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Sealing strategies to control the top losses in horizontal silos

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Introduction

Achieving and maintaining anaerobiosis is critical to successful ensilage. When no seal is applied, or when the seal is inadequate, air and moisture enter into the silo affecting both the ensiling process and the quality of silage during storing and feeding; therefore, silage is covered for two primary reasons (Holmes, 2006). The first is to exclude rainfall because precipitation washes

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organic acids and other soluble feed components from the forage and the second is to reduce exposure to air.

Oxygen enables various aerobic spoilage microorganisms to become active and to multiply themselves, resulting in aerobic deterioration (Pahlow et al., 2003) and substantial economic losses. The deterioration of the silage is indicated by temperature and pH increase, dry matter (DM) losses, lack of nutrient availability, surface mould growth and feed refusal by the animals.

Livestock farms can store silage in various ways such as horizontal silos (bunker and stacks), tower silos, bagged silos, or large wrapped bales. Several farms prefer horizontal silos due to relatively low construction costs, greater safety compared to tower silos (no toxic gases produced in closed areas, low risk of fall) and high work rates for filling and unloading (Savoie & Jofriet, 2003), but their design allows large areas of the ensiled material to be exposed to the environment and prone to spoilage, especially in the upper layer and near the walls (Ashbell & Kashanci, 1987; Borreani et al., 2007).

In horizontal silos, during the storage period, a spoilage layer is formed below the sealing sheet, known as "surface waste". Although there is also some evidence that invisible oxidation losses occur throughout the whole mass of silage during the storage period. A large percentage of the silage mass (about 25%) can be within the top 1 meter depending on silo size and depth.

The most common material used to seal horizontal silos is the plastic film. The principal function of the film is to seal the forage and allow anaerobic conditions to establish. In Brazil, mainly films of 150-200 μm thickness are used for this purpose. Although polyethylene sheeting has been the most common method used to protect silage near the surface, the protection provided is highly variable and often changes during storage (Savoie, 1988). Thus, the effectiveness of covering methods is very important to limit aerobic deterioration and losses in the large mass being protected.

This paper presents the main factors related to sealing methods that affect the extent of aerobic deterioration in horizontal silos. Furthermore the review aimed to identify proper management strategies to improve silage quality on commercial farms.

Unsealed silos

Along with proper harvesting and filling techniques, it is also equally as important to properly cover a bunker silo. Previous studies have demonstrated that the quality and recovery of silage is compromised if horizontal silos are not covered with plastic film.

Berger & Bolsen (2006) summarized the research that documents DM and nutrient losses when bunker and stacks silos are not sealed (Table 1). From 1990 to 1993, the top 0.90 m of silage from 127 horizontal silos in Kansas was sampled at three locations across the width of the silos. Sampling depths were: 0 to 0.45 m from the surface (depth 1) and 0.45 to 0.90 m (depth 2). All sealed silos were covered with a single sheet of black or black-on-white 100 to 150 μm polyethylene, which was held in place with tires, sidewall disks, or soil.

In the top 0.45 m, additional organic matter (OM) losses (losses in addition to the losses in well-preserved silage) ranged from 17 to 60%, and losses were higher in bunkers and stacks that were not sealed. Applying a seal reduced OM losses in the top 0.45 m and also reduced additional spoilage losses in the second 0.45 m. Silage near the exposed surface of the unsealed silos had pH values ranging from 4.75 to 8.55, which were typical of severely deteriorated silage.

The aerobic deterioration is initially limited to the top 15 to 30 cm in an uncovered silo. The reason for this is that aerobic microbial activity is great enough in the upper layer to remove all of the oxygen entering into the crop either by diffusion or convection. As the readily degradable components of the crop in the top layer are exhausted, the rate of microbial activity declines allowing oxy-

Table 1. Effect of sealing treatment on estimated additional spoilage losses of OM at the top of two depths in bunker and stacks silos (average 1990 to 1993).

Treatment	nº of silos	Depth 1 (0 to 0.45 m)		Depth 2 (0.45 to 0.90 m)	
		Average	Range	Average	Range
Sealed	9	23	17-31	5.3	1-12
Unsealed	54	50	44-60	14.0	9-19

Source: Adapted from Berger & Bolsen (2006) gen to move deeper in the silo and cause deterioration at that level (Muck, 1988).

Economics evaluations indicate that the reduced losses from using a cover return more than $8.00 for each $1.00 invested in plastic and labor to cover a bunker silo (Rotz & Muck, 1993). In a 200-t bunker silo (6 m wide by 20 m long by 2.5 m deep), an effective seal to protect the top 1 meter of silage can prevent the loss 100 to 400 dollars worth silage, depending on the value of the crop. Proper sealing with a plastic cover is therefore essential to reduce losses and to prevent microbial deterioration, which may result in the presence of toxins.

Lining bunker walls with plastic

A large part of the silage stored in horizontal silos is exposed to air and is prone to spoilage, especially in the upper part near the walls (at the shoulders of the silo), which are difficult to seal properly. Ashbell & Kashanci (1987) reported silage DM losses near the surface of bunker silos to be highest (76%) near the silo wall and lowest (16%) in the core. Thus, a problem still not fully solved is the connection of the cover to the bunker silos.

The best results are achieved by putting an additional film 1 to 2 m deep (depending of the silo size) between wall and forage, and then over the forage, before the main sheet is attached (Figure 1). The result of this additional effort is that silage quality along the wall is similar as that throughout the silo (Honig, 1991).

Types of plastic film to cover silage

A plastic film to cover silage has to fulfill four essential functions. The characteristics of the films are of different importance for these functions. First, the film must prevent precipitation and damage caused by meteorological effects. Secondly, the film must offer a certain protection against animal attack. These functions require certain mechanical characteristics of plastic film because a failure is usually due to handling, wind, hail, rodents or birds. Thirdly, the silo film guarantees anaerobic conditions in the silage.

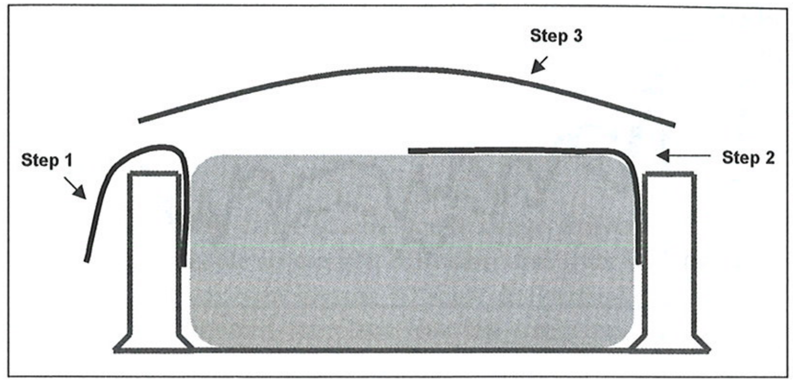

Figure 1. Bunker lining diagram. Step 1 = when filling, leave a flap of plastic over the silo walls; step 2 = fold the excessive plastic over the bunker after filling/packing; step 3 = cover the bunker with some additional plastic film.

The necessity of anaerobic conditions for the ensiling process is well known. Finally, the fourth function of the silo film is its influence on the temperature of the conserved forage. Moreover, the film should be UV resistant in order to withstand prolonged exposure to sunlight.

Effects of the colour and thickness of plastic film

The colour of sheet should affect the amount of air infiltration and subsequent aerobic losses because oxygen permeability into the silage is highly dependent on the temperature of the plastic. Only few data have been published about the thermal effects of covers on the upper silage layers. It is important to emphasize that these surface layers are highly susceptible to poor fermentation because of unsatisfactory compaction, the proximity of the sheet and the high temperature of the microclimate influence strongly the growth of microorganisms.

This is consistent with the observations by Bernardes et al. (2009a), who found highest DM losses and yeast counts when corn silages were sealing with black polyethylene. Black sheet also shows higher temperature in relation to black-on-white film during storage period (Figure 2).

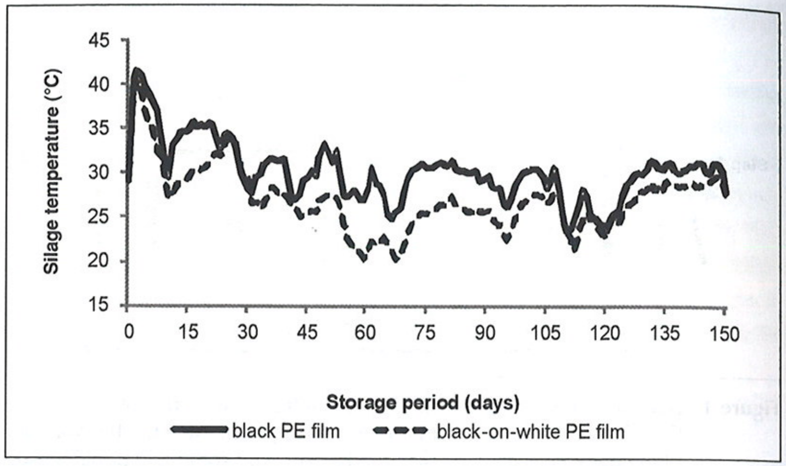

Figure 2. Effects of the colour of plastic film on temperature of corn silages during 150 days of storage.

Snell et al. (2003) reported the effects of the colour on the temperature of the film surfaces. They found that in the morning hours, temperature peaks were up to 16°C higher for the black film in comparison with the white film. As expected, the highest values were reached at midday, with the black and green coloured films showing a very similar thermal behaviour. The same applied for the evening hours.

Savoie (1988) developed a theoretical model to predict the total cost of plastic and respiration losses because of air infiltration through the film. An optimal thickness was derived as a function of storage period, silage density and DM content, film permeability and the relative value of plastic and silage. Polyethylene silage bags of different thickness (100, 150, and 200 μm) did not produce significant differences in losses in 130d, averaging 0.2% loss/month when perfectly sealed (Savoie, 1988). However, modeling of different film thickness indicated that 100 μm was economically optimum on a stack silo for 3 months storage, 150 μm for 7 months, and 200 μm for 12 months.

A very thin plastic film may be inefficient due to excess air infiltration through the film during a long storage period. Mechanical

failure and film thickness are interrelated because a very thin film will be a poor barrier to oxygen flow in addition to being more sensitive to tear and puncture.

Effects of the material properties on the oxygen permeability of plastic films

Air is the major cause of spoilage in silage. Polyethylene is not totally impermeable to oxygen diffusion and thus will not completely prevent oxygen ingress (O'Kiely & Forristal, 2003). There is a general agreement, therefore, that low oxygen permeability of the sheets has to be sought.

Borreani et al. (2007) reported that in the early 1990s, Daponte (1992) proposed the use of coextruded barrier films to seal silage, but at that time, plastic manufacturers had no commercial interest in these more expensive films. The situation is changing rapidly now, and new developments in sealing strategies have been reported recently, involving the use of a coextruded film with reduced oxygen permeability as an alternative to standard polyethylene.

A co-extruded polyethylene-polyamide film has been developed for covering horizontal silos (Borreani et al., 2007) by Industria Plastica Monregalese (Mondovi, Italy). It is 125 μm in thickness and comprises two outer layers of polyethylene with a central layer of polyamide (Silostop® 1-step).

Two trials were carried out in Brazil to evaluate a new black-on-white (125 μm) coextruded oxygen barrier film (OB) in a tropical climate. Bernardes et al. (2009a) studied eight covering systems and observed that the OB film had lower values of pH, yeasts and DM losses among the plastic films.

In a second trial (Bernardes et al. unpublished data), four black-on-white films were evaluated: 1) oxygen barrier film 125 μm thick (OB), 2) black-on-white (200 μm thick) polyethylene film (PE), 3) black-on-white (300 μm thick) polyvinyl chloride film (PVC), and 4) black-on-white (200 μm thick) polyvinyl alcohol film (PVOH). Table 2 shows the differences on oxygen permeability of the plastic sheets.

Oxygen permeability of the films influenced the DM losses in the upper 30 cm of the silage, as reported in Figure 3. The OB film

Table 2. Characteristics of the films used in the trial.

Item	Plastic film			
	OB	PE	PVC	PVOH
Nominal thickness, μm	125	200	300	250
Measured thickness, μm	121	189	280	238
Oxygen Permeability, cm³/m² per 24 h[1]	75 ± 1	722 ± 19	289 ± 5	982 ± 32

[1] At 23°C, 85% relative humidity
Source: Bernardes et al. (unpublished data)

affected the DM losses of the silage ($P < 0.05$). More lactic acid was produced in the silage sealed with the OB film and the yeast counts were always under the detection limit (1×10^5 cfu/g) in the OB corn silage (Bernardes et al., unpublished data).

The OB film has been tested on farm to assess the effects on the fermentation quality, the DM losses and the yeast and mold counts at opening of whole-crop corn bunker silos compared to conventional polyethylene (Borreani et al., 2007). Two trials were carried out in two commercial farms (Farm 1 and Farm 2). The bunkers were divided into two parts along the length so that half of the feed-out face was covered with PE film and the other with OB film. The pH of the peripheral silages was different, for Farm 1 and Farm 2 under the two films with lower values in the OB treatment. The OB film in Farm 1, affected the silage DM losses, which were reduced 3.7 times in comparison to the PE film sealing. The results indicate that the new OB film is a promising tool to constrain spoilage and DM losses in critical farm conditions, when inadequate amounts of silage are removed daily. The OB film further improved the stability of the corn silage in the peripheral area of the silos even when a proper harvest-to-feedout management was implemented (Borreani et al., 2007).

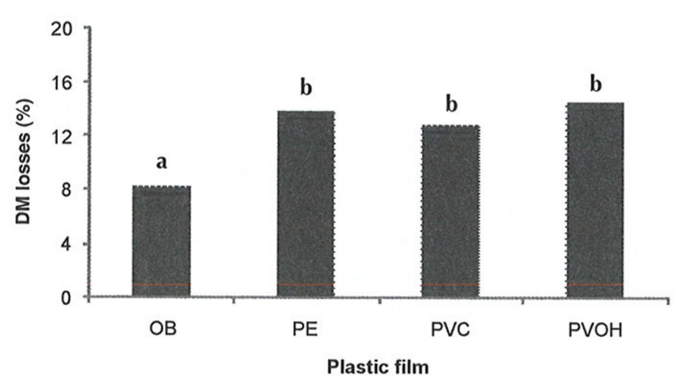

Figure 3. Effect of the plastic film on DM losses of corn silages. Bars with unlike letters differ (P < 0.05). Source: Bernardes et al. (unpublished data)

The same company has also developed a 45 μm non-UV-stabilized translucent barrier film (Silostop® 2-step clear) with similar oxygen permeability characteristics as their Silostop 1-step. Usually, the Silostop 2-step is used in combination with a protective tarpaulin, but in Brazil studies have been tested in combination with a polyethylene sheet (black or black-on-white).

From 2006 to 2009, the top of corn silage from six commercial stack silos was sampled (Bernardes et al., 2009b; Basso et al., 2009; Basso et al., unpublished data). Two treatments were compared in all trials: 1) a sheet of 180 μm-thick polyethylene film (PE) and 2) a sheet of 45 μm thick transparent oxygen barrier film (OB) plus a sheet of PE over the OB film. The stack silos were divided into two parts along the length: half was covered with PE film and half with OB plus PE film. During the filling of each silo, plastic net bags with fresh material were weighed and buried in the upper layer of each stack. When the feedout face reached a distance of 30 cm from the bags, these were removed from the silos for analysis. The fermentative characteristics, microorganisms' numbers and DM losses were affected by OB film. The results indicate that the OB film slightly reduced the occurrence of spoilage microorganisms and improved fermentation profile in corn silages at peripheral areas of the silos. All silos covered with OB film showed negligible visible mould. Four of the stacks had surface waste when were covered with PE film.

In Figure 4 are reported the contour map of temperatures of the silo face with two sealing system. During the feed-out phase the top temperatures at the working face exceeded 40°C in the silage covered with PE film, while in the silage sealed with OB film were similar than those recorded in central zone.

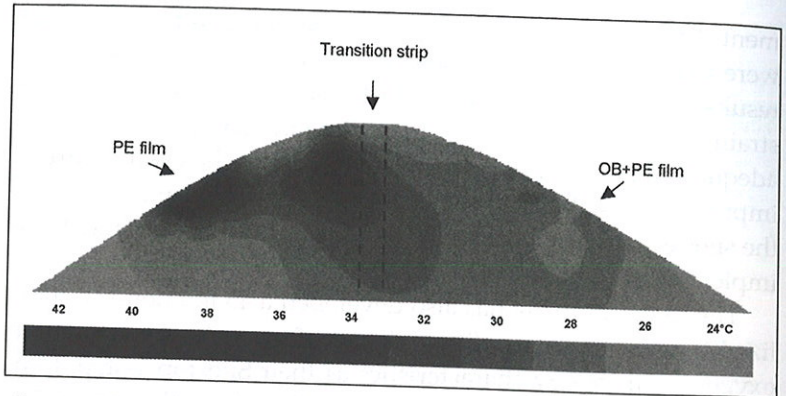

Figure 4. Contour map of temperatures of the silo face covered with polyethylene film (PE) or oxygen barrier film associated to PE (OB+PE). Source: Basso et al. (unpublished data)

Use of bacterial and chemical additives on the top of the silos

Especially in warm climates whole-crop cereal silages such as corn, sorghum and wheat are susceptible to aerobic deterioration. This is because aerobic yeasts are most active at 20 to 30°C (Ashbell et al., 2002). Therefore, efforts are being made to find additives that would inhibit fungi and protect the silage near the surface.

Muck (1996) was the first to suggest that inoculation with *Lactobacillus buchneri*, that is an obligate heterolactic acid bacterium, might improve the aerobic stability of silages. Since that time, *L. buchneri* has been used as a silage inoculant to enhance the aerobic stability in a variety of silages via the anaerobic degradation of lactic acid to acetic acid (Oude Elferink et al., 2001). In order to use additives to overcome the problem of aerobic deterioration of silages, it has been suggested that other types, such as sodium benzoate can be used (Kung et al., 2003).

A survey to verify the difference between polyethylene film (PE) and oxygen barrier film (OB) and an association with sodium benzoate (0.02%) or *L. buchneri* (1×10^6 cfu/g) applied onto the top of the silos was carried out by Amaral et al. (2009). Fermentation quality and DM losses from silages are shown in Table 3. The

Table 3. Effects of sealing treatment on fermentation quality of corn silages.

Item	Plastic film		Additives*		
	PE	OB	Control	LB	SB
DM, %	36.2	35.9	34.9^b	36.3^a	36.9^a
Ash, % of DM	4.67	4.71	4.79	4.76	4.52
pH	3.97	3.96	4.14^a	3.91^b	3.86^b
Acetic acid, % of DM	3.25	1.99	2.57	2.28	3.00
Butyric acid, % of DM	0.11	0.22	0.26^a	0.11^b	0.14^b
DM losses, %	8.07	8.77	9.73^a	7.69^b	7.83^b

PE = black-on-white polyethylene film (200 µm thick); OB = black-on-white coextruded polyethylene-polyamide film (125 µm thick); LB = *Lactobacillus buchneri* 1×10^6 cfu/g forage[1]; SB = sodium benzoate 0.02% (fresh basis). *$P < 0.05$. Source: Amaral et al. (2009)

pH values were lower in silages treated with additives (3.89) than control silages (4.14). The concentration of butyric acid was lower in silages covered with additives. The DM losses were decreased 18% in silages treated with additives. The authors concluded that the use of *L. buchneri* or sodium benzoate inhibited the aerobic deterioration from silos upper layer.

Use of tires, gravel, soil, and sugarcane bagasse to weight down the plastic cover

To prevent deterioration in horizontal silos, the common practice is to use polyethylene sheeting held in place with used car tires. These materials have been widely used because of their low cost and the ready availability.

In a study reported by Ruppel (1993) there was a reduction in the temperature and improved protein availability of hay crop silage when the amount of tires per square meter increased. The losses of DM in the top surface of silage were also reduced as the amount of tires per square meter increased. Based on this research it is suggested that there should be 20 to 25 tires per 10 square meters (25 tires per 10 square foot approaches "tire to tire" placement). Ashbell & Weinberg (1992) studied several covering methods on the reduction of the top silage losses and inferred that higher tire density (30 tires per 10 square meters) and sand bags along the shoulders resulted in lower losses.

Borreani & Tabacco (2007) presented the results of a survey for silage sealing systems under some farm conditions. A farm bunker silo was covered with a single black-on-white sheet and the length of the bunker was divided into two equal parts: half was covered with tires (25 kg/m²) and half with gravel (200 kg/m²) over the sheet. The silo was opened for summer consumption and had low feed-out rate (12 cm/d). The results showed that the difference in the sealing system affected the temperature in the peripheral area of the corn silage. The silage covered with tires reached the maximum temperature higher than 40°C.

It is important to emphasize that keep the plastic mostly weighed can be effective during storage and feed-out period. Borreani et al. (2008) reported that during feed-out, air can penetrate in the peripheral areas of a silo to up to 4 m from the feed-out face, especially when the sealing cover is not weighed down or is weighed only with tires, suggesting that, in these situations, daily removal rates should be higher than 30 cm/d to avoid extended aerobic spoilage.

The amount of soil placed on top of the polyethylene plastic also has an effect on silage quality. Bernardes et al. (2009a) studied the effectiveness of several sealing strategies that are used in Brazil on the reduction of the top losses. Lower losses were associated with decreased pH and ash content and lower counts of yeasts when corn silages were covered with soil (100 kg/m²) over the black sheet. The temperature of the silage anchored with soil was lower during throughout the storage period (Figure 5).

The most of farmers are particularly resistant to cover horizontal silos with soil, particularly large ones, feeling that the labor and trouble of handling the soil used to weigh the plastic are not worth. Moreover, the use of land can also be a source of contaminants in silage, mainly when unloading the silo.

Thus, another alternative has been studied in order to reduce aerobic deterioration in the peripheral area of the corn silage. Three treatments were evaluated: 1) black polyethylene (PE) film 200 μm thick, 2) black PE plus sugarcane bagasse (10 kg/m²) over the sheet, and 3) black PE plus soil (30 kg/m²) over the sheet (Amaral et al., unpublished data). Changes in the silage temperatures

in the top layer of treatments are given in Figure 5. The results showed that the difference in the covering system did not affect the temperatures during the storage period. However, after about 80d of fermentation the temperature started to rise in the control silage. This can be attributed to the effect of oxygen permeability of the film during a long storage period because the gas transmission rate is reduced by the presence of soil or sugarcane bagasse over the sheet. These results also suggest that the degree to which plastic is permitted to billow in the wind influences the amount of air drawn into the silo.

Biofilms and organic covers

An environmental objective is to reduce the quantity of plastic used in agriculture, and there may be the opportunity for achieving this by reducing the use of the film for sealing silos. However, horizontal silos produce less plastic wastes than most other systems that use polyethylene film for air tightness. Savoie (1988) reported that round bale silage requires at least 5.5 kg of plastic/t DM. Stack silos uses about 1.3 of plastic/t DM, four times less than the round bale silage system.

Edible biofilms made from starch, protein or vegetable oil, have been proposed to protect the top surface of silage and eliminate

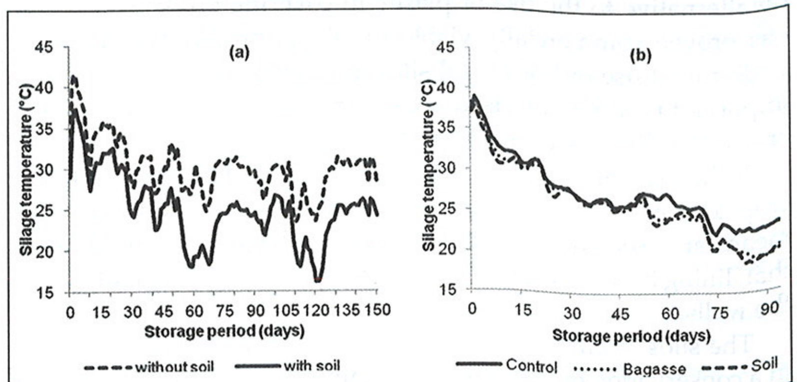

Figure 5. Effect of the covering system on silage temperature. (a) Bernardes et al. (2009a); (b) Amaral et al. (unpublished data)

the problem of plastic waste handling (Brusewitz et al., 1991). Currently, biofilms are not used commercially due to their relatively high cost and inadequate protection from air infiltration.

Considering the low cost of raw material and the beneficial impact on the environment, biodegradable coatings have become a possible alternative for sealing horizontal silos. The incorporation of beef fat in the heated coating formulation and the addition of a hydrophobic layer of zein were able to preserve the quality of silage for at least 4 months under laboratory assay (Denoncourt et al., 2004). Soy – and casein – based biodegradable coatings were evaluated for their ability to exclude oxygen and preserve corn silage. The results showed that biodegradable coatings were able to protect the quality of silage during 4 weeks but the biodegradable coatings were not as good as plastic at preserving silage after 8 weeks of storage (Denoncourt et al., 2006).

In summary, both farmers and scientists have tried alternatives to plastic sheet such as grain, chopped straw, molasses-based products, lime, and edible films. To date, the alternatives have been better than no cover but considerably less effective than the plastic film.

Conclusions

The detrimental effect of air at silage near the surface is a key point to avoid losses of dry matter and of quality. Unfortunately, no alternative to the use of plastic in covering bunkers or stacks has proven commercially viable for silage producers. Given the widespread use of horizontal silos in Brazilian farms, it is vitally important that the film used possesses good oxygen barrier properties as well as good mechanical properties.

In horizontal silos, the plastic needs to be held tightly to the crop. This is usually accomplished with used tires, but many other means are used such as gravel, sugarcane bagasse or soil. Besides that, lining bunker walls with plastic improves silage quality along the walls.

The silos' sealing will continue evolving to meet future needs in a conservation of fresh forage, to minimize loss and cost, reduce environment contamination, and to provide a safe and efficient on-farm feeding system.

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Silage pathogenicity and implications for the ruminant production chain

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The objective of this paper is to discuss pathogenic organisms and other harmful agents that may be present in silages, consider their implications for ruminant animal production, and to recommend management practices that are critical to ensuring the hygienic quality of silages.

Pathogens and harmful agents in silages

Yeasts

Unlike those on fresh crops that are nonfermentative, silage yeasts are facultative aerobic fungi that can tolerate oxygen depri-

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