre *et al.*, 2001b). The most dramatic effects of smaller particle size were observed in low moisture silages. Nevertheless, the silage DM increase associated with an increase in soluble carbohydrate supply (through addition of pelleted citrus pulp) showed a greater effect on the control of losses than did particle size reduction alone.

Although overall DM loss was not significantly reduced with smaller chop length in wet silages, a reduction in mean particle size should still be aimed for in tropical grass silages because smaller particle size allows greater bulk density and lower unit cost and minimises haulage and storage costs. Additionally, smaller particle size promotes smaller physical losses during unloading and feeding. However, the most important effects of smaller particle size are related to the higher potential intake by animals (Balsalobre *et al*., 2001a, Paziani, 2004).

Additives and inoculants

Acids, salts, fermentable carbohydrates, lactic acid bacterial cultures and enzymes can all be used to control silage fermentation. Recent reviews of additives (McDonald *et al*., 1991; Lindgren, 1999; Weinberg & Muck, 1996; Vilela, 1998) have characterised their different mode of actions and emphasised that different forages require different types of additive.

Coan *et al*. (2001) observed that the use of enzymatic-bacterial inoculant did not improve the quality, fermentation and nutritional characteristics of guineagrass (*Pannicum maximum)* silage, regardless of forage variety (Tanzania or Mombaça) or regrowth stage (45 or 60 days), and they therefore questioned the benefits of using inoculants. Nussio *et al.* (2001) evaluated the use of enzymatic-bacterial inoculant in Tifton 85 (*Cynodon dactylon*) silage of increasing DM content (25 to 65%) and observed positive results from the use of inoculant only in higher DM silage (>45%), mainly due to a more rapid fall in pH. Temperatures of inoculated silages were lower up to 8 days from silo sealing. There was no control of proteolysis with the use of inoculants in low DM silage (25%), as indicated by higher ammonia-N concentrations, but there was improved aerobic stability in inoculated silages of intermediate DM content (45%).

Enzymes that degrade plant cell walls have been suggested as silage additives based on the proposition of supplying additional soluble carbohydrate for lactic acid bacteria to promote a more rapid fall in pH and also as a way to increase forage organic matter digestibility (Lavezzo *et al*., 1983; Henderson, 1993). Castro (2002) concluded that lower electrical conductivity and an increase in water activity associated with the use of enzymatic-bacterial inoculant, was consistent with cell membrane disruption and leaching of cell contents, thus providing additional substrate for microorganisms and leading to a pronounced pH drop. Additionally, inoculant decreased ruminal N degradation and increased milk fat and protein yield. According to Loures (2004), addition of fibrolytic enzymes to “guineagrass” prior to ensilage - alone or combined with *L. plantarum* - led to lower NDF, ADF, cellulose and hemicellulose contents in wilted silage. However, no improvement was seen in either *in vitro* digestibility or *in vivo* digestibility. The lack of a response might be related to a lower digestibility of the residual cell wall fraction after enzyme degradation or to depletion of soluble sugars during silage fermentation resulting in negative effects on animal performance.

The effects of homolactic bacteria addition to tropical grass silages are not conclusive. Much of the data currently available in the literature suggests a more rapid drop in pH and a lower ammonia-N content and lower temperature but other data (Rodrigues *et al*., 2002a; Rodrigues *et al.*, 2002b) contradicts such claims. Paziani (2004) noted lower DM recovery and no change in ammonia-N in “guineagrass” silage made with added *L. plantarum.* When using large scale pressed bag silos, addition of *L. plantarum* increased unloading losses by 57%

($P<0.10$) but DM intake and animal weight gains were not different to those obtained with control silages.

Recent data also showed that inoculation with *Lactobacillus buchneri*, which produces acetic acid, may improve silage stability during storage (Lindgren, 1999). This effect is observed mainly when applied to high DM forage (Davies & Hall, 1999), and seems to be related to the inhibition of yeast development and a reduction of aerobic losses at the silo face during unloading. Pedroso (2003) observed remarkable effects of *L. buchneri* addition to sugarcane silages with lower ethanol levels, gaseous losses reduced by 25% and increased DM recovery (15%). Dairy heifers fed sugarcane silage-based diets of 46% DM inoculated with *L. buchneri* gained 32% more than those fed the control diet. During this trial, an important integrated effect was noticed in terms of silage fermentation, aerobic stability and animal performance. Among other treatments, the use of *L. buchneri*, urea, sodium benzoate and potassium sorbate were identified as being especially effective in terms of the overall efficiency of silage use.

Losses related to unloading of silos

Aerobic instability is an important source of DM losses and energy losses after opening a silo and few additives are able to prevent it. Considerations of the efficiency of conservation of energy in specific management practices must take account of such losses. Even though the effects of inoculants and chemical preservatives on silage fermentation are widespread, it is uncommon to find data on the effects of aerobic instability at unloading and on animal performance in temperate (Lindgren, 1999) or tropical grass silages. The benefits of any inoculant must consider fermentation efficiency and animal performance (Flores *et al*., 1999).

Exposure of silage to air, after unloading and during feeding, may lead to aerobic losses with higher costs due to DM and energy losses. The ability to predict the extent of tropical grass silage deterioration, based on fermentation pattern, is still uncertain, even though it would be a valuable farm tool. Some studies have concluded that the desired fermentation pattern does not always prevent unloading related losses. Such losses are not only associated with silage management, but with factors such as forage source and silo filling management. The greater the unloading rate, the lower are the losses but the extent of silage deterioration during unloading is related to its aerobic stability. Conventionally, aerobic stability is assessed from the time necessary, after silage unloading, to allow the temperature of the silage to rise by 2°C above the ambient temperature pattern (Kung Jr., 2001). Aerobic stability may be also assessed by measurement of the accumulated temperature rise compared to the environmental pattern, during 5 or 10 days after unloading (O'Kiely *et al*., 1999).

Since aerobic stability is one of the most important parameters in silage management, many studies have been conducted to minimise its effect and prevent undesired fermentation. By preventing butyric acid fermentation or restricting acetic acid yield, the risk of aerobically unstable silage is increased. A high concentration and prevalence of lactic acid in well-fermented silage is not necessarily a positive predictor of aerobic stability (Weinberg & Muck, 1996). In fact, better aerobic stability was observed in silages containing some acetic acid as well as lactic acid (Mayrhuber *et al*., 1999). The aerobic depletion of lactate by fungi, yeast and Bacillus reduces the potential stability of silage (Lindgren *et al*., 1985) due to lactate aerobic conversion to acetate or degradation to butyric or acetic acid with a consequent pH rise. Aerobic microorganisms readily degrade lactic acid to CO_2, ethanol and acetic acid after unloading the silo, while also generating heat through exothermic reaction (Kung Jr., 2001).

According to Salawu & Adegbola (1999), tropical grass silages of 30% DM tend to have higher concentrations of lactic acid and are more prone to aerobic instability. The higher content of intact sugars or soluble carbohydrates preserved from fermentation associated with low acetic acid concentration, and the presence of yeast and poor packing practice might explain this trend with high DM silages.

“Tanzania” guineagrass, chopped for silage at three different particle sizes and combined with three levels of citrus pulp addition (0, 5 and 10%) showed a strong trend of lower aerobic stability with reducing particle size. The silages containing citrus pulp also had lower aerobic stability than the control treatment (Balsalobre *et al*., 2001b). In contrast, Moura *et al*. (2001) observed a gradual increase in CO_2 yield with aerobic exposure up to 8 d in elephantgrass (*Pennisetum purpureum*) silage, but the addition of poultry litter (20%) and molasses (3%) during ensiling slowed the rate of deterioration. These results may indicate that the use of recommended silage practices aided carbohydrate preservation and assisted towards a good fermentation, attaining the ideal pH more rapidly but creating higher susceptibility to aerobic loss after unloading. The controversy surrounding unloading stability is due to the negative correlation between this parameter and the adequacy of the fermentation pattern.

Other factors may play a role in the aerobic stability of tropical grass silages. According to Bernardes (2003), in “palisadegrass” (*Brachiaria brizantha (A. Rich.) Stapf)* silages made with the addition of 5 or 10% pelleted citrus pulp, yeasts and fungal strains detected were more related to aerobic instability and resulted in small temperature increases. However, in wet silages (22% DM) the most important microorganisms growing under aerobic conditions were bacterial strains which lead to higher ammonia-N and pH increases. In both wet and additive-treated silages, the temperature increases were not closely related to DM losses or reductions in nutritive value indicating that temperature rises might not be considered as unique.

Conclusions

Tropical grasses have enormous potential as silage sources because of their biomass yield and their relatively low cost of production. However, production of tropical grass silages can incur overall losses greater than 30-40%, which in turn, may result in an expensive nutrient resource and lead to the wrong conclusions about the value of such silages. In order to assure the value of this system of forage conservation for animal feeding and for nutritive value and nutrient cost effectiveness, the control of losses at every step from the field through to the animal is essential.

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