**Revista Brasileira de Zootecnia**
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ISSN 1806-9290
www.sbz.org.br

**R. Bras. Zootec., 43(9):471-478, 2014**

# The influence of covering methods on the nutritive value of corn silage for lactating dairy cows

**Rafael Camargo do Amaral[1], Mateus Castilho Santos[1], João Luiz Pratti Daniel[1], Adir de Sá Neto[1], Álvaro Wosniak Bispo[1], Edward Hernando Cabezas-Garcia[1], Thiago Fernandes Bernardes[2], Luiz Gustavo Nussio[1]**

*[1] Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Departamento de Zootecnia, Piracicaba, SP, Brasil.*
*[2] Universidade Federal de Lavras, Departamento de Zootecnia, Lavras, MG, Brasil.*

**ABSTRACT** - The objective of this study was to evaluate the effect of covering methods on the nutritive value of corn silage and performance of dairy cows. Whole-plant corn was harvested at 340 g/kg of dry matter (DM) and ensiled for 135 d in horizontal silos covered with one of the following methods: oxygen barrier film (45-µm thick) + white-on-black polyethylene film (200-µm thick) over the oxygen barrier film (OB+WB); white-on-black polyethylene film (200-µm thick) (WB); black polyethylene film (200-µm thick) (B); or recycled black polyethylene film (200-µm thick) covered with a layer of 10 cm of sugarcane bagasse (RB+SB). Nutrient composition, fermentation profile, and yeast and mold counts in edible silages were similar across treatments. Silage temperature during the storage period was 24.6, 28.7, 28.4 and 33.1 °C for RB+SB, OB+WB, WB and B, respectively, and the proportion of spoiled silage ranged from 28.7 (for the RB+SB treatment) to 74.2 g/kg DM (for the B treatment). Dry matter intake was similar across treatments and averaged 21.9 kg/d. Milk production was higher for cows fed corn silage covered with RB+SB (34.4 kg/d) compared with those fed corn silage covered with B (30.4 kg/d), resulting in higher feed efficiency for RB+SB treatment. Silages covered with OB+WB and WB had intermediate values. *In vivo* digestibility of organic matter was higher for cows fed corn silage covered with RB+SB compared with those fed corn silage covered with WB and B, but were similar to those fed corn silage covered with OB+WB. The utilization of oxygen barrier films and the protection of polyethylene film with sugarcane bagasse are effective strategies to increase the recovery of digestible nutrients and, consequently, to enhance production efficiency of lactating dairy cows.

Key Words: dairy cow, film protection, *in vivo* digestibility, polyamide

## Introduction

The storage of forage crops as silage is performed in a number of ways, including the use of tower silos, horizontal silos, bags, and piles. Among these methods, horizontal silos have become one of the most attractive options because of their high storage capacities, low cost of construction, and relatively low maintenance requirements over time. However, the design of these silos results in large areas of the ensiled material that are exposed to the environment, making the silage prone to spoilage, especially in the upper layer (Borreani et al., 2007) and near the silo walls. The traditional method used to cover silos is through the use of polyethylene (PE) films; however, the protection provided is highly variable and often changes during storage (Savoie, 1988). Borreani et al. (2007) reported that the high $O_2$ permeability of PE films can contribute to the low quality of silage in the top layer of horizontal silos.

In recent years, new polymers claimed to have low oxygen permeability and resistance to tearing and puncturing have entered the market. They have been developed with the objective of reducing silage deterioration and improving silage quality. One of these polymers is composed of polyamide, and studies conducted in several countries, such as Italy (Borreani et al., 2007), the United States (Muck and Holmes, 2009), and Australia (Rich et al., 2009), have shown that the use of these polymers (oxygen barrier, OB film) reduced dry matter (DM) losses and top surface spoilage when compared with the use of standard plastic films. In a recent meta-analysis Wilkinson and Fenlon (2013) demonstrated that OB films reduced losses in the top layers of horizontal silos, and in baled silages, compared with standard PE films, by, on average 42%. Furthermore, the aerobic stability was improved by 2.5 d in the uppermost layer of silages under OB films.

Another method of covering silos to reduce silage deterioration near the surface is by placing tires on the top of the plastic film to create a boundary between the anaerobic environment of the silo and the aerobic

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Received January 16, 2014 and accepted July 3, 2014.
Corresponding author: jldaniel@usp.br

http://dx.doi.org/10.1590/S1516-35982014000900003

conditions of the atmosphere surrounding it (Berger, 2005). Although good silage can be made using these materials, the labor required to move tires onto the silo, their removal during the feedout phase, and their proper disposal after utilization discourages the use of this system (Berger, 2005), and re-emphasizes the need for alternative methods. Alternatively, the use of biodegradable or edible sealing strategies such as sugar cane bagasse positioned on the plastic sheet might help with insulation and protection of the silage surface. This is of particular importance for silages produced in tropical regions or during the summer season because the physical properties of the plastic films may be markedly altered during the storage period due to the excessive exposure of the films to high ambient temperature and solar radiation.

Therefore, the objective of this study was to investigate the effects of covering methods on silage quality and performance of dairy cows under tropical conditions. To date, this is the first study comparing the influence of covering methods during the silage conservation process on the performance of lactating dairy cows.

## Material and Methods

Pioneer (Pioneer Hi-Bred International, DesMoines, IA) corn hybrid 30F90 Bt was planted in the spring of 2010 on the experimental farm of the Universidade de São Paulo in Piracicaba, Brazil. Corn was monitored for milk-line and whole-plant DM concentration after the early dent stage of maturity. When the DM concentration was at 340 g/kg, whole plant corn was harvested using a Menta Suprema (Mentamit, Cajurú, Brazil) pull-type harvester at a theoretical chop length of 10 mm without kernel processing. Approximately 240 metric tons of forage were packed in four identical horizontal silos (15 m long × 4 m wide, with walls 1.80 m high) to achieve a final forage density of 550 kg/m$^3$. Each silo was sealed within a 2-3 d period from the start of filling with one of the following covering methods: oxygen barrier film (45-µm thick) + white-on-black PE film (200-µm thick) over the oxygen barrier film (OB+WB); white-on-black PE film (200-µm thick) (WB); black PE film (200-µm thick) (B); or recycled black PE film (200-µm thick) covered with a layer of 10 cm of sugarcane bagasse (RB+SB). Sugarcane bagasse was added with the objective of protecting the plastic film from ultra-violet radiation and decreasing oxygen permeability (Paillat and Gaillard, 2001). Furthermore, the bagasse layer can weigh down the plastic film, decreasing the ingress of air between the film and the silage.

Physical properties of the plastic films were evaluated after sealing the silos and at the middle and the end of the lactation trial. Samples (n = 6) of the films (1 m × 1 m) from each silo were sent to Dow Chemical do Brazil and analyzed for thickness, oxygen permeability, tear propagation resistance, puncture resistance, and elongation at break point according to the ASTM-D882 (ASTM, 1985) standard test method. At ensiling, temperature loggers (model iMiniPlus; Escort Data Loggers, Inc., Buchanan, VA, USA) were buried in the center of each silo 90 cm below the top surface and set to record the core temperature of the silage mass every 4 h throughout the storage period and during the lactation trial.

After 135 d of storage, the silos were opened simultaneously for feeding in a lactation study. During the feedout phase of the lactation study, visible spoilage from the top of each silo was manually separated, weighed and discarded every day; only the edible silage was offered to the cows. The weight of visibly spoiled silage was divided by the weight of the total silage removed daily to calculate the proportion of spoiled silage.

Twenty-four multiparous and 16 primiparous Holstein cows in mid lactation (111±36 d in milk), weighing 620±57 kg BW and averaging 36 kg of milk/d at the start of the study were housed in sand-bedded tie-stalls and offered a total mixed ration (TMR) twice daily (06.00 and 17.00 h). After a three-week period of adaptation to the tie-stalls, cows were stratified by pretreatment milk production, parity, and days in milk and were allocated randomly to the treatments.

Treatments consisted of 4 TMR that contained (DM basis) approximately 510 g/kg of one of the corn silages and 490 g/kg of concentrates. Cows were individually fed *ad libitum* to achieve refusals of approximately 100 g/kg, and DM intake (DMI) was measured daily on individual cows for a period of 14 weeks. Fresh water was available at all times, and the care of animals was conducted according to protocols approved by the Committee on Animal Use and Care at Universidade de São Paulo São Paulo/Escola Superior de Agricultura “Luiz de Queiroz”.

Throughout the study, milk yield was recorded twice daily at 06.00 and 17.00 h and milk samples were collected once weekly from consecutive afternoon and morning milkings for fat, protein, lactose, and milk urea-N (MUN) analysis by Fourier transform infrared spectroscopy and for somatic cell count (SCC) by flow cytometry (Clínica do Leite, Piracicaba, Brasil). Production of fat-corrected milk (40 g of fat/kg) was calculated as (NRC, 2001): FCM (kg/d) = [0.4 × milk yield (kg/d) + 15 × milk fat output (kg/d)].

Feed efficiency was calculated as milk yield (kg/d) divided by DMI (kg/d). Body weight (BW) was recorded during three consecutive days at the start and end of the study; therefore BW change (kg/d) was calculated as (Final BW − Initial BW)/98 d. During week 12 of the lactation trial, four cows from each treatment were used in a digestibility study, which consisted of a 3-d total fecal collection. During fecal collections, TMR samples from each treatment and orts for each cow were taken daily.

Representative samples of fresh forage were obtained at ensiling. Edible silage samples were collected daily from each silo and pooled weekly during the lactation study for analysis. Representative samples of TMR and orts were also collected weekly.

Samples of silages, TMR, orts, and feces were dried at 55 °C for 72 h in a forced draft oven and ground to pass a 1-mm screen using a Wiley mill (Arthur H. Thomas Company, Philadelphia, PA). After grinding, absolute DM was obtained by oven-drying the samples at 105 °C for 72 h and the ash concentration was determined by complete combustion in a muffle furnace at 600 °C for 5 h. Silages, TMR, and orts were also analyzed for ether extract according to AOAC (2004), NDF (with sulfite and heat stable alpha-amylase) and ADF according to Van Soest et al. (1991) using the ANKOM system, and nitrogen by combustion (Leco Instruments Inc., St. Joseph, MI; AOAC, 2004). Crude protein was obtained as N × 6.25.

A water extract was prepared for each sample by adding 30 g of fresh forage or silage to 270 g of distilled water and homogenizing the mixture for 4 min (Tabacco et al., 2009) using a laboratory Stomacher blender (model 400 circulator; Seward Inc., Bohemia, New York, USA). After the pH measurement using a pH meter (model HI 208, Splabor, São Paulo, Brazil), water extract was filtered through Whatman 54 filter paper (Whatman, Clifton, NJ) and frozen prior to further analysis. Frozen water extracts were thawed, and the concentration of water-soluble carbohydrates (WSC) was determined according to the method of Dubois et al. (1956). Water extracts from silage samples were also centrifuged for 15 min at 10,000 × g and analyzed for acetic and butyric acids by gas chromatography (Palmquist and Conrad, 1971) with a Hewlett Packard 5890 GC (Hewlett Packard, Avondale, PA). The concentration of lactic acid was measured in the water extract of silage samples using the method described by Pryce (1969).

For microbial counts, 30 g of forage and silage samples were homogenized for 4 min with 270 g of sterile peptone physiological salt solution (PPS: 1 g of neutralized bacteriological peptone and 9 g of sodium chloride per liter) using a laboratory Stomacher blender. This solution was serially diluted (1:10), and appropriate dilutions were inoculated onto Petrifilm plates (Petrifilm yeast and mold count plates, 3M Microbiology Products, St. Paul, MN) for the determination of yeast and molds. Plates were incubated at 25 °C for yeast and mold colony count at 3 and 5 d, respectively.

Physical properties of the plastic films and forage traits were presented as mean±confidence interval ($\alpha = 0.05$). Cow performance data were analyzed as a randomized complete block design using the repeated measure approach of the MIXED procedure of SAS (Statistical Analysis System, version 9.3), with the data from the preliminary period as a covariate. The covariance structure with the smaller value for the Akaike's information criterion was used. The covariance structures considered were the autoregressive (1), compound symmetry, unstructured, and variance components. The model included treatment, week, and treatment × week interaction as fixed effects, and block as a random effect. Week and week × treatment effects were deleted from the model to analyze BW change and *in vivo* digestibility data. All values are presented as least squares means, and differences among treatments were compared using Tukey's test ($\alpha = 0.05$).

## Results

Regarding the physical properties of the plastic films (Table 1), the measured thickness of 53 µm obtained with the OB film was slightly higher than the thickness provided by the manufacturer (45 µm). For the white-on-black, black, and recycled black PE films, the thicknesses obtained in the present study were 136, 144 and 137 µm, respectively, and differed from the nominal thickness of 200 µm provided by the manufacturer. Although the OB film was thinner, its oxygen permeability at 35 °C was 208 $cm^3/m^2$ per 24 h, whereas for the white-on-black, black, and recycled black PE films, the $O_2$ permeability obtained at the same temperature was 1,701, 1,708, and 1,053 $cm^3/m^2$ per 24 h, respectively. Tear propagation resistance, elongation at break and puncture resistance of the plastic films varied from 58 to 895 *g*, from 144 to 837% and from 0.69 to 1.64 $J/cm^3$, respectively.

The DM concentration of the corn silages fed throughout the lactation study ranged from 331 to 358 g/kg and the ash, WSC, CP, NDF, and ADF concentrations averaged 43, 34, 71, 519, and 317 g/kg DM, respectively (Table 2). The pH of the silages sealed with different covering methods ranged from 4.17 to 4.35. All the silages were well fermented, and the main fermentation acids found were lactic and acetic acids, whereas butyric acid was detected in concentrations

<1 g/kg DM. The numbers of yeasts and molds across treatments averaged 3.87 and 3.89 $\log_{10}$ cfu/g of silage, respectively. The temperature of the silage mass during the storage period for RB+SB, OB+WB, WB and B was 24.6, 28.7, 28.4 and 33.1 °C, respectively. The proportion of spoiled silage obtained in the current study ranged from 28.7 (for the RB+SB treatments) to 74.2 g/kg DM (for the B treatment). Analysis of collected samples showed that the TMR were similar for all treatments, averaging 484 g DM/kg as fed, 159 g/kg CP, 406 g/kg NDF, 24 g/kg ether extract, 65 g/kg ash and 346 g/kg nonfiber carbohydrates, on a DM basis (Table 3).

Interactions between treatment and week were statistically significant for DMI and feed efficiency because DMI oscillated over the weeks, even though the magnitude of treatment responses were roughly similar over time. Although the type of covering method did not affect DMI through the trial (average 21.9 kg/d; Table 4), it was observed that milk production was substantially higher for cows fed corn silage covered with RB+SB (34.4 kg/d) compared with those fed corn silage covered with B (30.4 kg/d), and did not differ from cows fed corn silage covered with OB+WB (32.3 kg/d) and WB (32.9 kg/d). The same response was observed for FCM, which was greater (P = 0.038) for RB+SB than for B and did not differ from the OB+WB and WB treatments. Therefore, feed efficiency was greater (P = 0.033) by 0.150 kg of milk per kg of DMI for cows fed corn silage covered with RB+SB compared

Table 1 - Physical properties of the plastic films used to seal the horizontal silos

| Item[1] | Plastic film | | | |
|---|---|---|---|---|
| | OB | WB | B | RB |
| Measured thickness (μm) | 53±2 | 136±3 | 144±4 | 137±9 |
| Oxygen permeability[2] ($cm^3/m^2$ per 24 h) | 208±54 | 1701±325 | 1708±317 | 1053±215 |
| Tear propagation resistance (*g*) | 58±5 | 636±26 | 314±30 | 895±32 |
| Elongation at break (%) | 368±28 | 341±43 | 144±65 | 837±47 |
| Puncture resistance ($J/cm^3$) | 1.64±0.62 | 0.69±0.11 | 1.09±0.42 | 1.40±0.44 |

OB - oxygen barrier film (45-μm thick); BW - black-on-white polyethylene film (200-μm thick); B - black polyethylene film (200-μm thick); RB - recycled black polyethylene film (200-μm thick).

[1] Averages from samples of the plastic films collected immediately after sealing the silos and at the middle and the end of the lactation trial.

[2] Oxygen permeability measured at 35 °C.

Table 2 - Chemical and microbial composition of fresh corn and corn silages, core temperature of the silage mass and proportion of spoiled silage stored in horizontal silos and fed throughout the lactation study (g/kg DM, unless otherwise stated)

| Item | Treatment | | | |
|---|---|---|---|---|
| | OB + WB | WB | B | RB + SB |
| Composition of fresh corn | | | | |
| Dry matter (g/kg as fed) | 336±18 | 331±20 | 340±14 | 332±19 |
| Ash | 53±5 | 50±4 | 44±3 | 44±4 |
| Water-soluble carbohydrates | 57±10 | 60±11 | 58±9 | 59±12 |
| Crude protein | 69±5 | 63±4 | 67±5 | 67±4 |
| Neutral detergent fiber | 545±27 | 524±23 | 532±26 | 535±19 |
| Acid detergent fiber | 316±13 | 319±17 | 305±14 | 321±15 |
| Composition of corn silage[1] | | | | |
| Dry matter (g/kg as fed) | 333±14 | 358±19 | 337±15 | 331±16 |
| Ash | 41±3 | 42±4 | 45±5 | 44±3 |
| Water-soluble carbohydrates | 37±7 | 30±7 | 34±6 | 36±9 |
| Crude protein | 72±6 | 70±3 | 71±4 | 70±4 |
| Neutral detergent fiber | 506±23 | 515±29 | 528±15 | 526±20 |
| Acid detergent fiber | 312±14 | 309±19 | 320±12 | 327±14 |
| pH | 4.17±0.15 | 4.23±0.11 | 4.35±0.15 | 4.27±0.10 |
| Lactic acid | 29.1±7.4 | 30.8±7.0 | 33.5±8.4 | 37.8±9.5 |
| Acetic acid | 13.1±1.7 | 14.4±4.2 | 10.8±3.3 | 11.4±1.5 |
| Butyric acid | 0.5±0.1 | 0.7±0.4 | 0.8±0.1 | 0.3±0.1 |
| Yeasts ($\log_{10}$ cfu/g) | 3.25±1.86 | 3.47±1.78 | 4.23±1.72 | 4.51±1.05 |
| Molds ($\log_{10}$ cfu/g) | 3.62±1.55 | 2.93±2.18 | 4.36±1.80 | 3.83±1.78 |
| Silage temperature[2] (°C) | 28.7±3.3 | 28.4±2.3 | 33.1±1.8 | 24.6±1.7 |
| Spoiled silage | 38.6±4.2 | 59.6±6.5 | 74.2±13.0 | 28.7±4.6 |

OB + WB - oxygen barrier film (45-μm thick) + white-on-black polyethylene film (200-μm thick) over the oxygen barrier film; WB - white-on-black polyethylene film (200-μm thick); B - black polyethylene film (200-μm thick); RB + SB - recycled black polyethylene film (200-μm thick) covered with a layer of 10 cm of sugarcane bagasse.

[1] Average from samples collected daily from each silo and pooled weekly during the lactation study.

[2] Average temperature recorded every 4 h throughout the storage period and during the lactation trial at 90 cm below the top surface of each silo.

with those fed corn silage covered with B or WB, but did not differ from cows fed corn silage covered with OB+WB. The BW changes of the cows were not different across treatments and averaged 0.426 kg/d.

Milk composition and daily yield of milk components were not affected by treatments, with the exception of the protein concentration and yield of lactose. Protein concentration was slightly lower for the RB+SB treatment in comparison with B and did not differ from the OB+WB and WB treatments. The daily yield of lactose was higher for cows fed corn silage covered with RB+SB in comparison with cows fed corn silage covered with B but did not differ from cows fed corn silage covered with OB+WB and WB.

Although the type of covering method did not affect the intake of DM, organic matter, and NDF, it was observed that the digestibility of DM and organic matter was greater ($P = 0.019$ and $P = 0.034$, respectively) for cows fed RB+SB compared with those fed corn silage covered with WB and B, but was similar to those fed corn silage covered with OB+WB (Table 5).

Table 3 - Ingredients and chemical composition of TMR fed to lactating cows (g/kg DM, unless otherwise stated)

| Item | Treatment | | | |
|---|---|---|---|---|
| | OB + WB | WB | B | RB + SB |
| Ingredient | | | | |
| Corn silage | 514 | 511 | 508 | 514 |
| Dry ground corn | 178 | 179 | 180 | 178 |
| Citrus pulp | 78 | 79 | 79 | 78 |
| Soybean meal | 209 | 210 | 212 | 209 |
| MetaSmart[1] | 1.3 | 1.3 | 1.3 | 1.3 |
| Mineral-vitamin mix[2] | 20 | 20 | 20 | 20 |
| Chemical composition | | | | |
| Dry matter (g/kg as fed) | 489 | 487 | 470 | 488 |
| Crude protein | 159 | 159 | 160 | 159 |
| Neutral detergent fiber | 403 | 407 | 409 | 404 |
| Ether extract | 24 | 24 | 25 | 24 |
| Ash | 65 | 65 | 65 | 65 |
| Nonfiber carbohydrates[3] | 349 | 345 | 341 | 348 |

TMR - total mixed rations; OB + WB - oxygen barrier film (45-µm thick) + white-on-black polyethylene film (200-µm thick) over the oxygen barrier film; WB - white-on-black polyethylene film (200-µm thick); B - black polyethylene film (200-µm thick); RB + SB - recycled black polyethylene film (200-µm thick) covered with 10 cm of sugarcane bagasse.

[1] Composition: 570 g/kg of isopropyl ester of 2-hydroxy-4-methylthiobutanoic acid monomer esters (MetaSmart, Adisseo, Alpharetta, GA).

[2] Mineral mix contained (DM basis): 100 g/kg Ca; 20 g/kg S; 40 g/kg P; 50 g/kg Mg; 20 g/kg K; 2,800 mg/kg Zn; 490 mg/kg Cu; 18 mg/kg Se; 1,400 mg/kg Mn; 14 mg/kg Co; 56 mg/kg I; 20 mg/kg Cr; 400,000 IU/kg vitamin A; 40,000 IU/kg vitamin D; 1,200 IU/kg vitamin E; 80 mg/kg biotin; and 600 mg/kg monensin.

[3] $NFC = 100 - (NDF + CP + EE + ash)$.

Table 4 - Dry matter intake, milk production, and milk composition by cows fed TMR containing corn silages covered with different types of covering methods

| Item | Treatment | | | | SEM | P-value[1] | | |
|---|---|---|---|---|---|---|---|---|
| | OB + WB | WB | B | RB + SB | | T | W | T × W |
| DMI (kg/d) | 21.7 | 22.7 | 21.3 | 21.9 | 0.7 | 0.466 | <0.001 | <0.001 |
| Milk yield (kg/d) | 32.3ab | 32.9ab | 30.4b | 34.4a | 1.6 | <0.001 | <0.001 | 0.345 |
| FCM (kg/d) | 30.3ab | 30.4ab | 29.5b | 32.5a | 1.1 | 0.042 | <0.001 | 0.160 |
| Fat (g/kg) | 36.5 | 35.7 | 38.3 | 36.1 | 1.4 | 0.408 | <0.001 | 0.816 |
| Protein (g/kg) | 32.9ab | 33.4ab | 34.4a | 31.8b | 0.7 | 0.028 | <0.001 | 0.865 |
| Lactose (g/kg) | 46.5 | 46.7 | 46.4 | 46.5 | 0.6 | 0.973 | <0.001 | 0.471 |
| SCC (×1,000/mL) | 105 | 153 | 107 | 85 | 38 | 0.643 | 0.399 | 0.801 |
| MUN (mg/dL) | 14.1 | 15.0 | 14.6 | 14.4 | 0.5 | 0.565 | 0.432 | 0.354 |
| Fat (kg/d) | 1.16 | 1.15 | 1.16 | 1.25 | 0.04 | 0.144 | <0.001 | 0.232 |
| Protein (kg/d) | 1.05 | 1.09 | 1.05 | 1.09 | 0.04 | 0.591 | <0.001 | 0.264 |
| Lactose (kg/d) | 1.51ab | 1.54a | 1.41b | 1.61a | 0.08 | 0.019 | <0.001 | 0.476 |
| Feed efficiency[2] | 1.49ab | 1.44b | 1.44b | 1.59a | 0.05 | 0.030 | <0.001 | <0.001 |
| BW change (kg/d) | 0.485 | 0.400 | 0.404 | 0.413 | 0.083 | 0.867 | - | - |

TMR - total mixed rations; OB + WB - oxygen barrier film (45-µm thick) + white-on-black polyethylene film (200-µm thick) over the oxygen barrier film; WB - white-on-black polyethylene film (200-µm thick); B - black polyethylene film (200-µm thick); RB + SB - recycled black polyethylene film (200-µm thick) covered with 10 cm of sugarcane bagasse.

DMI - dry matter intake; BW - body weight; FCM - fat-corrected milk (40 g fat/kg milk); SCC - somatic cell count; MUN - milk urea-N.

[1] Effects of treatment (T), week (W) and treatment × week (T × W) interaction.

[2] Feed efficiency = milk yield/DMI.

a,b - values within a row with different letters differ significantly at $P<0.05$.

Table 5 - Intake and total tract digestibility of the TMR from the digestibility study conducted during the lactation trial

| Item[1] | Treatment | | | | SEM | P-value |
|---|---|---|---|---|---|---|
| | OB + WB | WB | B | RB + SB | | |
| Intake (kg/d) | | | | | | |
| Dry matter | 22.3 | 22.3 | 21.0 | 21.8 | 1.1 | 0.161 |
| Organic matter | 20.8 | 20.9 | 19.7 | 20.6 | 1.1 | 0.155 |
| Neutral detergent fiber | 8.3 | 8.1 | 7.4 | 7.5 | 0.6 | 0.663 |
| Digestibility | | | | | | |
| Dry matter | 0.650ab | 0.603b | 0.592b | 0.675a | 0.016 | 0.019 |
| Organic matter | 0.729ab | 0.699b | 0.693b | 0.741a | 0.015 | 0.031 |
| Neutral detergent fiber | 0.495 | 0.439 | 0.382 | 0.470 | 0.038 | 0.203 |

TMR - total mixed rations; OB + WB - oxygen barrier film (45-µm thick) + white-on-black polyethylene film (200-µm thick) over the oxygen barrier film; WB - white-on-black polyethylene film (200-µm thick); B - black polyethylene film (200-µm thick); RB + SB - recycled black polyethylene film (200-µm thick) covered with 10 cm of sugarcane bagasse.

[1] Averages were obtained using 16 cows during the digestibility study.

a,b - values within a row with different letters differ significantly at $P<0.05$.

## Discussion

The ability of sealing strategies to prevent air from infiltrating the silage during storage has considerable effects on feed quality. Among the studied strategies, the OB film had the lowest $O_2$ permeability because it was composed of polyamide, a polymer that is known for its gas impermeability. Low-polarity gas molecules such as $O_2$ and $CO_2$ exhibit only weak interactions with the high polar groups in films composed of polyamide, and this weak interaction combined with the presence of crystalline regions reduces the permeability rates of the gases (Stern et al., 1987), resulting in good gas-barrier properties. In contrast, the PE film is known to be more permeable to $O_2$ diffusion. A recent study conducted by Borreani and Tabacco (2010) reported that $O_2$ permeability of the PE stretch films was 18-fold higher than that observed in OB stretch films. Bernardes et al. (2012) observed a positive correlation between $O_2$ permeability and DM losses, whereas the thickness of plastic films did not correlate with DM losses, suggesting that $O_2$ permeability was the most important feature when considering the retention of nutrients in the silages. Furthermore, based on the results of the physical properties of the plastic films, it may be suggested that the utilization of OB films or the protection of PE films are effective methods to improve the resistance of the plastic film against damages during the storage period, in addition to being important for the maintenance of an anaerobic environment for the fermentation process.

On the other hand, covering the PE film with sugarcane bagasse was even more effective than OB to prevent air infiltration, as noticed by the lower proportion of visually deteriorated silage on top layers. The proportion of spoiled silage obtained in the current study ranged from 28.7 (for the RB+SB treatments) to 74.2 g/kg DM (for the B treatment) and this variation might be attributed to differences in the $O_2$ infiltration. Thus, these results suggest that silage deterioration can be reduced by the utilization of covering methods, which reduces the influx of air into the silo. These covering methods may also increase the levels of $CO_2$ trapped in silage mass, improving the anaerobic conditions for the fermentation process. A previous study conducted by Borreani et al. (2007) reported differences in DM losses of bunker silos sealed with two types of plastic sheets (standard PE vs. OB film) on two commercial farms in Italy. In one of the farms, the authors reported that the DM losses were 3.7 times lower for OB films than for the standard PE film, whereas for the other farm, the DM losses were numerically greater in the silage sealed with the standard PE film compared with the OB film (90 vs. 59 g/kg, respectively).

Nevertheless, in the current study the nutrient composition of edible silages was similar across treatments at silo opening and represented a typical corn silage harvested at approximately 300-350 g/kg DM. A previous study conducted by O'Kiely and Forristal (2003) did not find differences in the nutrient composition of grass silage stored in bunker silos covered with either two sheets of black polythene film of 125-µm thickness or a single layer of OB film overlaid with a single protective sheet of black polythene. The authors stated that both systems were successful when operated properly and resulted in negligible surface waste or visible mold. In a recent study, Dolci et al. (2011) reported that the low permeability to oxygen of the OB film helped to create a more anaerobic environment, and this was reflected in silages with higher lactic acid concentrations and lower pH and acetic acid concentrations, when compared with PE films. In contrast, O'Kiely and Forristal (2003) did not find differences in the fermentation end-products of grass silages stored in bunker silos covered with either two sheets of black polythene film of 125-µm thickness or a single layer of OB film overlaid with a single protective sheet of black polythene.

The numbers of yeasts and molds across treatments were relatively low and were most likely insufficient to cause any modification in the fermentation profile of edible silages. In a previous study, Woolford (1990) reported that silages are more susceptible to rapid aerobic deterioration when the population of yeasts is greater than $10^5$ cfu/g FM. On the other hand, the temperature of the silage mass during the storage period was in line with sealing effectiveness, as influenced by the color and oxygen permeability of the plastic films, as well as by the addition of a layer of sugar cane bagasse on the top of the plastic film.

Remarkably, even after discarding the visually spoiled silages, effective sealing strategies (e.g. RB+SB) led to better edible silages than poorer methods, as supported by higher nutrient digestibility and milk production, whereas DMI was not significantly altered. Therefore, feed efficiency was greater for cows fed corn silage covered with RB+SB compared with those fed corn silage covered with B or WB, but did not differ from cows fed corn silage covered with OB+WB, indicating that milk production efficiency can be substantially altered by the utilization of different covering methods. The BW changes of the cows were not different across treatments, suggesting that the effect of body fat reserves on milk production occurred in a consistent manner for all the treatments. The lower ingress of oxygen may have contributed to the preservation of the digestible components of the silages by reducing the spoiling of the silage mass. In a previous study with sorghum silage, Rich et al. (2009) reported that the concentration of metabolizable energy tended to be decreased due to ensiling for material stored under conventional PE white-on-black film, but not for crops stored under an oxygen barrier film. The findings of the digestibility study suggest that the greater milk production efficiency reported for cows fed corn silage covered with RB+SB and OB+WB was most likely due to the higher organic matter digestibility observed for these two treatments. Even after discarding the visually spoiled silages, poorer sealing strategies (e.g. B treatment) led to worse edible silages than covering methods capable to prevent the occurrence of deteriorated areas such as RB+SB.

## Conclusions

There is a great influence of covering methods on the recovery of digestible nutrients and, consequently, the performance and efficiency of lactating dairy cows can also be markedly affected. Promising results are obtained with the utilization of oxygen barrier (45-µm thick) films and the protection of polyethylene films. Furthermore, it is also possible that the impact of these results are even more significant under field conditions if inadequate management of the silos is implemented (e.g., slow filling rates, low packing densities, and insufficient quantities of silage removed between feedings) or when the spoiled silage is not discarded routinely and is fed to the animals. Even after discarding spoiled silage, poorer sealing strategies lead to worse silages than covering methods capable to prevent the occurrence of spoiled areas.

## Acknowledgments

The authors wish to thank Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Silostop for the funding of this project.

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