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Research Paper

Dry matter concentration and corn silage density: Effects on forage quality

Concentración de materia seca y densidad de ensilaje de maíz: Efectos en la calidad del forraje

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Abstract

Considering the hypothesis that density and dry matter (DM) concentration may be used as indicators of silage nutritional quality, the aim of the present study was to determine density and maturation stage (i.e. DM concentration) of corn silages under farm conditions in Brazil, establishing relationships between density and physical and chemical characteristics. In a completely randomized design, 20 bunkers of corn silage, each from a different farm, were used for data collection. Using a coring machine, 5 samples of silage were extracted from an exposed face of each silo and samples were analyzed for density of compaction, plus concentrations of DM, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), total digestible nutrients (TDN), total carbohydrate (TC), non-fiber carbohydrate (NFC) and starch (STA), as well as electrical conductivity. There was significant variation in many of the parameters measured with the greatest variation in density on a natural matter basis. Negative correlations were observed between percentages of DM, NDF and ADF in the silage and silage density on a natural matter basis ($P<0.05$). On the other hand, DM% was positively correlated with concentrations of STA, TDN and TC ($P<0.05$). Density on a DM basis showed positive correlation with STA but was negatively correlated with NDF and ADF ($P<0.05$) indicating that the more fibrous material is harder to compact. A technology transfer program seems warranted to inform Brazilian farmers of these findings and the importance of harvesting forage at a stage of growth when quality would be better to increase the probability of achieving adequate compaction of the ensiled material and hence better quality of material at feeding out.

Keywords: Bunker silos, compaction, forage conservation, silage quality, specific mass.

Resumen

Con base en la hipótesis que la densidad y la concentración de materia seca (MS) son indicadores de la calidad nutritiva del ensilaje, el objetivo del presente estudio fue determinar ambas características en ensilaje de maíz a nivel de fincas en el estado de Paraná, Brasil. La recolección de datos se hizo en 20 silos búnker en diferentes fincas y para su análisis se usó un diseño completamente aleatorio. En cada silo se tomaron 5 muestras y se determinaron la densidad de compactación y las concentraciones de MS, proteína cruda (PC), fibra detergente neutra (FDN), fibra detergente ácida (FDA), nutrientes digestibles totales (TDN), carbohidratos totales (CT), carbohidratos no fibrosos (CNF) y almidón (STA), así como la conductividad eléctrica. La densidad basada en materia natural fue el parámetro que presentó la mayor variación entre silos. Se observaron correlaciones negativas entre los porcentajes de MS, FDN y FDA y la densidad del ensilaje basada en materia natural ($P<0.05$). Por otro lado, el porcentaje de MS se correlacionó positivamente con las concentraciones de STA, TDN y CT ($P<0.05$). La densidad basada en materia seca mostró una

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correlación positiva con STA pero negativa con FDN y FDA (P<0.05), lo que indica que el material más fibroso es más difícil de compactar. Un programa de transferencia de tecnología parece justificado para informar a los ganaderos brasileños de estos resultados y resaltar la importancia de cosechar forraje en una etapa de crecimiento que facilite una compactación adecuada del material y por tanto, una mejor calidad del forraje ensilado.

Palabras clave: Calidad de ensilaje, compactación, conservación de forraje, masa específica, silos búnker.

Introduction

Major challenges for high quality silage production occur at the stages of ensiling, storing and discharging from bunker silos. During these stages, microbial activities may affect fermentation processes in the ensiled forage and consequently its nutritional quality. Thus, to reduce quality losses, parameters related to the forage itself at the harvest stage, such as moisture content, crude protein concentration and particle size, must be evaluated as well as those related to the type of bunker silo, which will determine the exposure of the ensiled material to oxygen and compaction (Cardoso et al. 2016).

One of the most important factors influencing silage quality is its density (Craig and Roth 2005), which is primarily determined, among other things, by the average particle size of the forage plant, its stage of maturity at harvest and how efficiently the compaction of the material is carried out, which usually in bunker silos is done by using packing tractors (Muck and Holmes 2000). Silages with low density often contain high residual air mass, resulting in longer periods of oxygen exposure and consequently increased consumption of soluble carbohydrates, plus reduced production of organic acids and higher pH (McDonald et al. 1991).

In addition, low density values lead to higher porosity and passage of air into the bunker silo, affecting the aerobic stability and increasing losses during utilization of the silage (Jobim et al. 2007). Thus, reduction of porosity/increasing compaction or density during ensiling is a crucial management practice for reducing aerobic deterioration (Bernardes et al. 2009; Hentz et al. 2017). Aerobic deterioration, besides reducing the nutritional value of the ensiled material, can increase the proliferation of pathogenic or undesirable microorganisms, impairing the performance of animals fed on these forages (Barbosa et al. 2011). Greater compaction results in higher density, allowing a better retention of soluble carbohydrates and reduced proteolysis, resulting in improved acceptability to animals and nutritional quality of the ensiled material (Velho et al. 2007; Sucu et al. 2016).

Based on the above, we hypothesized that measuring density and dry matter (DM) concentration of silages on farm could provide reliable indicators of the nutritional quality of the feed. We designed this study to sample corn silages under farm conditions in Paraná, Brazil, determine their density and DM percentage, and calculate the relationships between these variables and physical and chemical characteristics of silages.

Materials and Methods

Following a completely randomized design, samples of corn silages were collected from 20 bunker silos on 20 typical dairy farms in the ABCW dairy basin, Paraná State, Brazil, specifically in the municipalities of Arapoti (24º09' S, 49º49' W), Piraí do Sul (24º31' S, 49º56' W), Castro (24º47' S, 50º00' W), Carambeí (24º55' S, 50º05' W) and Ponta Grossa (25º05' S, 50º09' W). Before starting the sampling procedure, a slice of silage was removed from the vertical face of each silo panel in order to remove any loose silage, so that the samples were collected from undisturbed material.

Density measurements (i.e. specific mass) were made by employing the methodologies described by Muck and Holmes (2000) and D'Amours and Savoie (2004); a metal cylinder (20 cm long and 10 cm diameter) with a serrated cutting edge and attached to a chainsaw was used as described by Craig and Roth (2005) and Krüger et al. (2017). The force generated by the chainsaw screwed the cylinder horizontally into the vertical face of the silage panel. When the silage sample was withdrawn from the silage, the depth was measured with a rule to calculate the volume of the sample. Silage samples were withdrawn at 5 points (replications) on the vertical face of the silo panel: 3 locations at the top and 2 at the bottom, forming a "W" like pattern. The samples were weighed when withdrawn and from the cylinder volume and the mass of the sample, density of silage in the silo on a natural matter basis (DNM) was calculated, assuming uniform density throughout the silo. Samples were then dried (55 °C for 72 h in a forced air circulation oven) and density on a dry matter basis (DDM) was calculated in order to account for differences in moisture content between silages.

The Penn State particle size separator method (Heinrichs 1996) was used to determine the average particle size (APS) in each composite sample (5 replicates from the silo panel). Calculations of particle size were carried out according to manufacturer's instructions. This particle separator contains sieves of 19 and 8 mm, in which the 19 mm sieve was designed to retain forage or feed particles that would be buoyant in the rumen (form the forage mat) and require substantial cud chewing by the animal; in theory this would supply additional buffering to the rumen and help modify rumen pH. After that, the 8 mm sieve collects primarily forage particles that are also part of the forage mat in the rumen, but will be broken down faster with less cud chewing and will hydrate in the rumen faster to allow more rapid rumen microbial breakdown. Additionally, there is a bottom pan where all the other smaller particles should be collected. Subsequently, APS is calculated according to the percentage (on natural matter mass basis) of material retained in each sieve.

A digital potentiometer was used to measure pH according to Cherney and Cherney (2003) and electrical conductivity was determined as described by Jobim et al. (2007) using a digital conductivity meter.

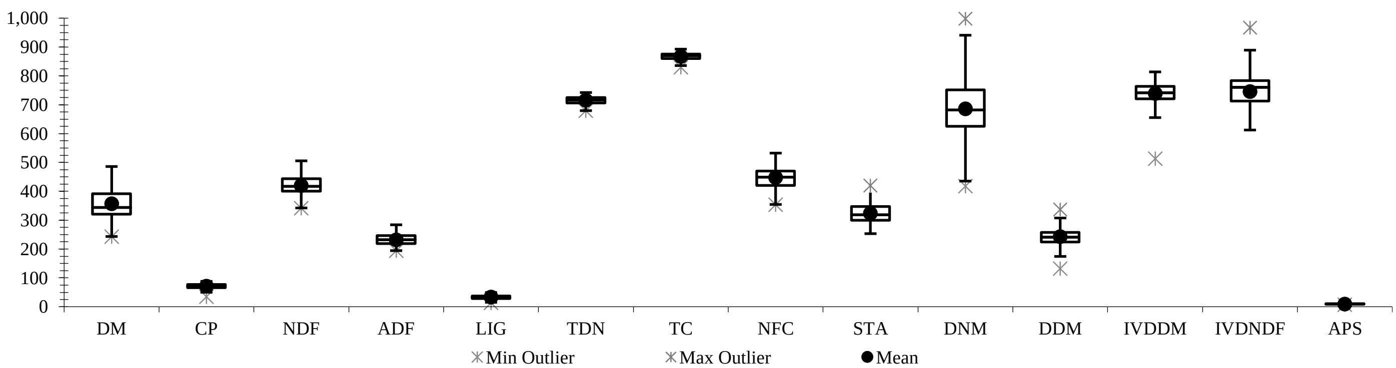
For chemical composition analysis, dried silage samples (55 °C for 72 h in a forced air circulation oven) were ground in a Wiley mill through a 1 mm screen. The concentrations of DM (ID number: 934.01), crude protein (CP; ID number: 2001.11), ether extract (EE; ID number: 2003.5) and ash (ID number: 942.05) were determined according to AOAC International (2011). Starch (STA) determination followed the methodology described by Pereira and Rossi (1995), while neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin (LIG) were determined according to Van Soest et al. (1991). Total carbohydrates (TC) were calculated using the equation: TC = 1,000 – [CP (g/kg DM) + EE (g/kg DM) + ash (g/kg DM)]. Non-fiber carbohydrates (NFC) were calculated as the difference between TC and NDF (Hall 2000). Total digestible nutrients (TDN) were calculated using the equation: TDN (g/kg) = 87.84 – (0.70 × ADF) (Undersander et al. 1993). All chemical composition parameters, except for DM, were determined on a DM basis.

The methodology proposed by Tilley and Terry (1963), adapted to a Daisy II incubator system (ANKOM® - Technology Corporation) as described by Santos et al. (2000), was used to determine the in vitro digestibility of DM (IVDDM) and NDF (IVDNDF).

Statistical analysis was performed using the software SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA). Correlation (Proc CORR) and factor analysis (Proc Factor) were performed to verify the relationships between the obtained variables. For all procedures, 5% significance level was adopted.

Results

The means and variation between tested silage samples in physical and chemical composition parameters are presented as a boxplot in Figure 1. The greatest variation was shown for DNM, being much greater than the variation in DDM, while the variation in total carbohydrates, TDN and pH was minimal as shown by standard deviation (SD) values below. Average electrical conductivity and pH for silages were 591 ± 100.9 (µS/cm) and 4.0 ± 0.09 (mean ± SD), respectively.



DM – dry matter (g/kg); CP – crude protein (g/kg DM); NDF – neutral detergent fiber (g/kg DM); ADF – acid detergent fiber (g/kg DM); LIG – lignin (g/kg DM); TDN – total digestible nutrients (g/kg DM); TC – total carbohydrates (g/kg DM); NFC – non-fiber carbohydrates (g/kg DM); STA – starch (g/kg DM); DNM – density on natural matter basis (kg NM/m^3); DDM – density on dry matter basis (kg DM/m^3); IVDDM – in vitro digestibility of dry matter (g/kg); IVDNDF – in vitro digestibility of neutral detergent fiber (g/kg); APS – average particle size (mm).

Figure 1. Boxplot of chemical, physical and nutritional variables of corn silages for dairy cattle on 20 farms in Paraná State, Brazil. Boxplot elements – upper and lower hinges: 75th and 25th quartiles; inner horizontal line: median; vertical lines: extensions of the hinges to the largest and smallest values at most 1.5 times of interquartile range; upper and lower markers: outlier values; internal circle markers: mean values.

Dry matter percentage in silage was negatively correlated with NDF (r = -0.44*), ADF (r = -0.42*) and DNM (r = -0.48*) but was positively related to DDM (r = 0.54*) (Table 1). However, DDM and DNM were positively correlated (r = 0.47*), while DDM was negatively related to NDF (r = -0.46*) and ADF (r = -0.40*). These correlations may be clearly observed in the 2 main factor analysis (Figure 2 – variables next to one another along the axes are positively correlated while those in opposite positions are negatively correlated), which explained 49.1% (i.e. sum of autovectors) of the variance observed between the parameters evaluated.

Discussion

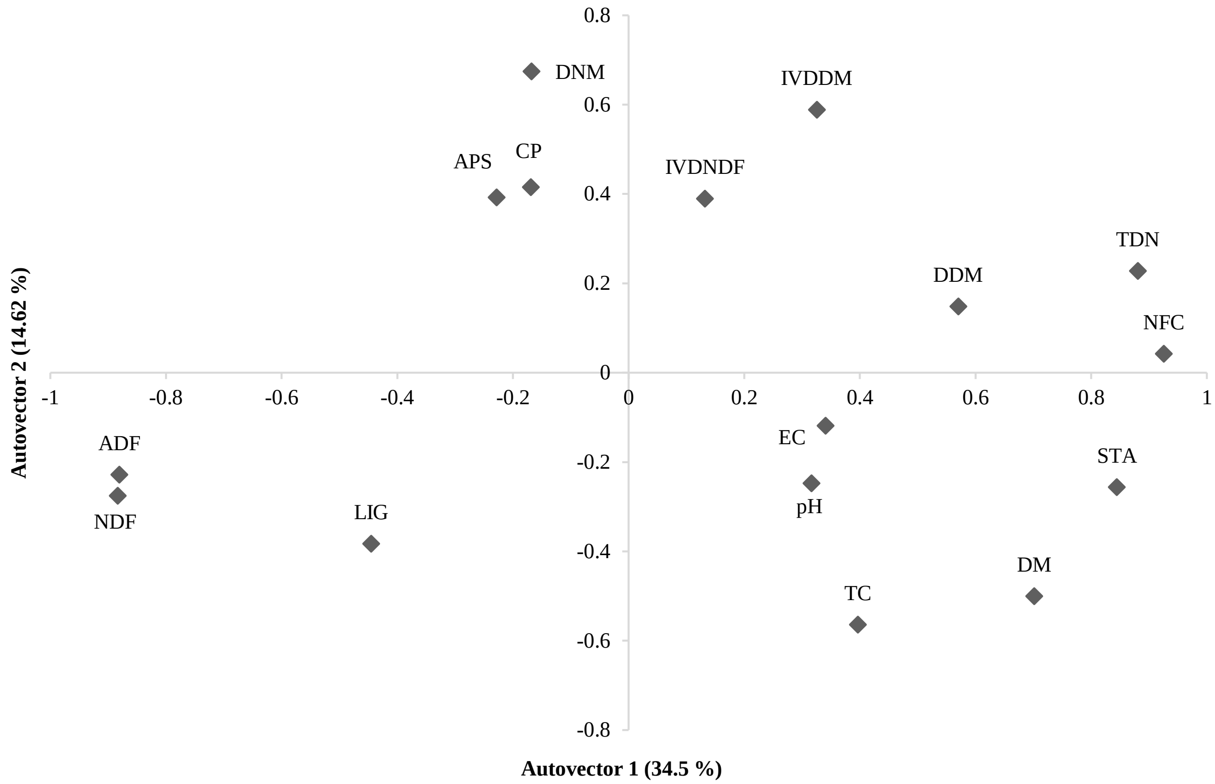
An important outcome of this study was the demonstration that maize silage being made on dairy farms in this region varied greatly in quality, which can probably be related to the stage of maturity of the maize crop at harvesting (Figure 1). The ability to compress the ensiled forage depends greatly on factors like fiber levels, moisture content, particle size etc. High density of compaction can prevent loss of nutrients because more air is expelled from the compacted material and the opportunity for aerobic respiration to occur is reduced. On the other hand, low density of compression can result in an environment favorable for aerobic respiration, increasing the proliferation of molds and mycotoxins (Sucu et al. 2016; Hentz et al. 2017). Amaral et al. (2007) showed that low density of compaction resulted in greater gas production, while high density of compaction resulted in a greater preservation of DM content of *Brachiaria brizantha* cv. Marandu silage. In addition, reduced pH was associated with high density of compaction, indicating that the environment was more suitable for the proliferation of lactic acid-producing bacteria (Amaral et al. 2007). Santos et al. (2010a) demonstrated that high density of compaction in tropical forage silages was possible when NDF and ADF concentrations in the ensiled material were low and the in vitro digestibility was high.

Our results showed that DNM was negatively related to STA, possibly due to the adequate environment for the fermentation process, since the microorganisms prefer low molecular weight carbohydrates as soluble sugars (Hentz et al. 2017). The DM% and density of the ensiled material has significant impacts on the final result of the fermentation process, because when DM concentration exceeds the ideal, it is more difficult to achieve the desired level of compaction in the ensiling process. Average DM observed here was 358 ± 50.3 g/kg (mean ± SD), which was at the upper limit of the ideal range for corn silage (300–350 g DM/kg) suggested by Marafon et al. (2015). The positive correlations between DM% and parameters such as STA, TDN and TC lend weight to this suggestion (Table 1; Figure 2).

Table 1. Pearson correlation coefficients among evaluated variables in corn silages for dairy cattle on 20 farms in Paraná State, Brazil.

	DM	CP	ADF	LIG	NDF	TDN	TC	NFC	STA	DNM	DDM	IVDDM	IVDNDF	pH	EC
CP	-0.14														
ADF	-0.42*	0.00													
LIG	-0.08	0.09	0.40*												
NDF	-0.44*	0.01	0.83*	0.42*											
TDN	0.42*	0.00	-100.00*	-0.40*	-0.83*										
TC	0.39*	-0.77*	-0.16	-0.10	-0.13	0.16									
NFC	0.53*	-0.29*	-0.79*	-0.40*	-0.93*	0.79*	0.48*								
STA	0.68*	-0.25*	-0.64*	-0.32*	-0.65*	0.64*	0.55*	0.78*							
DNM	-0.48*	0.28*	0.06	0.00	0.01	-0.06	-0.30*	-0.11	-0.23*						
DDM	0.54*	0.11	-0.40*	-0.10	-0.46*	0.40*	0.12	0.45*	0.47*	0.47*					
IVDDM	-0.01	-0.08	-0.34*	-0.40*	-0.41*	0.34*	-0.05	0.35*	0.07	0.15	0.14				
IVDNDF	-0.08	-0.03	-0.14	-0.19	-0.13	0.14	-0.07	0.09	-0.01	0.14	0.07	0.31*			
pH	0.49*	0.10	-0.18	-0.09	-0.20*	0.18	-0.06	0.16	0.21*	-0.30*	0.24*	-0.09	-0.01		
EC	0.45*	0.34*	-0.28*	0.01	-0.26*	0.28*	-0.22*	0.16	0.18	-0.20*	0.27*	-0.14	0.12	0.31*	
APS	-0.34*	-0.13	0.19	-0.28*	0.03	-0.19	-0.17	-0.09	-0.24*	0.11	-0.23*	0.23*	0.00	-0.07	-0.37*

DM – dry matter (g/kg); CP – crude protein (g/kg DM); ADF – acid detergent fiber (g/kg DM); LIG – lignin (g/kg DM); NDF – neutral detergent fiber (g/kg DM); TDN – total digestible nutrients (g/kg DM); TC – total carbohydrates (g/kg DM); NFC – non-fiber carbohydrates (g/kg DM); STA – starch (g/kg DM); DNM – density on natural matter basis (kg NM/m^3); DDM – density on dry matter basis (kg DM/m^3); IVDDM – in vitro digestibility of dry matter (g/kg); IVDNDF – in vitro digestibility of NDF (g/kg DM); EC – electrical conductivity (μS/cm); APS – average particle size (mm).



DM – dry matter (g/kg); CP – crude protein (g/kg DM); ADF – acid detergent fiber (g/kg DM); LIG – lignin (g/kg DM); NDF – neutral detergent fiber (g/kg DM); TDN – total digestible nutrients (g/kg DM); TC – total carbohydrates (g/kg DM); NFC – non-fiber carbohydrates (g/kg DM); STA – starch (g/kg DM); DNM – density on natural matter basis (kg NM/m^3); DDM – density on dry matter basis (kg DM/m^3); IVDDM – in vitro digestibility of dry matter (g/kg); IVDNDF – in vitro digestibility of neutral detergent fiber (g/kg); EC – electrical conductivity (µS/cm); APS – average particle size (mm).

Figure 2. Factor analysis evaluating chemical, physical and nutritive parameters of corn silages for dairy cattle on 20 farms in Paraná State, Brazil.

The IVDDM was not related to DM% of silage, but we found evidence that excessive maturity in material at ensiling can result in reduced nutritional quality of silage, since STA, TDN and TC were negatively related to the fiber content (ADF and NDF), a factor which is emphasized by the extremely opposite positions of these variables along the axes in Figure 2. Still concerning the fiber levels in the silages, IVDDM was negatively correlated with NDF and ADF concentrations, indicating the importance of ensiling crops at the most appropriate maturity stage to obtain high quality silage (Souza Filho et al. 2011). In addition, the positive relationship between DDM and STA as well as IVDNDF indicated the importance of ensuring adequate compaction while ensiling forage material. Our results showed that DM% in silage and density are parameters that must be considered by producers to achieve better productivity results, since both are related to good quality indexes of the ensiled material (Figure 2), and are also supported by other studies in the literature (Santos et al. 2010b; Hentz et al. 2017).

It was interesting that CP concentration in ensiled material was negatively related to total carbohydrates, non-fiber carbohydrates and starch, which might all be expected to increase as plants matured, i.e. when cobs were formed and seeds were produced. Crude protein levels would also be expected to fall at this stage of growth, while at the same time, they are positively related to density on a natural matter basis, again following a logical pattern. As the plants mature the forage becomes more fibrous so the material is harder to compact, while CP% declines.

Electrical conductivity measurements have been used in studies carried out in Brazil (Jobim et al. 2007). The EC is defined as the ability that water has to conduct electrical current, which is related to the presence of dissolved ions. The EC values found in our study are lower than those found by Castro et al. (2006) evaluating *Cynodon* sp. silage (965 µS/cm). This measurement does not express specifically what ions are present in a given sample, but is related to the loss of intracellular material, i.e. soluble substances such as pectin, during the ensiling process as evidenced by its significant correlation with TC (r = -0.22*), CP (r = 0.34*) and TDN (r = 0.28*). The effects of fermentation products on EC are still not properly understood; however, the results can be used to draw inferences about adequate APS (r = -0.37*) and desirable DM% in forage at ensiling (Figure 2) (Jobim et al. 2007; Bumbieris Jr et al. 2010).

Adequate APS values for corn silages should be in the range of 8–12 mm, when DM content is in the range of 300–370 g/kg (Weirich Neto et al. 2013), which was the case for most samples we evaluated (Figure 1), limiting the extent of unwanted fermentations and improving preservation of the nutritional quality (Neumann et al. 2007) by allowing higher density of compaction (DDM; r = -0.23*).

In addition, we found that the APS of our samples was associated with higher digestibility of the ensiled material (IVDDM; r = 0.23*); it is important to emphasize that this correlation applies specifically to the data set we worked here (APS of samples in the range of 8–12 mm) since excessively long fiber particles are often correlated with reduced digestibility when compared with shorter particles. Hildebrand et al. (2011) emphasized that finely ground silage led to higher gas production on in vitro batch culture assay, while in a rumen simulation technique (Rusitec) assay, coarsely ground corn silage led to increased organic matter degradability, which the authors attributed to increased degradability of NFC and CP. Despite of observing a positive correlation between IVDDM and APS, the correlation had a relatively low r value (0.23) indicating that particle size explained very little of the variation in IVDDM values.

The APS is also important in diet formulation, since it is directly related to animal selectivity, rumination time, stability of ruminal pH, passage rate and microbial degradation and consequently affects animal production (Santos et al. 2010a; Marafon et al. 2015). Corroborating the idea that silage materials with high DM% usually present higher pH values (Senger et al. 2005), our results showed that pH was affected by compaction levels (DNM = -0.30), with greater pH values in low density samples, which may be associated with poor nutritional quality of the silage and reduced acceptability by the animals.

Conclusions

Our study has demonstrated that the corn silages produced on dairy farms used in our study varied greatly in parameters such as DM% and CP concentration but the most variable characteristic was the degree of compaction, which has such an important influence on the quality of the silage produced. Silages which were well compacted, i.e. with a high DDM, were also high in TDN, NFC and starch, but were low in fiber, i.e. were of better quality. On the other hand, more mature material at ensiling, i.e. with higher fiber levels, was difficult to compact and had lower DDM levels. These findings reveal a need for a technology transfer initiative to inform farmers of the variation which exists in terms of quality of silage produced and deficiencies in the silage making process. In utilization and conservation of forage there is always a trade-off between quantity and quality of material produced. In the case of silage, delaying harvesting until forage is quite mature can result in a poor outcome because of inappropriate levels of compaction combined with reduced quality of the forage ensiled. Farmers should be informed of the need to ensile material at a stage of growth when forage is still of good quality and good compaction of the ensiled material can be achieved. While high quality of the material at ensiling is positive, an added benefit is the reduced losses of nutrients during the fermentation process. When removed from the silo for feeding, the silage would retain much of its better quality at ensiling and resulting production from livestock would be greater.

Acknowledgments

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(Note of the editors: All hyperlinks were verified 15 January 2020.)

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