Morphological characteristics of maize plants in estimate the silage chemical composition

Características morfológicas de plantas de milho estimam a composição bromatológica da silagem

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Abstract

The aim of this study was to estimate the chemical composition of maize silage based on the morphological characteristics of maize plants and to evaluate the effect of nitrogen fertilization and the inclusion of a microbial inoculant during the ensiling process on the production of maize silage and its morphological, qualitative and fermentative characteristics. The experimental treatments consisted of four levels of nitrogen fertilization with urea (0, 100, 200 and 300 kg ha^{-1}) and the inclusion or exclusion of the microbial inoculants during the ensiling process. A completely randomized design was used in a 4 × 2 factorial arrangement of treatments. The maize silage chemical composition was estimated by evaluating the plant height (PH) and ear characteristics (NRE= number of rows per ear; NKE= number of kernels per ear; ELS= ear length with straw; EL= ear length without straw) using the following equations:CP= -12.44 + 5.871 × PH + 0.01814 × NRE^2 (R^2= 0.89; $P < 0.0001$); NDF= 587.93-0.78×NKE-11.67×ELS-0.47×EL+0.0000007×NKE^3+0.006×EL^3 (R^2=0.92; P = 0.003); ADF= 41.48 -0.046 × NRE^2 (R^2= 0.42; P = 0.02);TDN= 57.81 - 0.0319 × NRE^2 (R^2= 0.42; P = 0.02);EDDM= 56.58 + 0.035 × NRE^2 (R^2= 0.42; P = 0.02) andNEL= 1.31 + 0.000757 × NRE^2 (R^2= 0.41; P = 0.02). In conclusion, nitrogen fertilization increases the silage energy and protein content; while the inclusion of microbial inoculants during the ensiling process does not alter the chemical and fermentative characteristics of the maize silage.

Keywords: Plant height. Aerobic stability. Microbial inoculants. Maize Silage. Urea.

Resumo

O objetivo do presente estudo foi estimar a composição bromatológica da silagem por meio de características morfológicas das plantas de milho, e avaliar o efeito de níveis de adubação nitrogenada e da inclusão de inoculante microbiano na ensilagem sobre as características produtivas, morfológicas, bromatológicas e fermentativas de silagem de milho. Os tratamentos consistiram em quatro níveis de adubações com ureia: 0; 100; 200 e 300 Kg ha^{-1}, e da inclusão ou não de inoculante microbiano. Foi utilizado um delineamento inteiramente casualizado, com arranjo fatorial de tratamentos 4 × 2. A composição bromatológica da silagem foi estimada pela altura das plantas (AP) de milho e pelas características da espiga (NLE = número de linhas de grãos por espiga; NGE = Número de grãos por espiga; CCP = comprimento da espiga com palha; CSP = comprimento da espiga sem palha) por meio das seguintes equações: PB = -12,44 + 5,871 × AP + 0,01814 × NLE^2 (R^2 = 0,89; P < 0,0001); FDN = 587,93 – 0,78 × NGE – 11,67 × CCP – 0,47 × CSP + 0,0000007 × NGE^3 + 0,006 × CCP^3 (R^2 = 0,92; P = 0,003); FDA = 41,48 - 0,046 × NLE^2 (R^2 = 0,42; P = 0,02); NDT = 57,81 – 0,0319 × NLE^2 (R^2 = 0,42; P = 0,02); DMSE = 56,58 + 0,035 × NLE^2 (R^2 = 0,42; P = 0,02) e ELL = 1,31 + 0,000757 × NLE^2 (R^2 = 0,41; P = 0,02). Pode-se concluir que a adubação nitrogenada aumenta o teor de energia e de proteína da silagem; enquanto a inclusão de inoculante microbiano não altera as características bromatológicas e fermentativas da silagem de milho.

Palavras-chave: Altura de planta. Estabilidade aeróbia. Inoculante microbiano. Silagem de milho. Ureia.

Introduction

Nitrogen fertilization is one of the main crop practices used to increase maize production. The growth potential of the maize plant is positively associated with the nutrient content of the soil.

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Therefore, increasing the concentration of nitrogen present in the soil leads to higher crop yields and hence may increase the farm profitability (FRANÇA et al., 2007). Additionally, adequate levels of nitrogen fertilization improve plant performance and increase dry matter production. However, few studies have evaluated the effect of nitrogen fertilization on the morphological characteristics of maize used for silage (MELLO et al., 2005; VIEIRA et al., 2013), and no study has estimated the chemical composition of maize silage based on the morphological characteristics of maize in the field.

Chemical analyses are important for the diet formulation and nutritional management of ruminants; however, these laboratory analyses are not always available and are expensive and time consuming, imposing limitations to their use on some farms, especially those with small and medium herds. Therefore, estimating the silage chemical composition using the morphological characteristics of maize plants on farmland may benefit farmers in relation to the use of tabulated values for the formulation of ruminant diets.

Inadequate procedures performed during and after harvesting maize can affect the final quality of the maize silage and also reduce the efficiency of agronomic practices performed during crop development. The use of microbial inoculants at the ensiling time is a recommended practice that can be performed to reduce quality losses caused by inadequate fermentation. The lactic acid produced by homolactic bacteria can reduce the enzymatic proteolysis caused by the rapid pH decrease during silage production, reducing the dry matter losses(HENDERSON, 1993). However, homolactic bacteria reduce the aerobic stability after opening the silo due to the decreased production of antifungal compounds, such as acetic acid. Thus, the silage quality after opening the silo and during the animal feeding can be maintained by a combination of homolactic bacteria (Lactobacillus plantarum and *Pediococcus pentosaceus*) and hetero fermentative lactic acid bacteria (*Lactobacillus buchneri*) inoculated at the time of ensiling(RANJIT; TAYLOR; KUNG JR, 2002; WOOLFORD, 1990).

The aims of this study were(a) to estimate the chemical composition of maize silage using the morphological characteristics of maize plants in the field and (b) to evaluate the effect of nitrogen fertilization associated with two microbial inoculants(homolactic and hetero fermentative lactic acid bacteria) at the ensiling time on the production, chemical and fermentative characteristics of maize silage.

Materials and Methods

The present study was conducted in a soil classified as distrofic red latosol, and the climate was classified as subtropical Cfa according to the Köppen climate classification (27°53'58" S, 53°18'49" W, and 639 m above sea level). The experiment began in a direct seeding system (60,000 plants ha^{-1}) and at a between-row-spacing of 70 cm. In this study, the corn hybrid used was the STATUS® (Syngenta®, Basel - Switzerland). Basal fertilization was performed with 240 kg ha^{-1} NPK 10-20-10 and 426.67 kg ha^{-1} pelletized turkey litter (1.5% N, 20% organic carbon, pH 6 and 20% humidity).

A completely randomized design with a factorial arrangement of treatments (4 × 2) and three replications was used in the study. The treatments consisted of four levels of nitrogen fertilization, including or excluding a microbial inoculant during the process of maize ensiling. Top-dress fertilization with nitrogen with urea (45% N) was used and was applied in four levels (0, 100, 200 and 300 kg ha^{-1}) and two applications: the first when the maize plants presented four leaves and the second when the maize plants presented eight leaves.

Twelve experimental plots (length of 3m and width of 5 m each) were used for planting maize. Five plants and five ears from each plot were randomly collected when the maize kernels were considered mature (one-third milky and two-thirds farinaceous). The maize plants and ears within 50 cm of the field borders were not collected, and the following morphological data were recorded from the remaining maize in the field: ear diameter and length with straw (EDS and ELS, respectively), ear diameter and length without straw (ED and EL, respectively), cob diameter (CD), and plant height (PH). Except for PH, which was measured using metric tape, the remaining morphological characteristics were measured by a caliper rule. The number of rows per ear (NRE) and the average number of kernels per row (AKR) were also evaluated in the selected ears. The number of kernels per ear (NKE) was obtained by the following equation: NKE= NRE×AKR. The number of ears per plot (NEP) and the number of plants per plot (NPP) were also evaluated by a total count of ears and plants per each plot. After the morphometric evaluations, the plants were manually cut 20 cm above the ground and subsequently chopped in stationary ensiling equipment that was adjusted to produce a mean particle size of 2 cm.

After chopped process, two mini-silos weighing 10 kg each (one with and the other without the inoculant) were produced for each of the twelve plots. The filling, compressing and sealing of the mini-silos were performed in 10-L plastic buckets that were internally coated with plastic bags. During the ensiling process, the microbial inoculant MercosilMais11C33® (Pioneer®, DuPont Agriculture and Nutrition, Johnston, Iowa - USA) was added to the chopped maize. The microbial inoculant was previously diluted in distilled water according to the manufacturer's recommendations. The microbial inoculant used in this study consisted of *Lactobacillus plantarum* (8.0 × 109 CFU/g), *Lactobacillus buchneri* (1.0 x 1011 CFU/g) and *Enterococcus faecium* (2.0 × 109 CFU/g). After opening the silo (30 days after the ensiling process), the samples were collected and maintained at -20°C.

The samples of chopped maize plants and maize silage were collected in amounts of approximately 400 g and were subsequently dried in a forced draft oven (60ºC/72 h), ground through a 2 mm screen and then stored until analyzing the following chemical characteristics: dry matter (DM) and crude protein (CP) (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. AOAC, 1995), neutral detergent fiber (NDF) and acid detergent fiber (ADF) (VAN SOEST; ROBERTSON; LEWIS,1991). Total digestible nutrients (TDN), metabolizable energy (ME), net energy for lactation (NEL), net energy for gain (NEG), net energy for maintenance (NEM) and estimate dry matter digestibility (EDDM) according to National Research Council (NRC, 1989):TDN (%)= 87.84 – (%ADF × 0.70); NEL(Mcal/Kg DM)=(%TDN × 0.02456) – 0.119; NEG(Mcal/Kg DM)= (%TDN × 0.02906) –1.012; NEM(Mcal/Kg DM)= (%TDN × 0.02906) – 0.291;EDDM (%)= 88.9 – (0.779 × %ADF).

The mini-silos underwent two weighing processes: the first was performed shortly after the mini-silo sealing and the second at the opening of the mini-silo. Thus, the loss of silage dry matter mostly caused by fermentation during the ensiling process was calculated by the difference between the initial and final DM weight of each mini-silo. The silage samples (2 kg) were collected from the mini-silos and maintained aerobically in isothermal boxes(2 L) to evaluate the temperature, which was measured by a thermometer inserted 10 cm into the material at 0, 12, 24, 48, 72, 96 and 120 h. The aerobic stability was calculated as the quotient between the maximum temperature observed during the measurement process and the time required to reach this temperature (RUPPEL et al., 1995).

The data were analyzed using the Statistical Analysis System® (2001) after testing for the normality of residuals and the homogeneity of variance with the UNIVARIATE procedure. The main effects (four levels of nitrogen fertilization and the use of the inoculant) and interaction among the fertilization levels and the use of the inoculants were analyzed using PROC GLM. The effects of nitrogen fertilization were decomposed into two orthogonal polynomial contrasts (linear and quadratic), and the equations were obtained using the PRO CREG command. For all statistical analyses, significance was declared at P ≤ 0.05 and trends at P ≤ 0.10. A Pearson correlation was determined to evaluate the associations between the studied variables using the PROC CORR command. To estimate the silage chemical composition using morphological variables, a multiple regression analysis was applied using the "Stepwise" method for variable selection.

Results

Increased levels of nitrogen fertilization linearly increased the yield of the natural and dry matter of maize silage (Figure 1).Similarly, nitrogen fertilization increased as the length and diameter of corn ears (with or without straw), cob diameter and plant height (Table 1). Additionally, the average number of kernels per row and the number of kernels per ear increased in a quadratic form with the inclusion of urea. However, the number of rows per ear was not altered by nitrogen fertilization. Increased levels of urea fertilization had a quadratic effect on the content of maize crude protein (CP) assessed shortly before ensiling process, which peaked with the inclusion of 285.71 kg urea ha^{-1}. However, nitrogen fertilization had no effect on the maize chemical composition related to the plant energy(TDN, ME, NEL, NEG, NEM), EDDM (Table 2) and ADF content.

There was no interaction between the level of urea fertilization and the inclusion of a microbial inoculant on the chemical composition and fermentation characteristics of maize silage. However, the silage containing the microbial inoculant had a tendency (*P* = 0.10) to reduce the dry matter losses by fermentation (Table 3). The crude protein content of the maize silage had a similar response to the levels of nitrogen fertilization as was observed for the entire plant before ensiling (Figure 2). However, the maximum response to the nitrogen fertilization of maize silage CP was observed with the inclusion of 260 kg urea ha^{-1}. Additionally, top-dress fertilization with urea linearly increased the silage levels of TDN, ME, NEL, NEG and EDDM (Table 4). In contrast, the silage ADF content decreased linearly as a result of the increase of urea in the field.

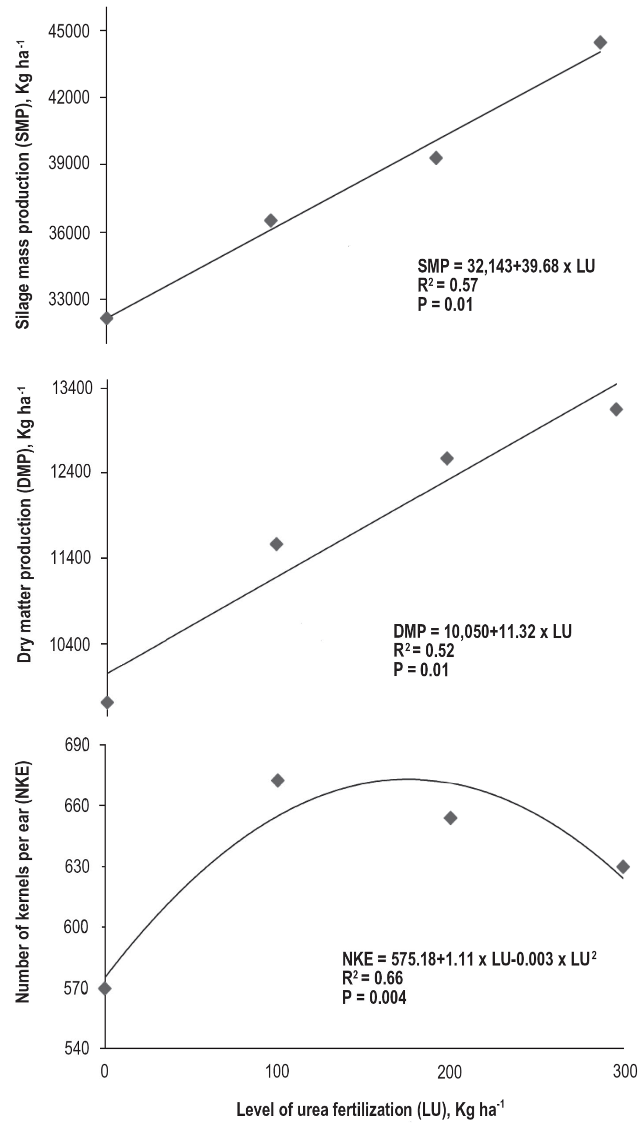

Figure 1 – Effect urea fertilization on the: a= Maize silage mass production (natural matter); b= Dry matter production of the maize silage; c= Number of kernels per ear – Palmeira das Missões, RS – Brasil – 2012

Source: (MARTINS et al., 2014)

Table 1 – Effect of nitrogen fertilization on the yield and morphological characteristics of maize samples that were collected before the ensiling process – Palmeira das Missões, RS – Brasil – 2012

Item	Level of urea fertilization (LU; kg ha^{-1})				*SEM	**P	
	0	100	200	300		L	Q
SMP[1], kg ha^{-1}	32,142.9	36,507.9	39,285.7	44,444.4	1,772.1	0.01	0.89
DMP[2], kg ha^{-1}	9,710.4	11,563.2	12,571.4	13,146.7	528.8	0.01	0.46
EDS[3], mm	56.2	57.1	58.5	59.8	0.56	0.02	0.83
ELS, cm	24.1	25.9	24.9	25.8	0.30	0.10	0.32
ED[4], mm	44.7	46.1	48.80	48.2	0.64	0.02	0.32
EL[5], cm	19.1	26.0	20.5	20.2	0.71	0.23	<0.0001
NRE	17.4	17.7	17.9	17.8	0.15	0.40	0.57
AKR[6]	32.7	37.9	36.6	35.4	0.62	0.03	0.0005
CD[7], mm	26.1	26.6	28.3	28.4	0.42	0.03	0.78
PH[8], m	2.3	2.3	2.5	2.4	0.03	0.03	0.15
NPP	89.7	81.0	85.7	90.7	1.68	0.57	0.051
NEP	108.7	102.0	117.0	120.3	3.41	0.11	0.44
NKE[9]	569.4	672.2	653.7	629.6	13.5	0.05	0.004

SMP= Silage mass production (natural matter); DMP = dry matter production; EDS = ear diameter with straw; ELS = ear length with straw; ED= ear diameter without straw; EL= ear length without straw; NRE = number of rows per ear; AKR = average number of kernels per row; CD = cob diameter; PH= plant height; NPP = number of plants per plot; NEP = number of ears per plot; NKE = number of kernels per ear. *SEM = standard error of mean; **L = linear effect; Q = quadratic effect; C = cubic effect. [1] SMP = 32,143+39.68×LU, R^2=0.57; [2] DMP = 10,050+11.32×LU, R^2=0.52; [3] EDS = 56.08+0.01×LU, R^2 = 0.52; [4] ED= 45.01+0.01×LU, R^2 = 0.47; [5] EL= 19.68+0.0407×LU-0.000136×LU^2, R^2 = 0.34; [6] AKR= 33.06+0.054×LU-0.000159×LU^2, R^2 = 0.72; [7] CD = 26.09+0.008×LU, R^2 = 0.45; [8] PH = 2.31+0.0005×LU, R^2 = 0.34; [9] NKE = 575.18+1.11×LU-0.003×LU^2, R^2= 0.66

Table 2 – Effect of nitrogen fertilization on the chemical composition of maize plants that were collected before the ensiling process – Palmeira das Missões, RS – Brasil – 2012

Item	Level of urea fertilization (LU; kg ha^{-1})				*SEM	**P	
	0	100	200	300		L	Q
DM, %	30.2	30.5	31.0	29.6	0.45	0.52	0.12
CP[1], %	7.3	7.9	9.0	8.8	0.21	<0.0001	0.01
NDF, %	64.9	65.3	63.3	62.4	0.85	0.27	0.71
ADF, %	27.7	29.6	26.7	28.7	0.44	0.95	0.88
TDN, %	67.4	66.1	68.2	66.7	0.31	0.95	0.88
ME, Mcal/kg	2.4	2.4	2.5	2.4	0.01	0.93	0.88
NEL, Mcal/kg	1.5	1.5	1.5	1.5	0.007	0.80	0.78
NEM, Mcal/kg	1.7	1.6	1.7	1.6	0.008	0.87	0.90
NEG, Mcal/kg	0.9	0.9	1.0	0.9	0.008	0.87	0.90
EDDM, %	67.3	65.9	68.1	66.5	0.37	0.86	0.71

DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients; ME = metabolizable energy; NEL = net energy for lactation; NEM= net energy for maintenance; NEG= net energy for gain; EDDM= estimate digestible of dry matter. *SEM = standard error of means; **L = linear effect; Q = quadratic effect. [1] CP= 7.22+0.012LU-0.000021×LU2, R^2= 0.85

Table 3 – Effect of microbial inoculant inclusion on the fermentation and chemical characteristics of maize silage – Palmeira das Missões, RS – Brasil – 2012

Item	Microbial inoculant		*SEM	*P*
	Yes	No		
DM, %	30.10	31.00	0.53	0.31
CP, %	7.30	7.30	0.14	0.45
NDF, %	59.0	59.50	0.55	0.71
ADF, %	27.20	27.40	0.24	0.65
TDN, %	67.8	67.70	0.17	0.64
ME, Mcal/kg	2.40	2.40	0.006	0.60
NE_L, Mcal/kg	1.50	1.50	0.004	0.73
NE_M, Mcal/kg	1.70	1.70	0.005	0.79
NE_G, Mcal/kg	1.00	0.90	0.005	0.85
EDDM, %	67.7	67.50	0.19	0.65
Aerobic stability	0.30	0.20	0.03	0.60
DM losses, %	1.20	1.70	0.16	0.10

DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients; ME = metabolizable energy; NE_L = net energy for lactation; NE_M= net energy for maintenance; NE_G= net energy for gain; EDDM= estimate digestible of dry matter. *SEM = standard error of mean

Table 4 – Effect of nitrogen fertilization on the qualitative and fermentative characteristics of maize silage – Palmeira das Missões, RS – Brasil – 2012

Item	Level of urea fertilization (LU; kg ha^{-1})				*SEM	***P*	
	0	100	200	300		L	Q
DM, %	30.2	31.5	31.0	29.6	0.44	0.53	0.31
CP[1], %	6.3	7.1	8.02	7.8	0.14	<0.0001	0.0006
NDF, %	59.1	60.0	60.2	57.7	0.55	0.43	0.17
ADF[2], %	28.5	27.4	26.2	26.7	0.24	0.005	0.18
TDN[3], %	66.9	67.7	68.2	68.2	0.17	0.005	0.17
ME[4], Mcal/kg	2.4	2.4	2.5	2.4	0.006	0.005	0.13
NE_L[5], Mcal/kg	1.5	1.5	1.6	1.5	0.004	0.003	0.15
NE_M[6], Mcal/kg	1.6	1.7	1.7	1.7	0.005	0.008	0.10
NE_G[7], Mcal/kg	0.9	0.9	1.0	1.0	0.005	0.007	0.11
EDDM[8], %	66.7	67.6	68.2	68.1	0.19	0.005	0.18
Aerobic stability	0.3	0.2	0.3	0.2	0.03	0.39	0.81
DM losses, %	1.5	1.2	1.2	1.9	0.16	0.20	0.08

DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients; ME = metabolizable energy; NE_L = net energy for lactation; NE_M= net energy for maintenance; NE_G= net energy for gain; EDDM = estimate digestible of dry matter. *SEM = standard error of mean; **L= linear effect; Q = quadratic effect. [1] CP= 6.28+0.013LU-0.000025×LU2,R2=0.83; [2] ADF= 28.24-0.006×LU, R^2= 0.35; [3] TDN= 67.07+0.004×LU, R^2= 0.35; [4] ME= 2.42+0.0001×LU, R^2= 0.34; [5] NEL= 1.53+0.0001×LU, R^2= 0.39; [6] NEM= 1.66+0.0001×LU, R^2= 0.31; [7] NEG= 0.94+0.0001×LU, R^2= 0.31; [8] EDDM= 66.90+0.005×LU, R^2= 0.35

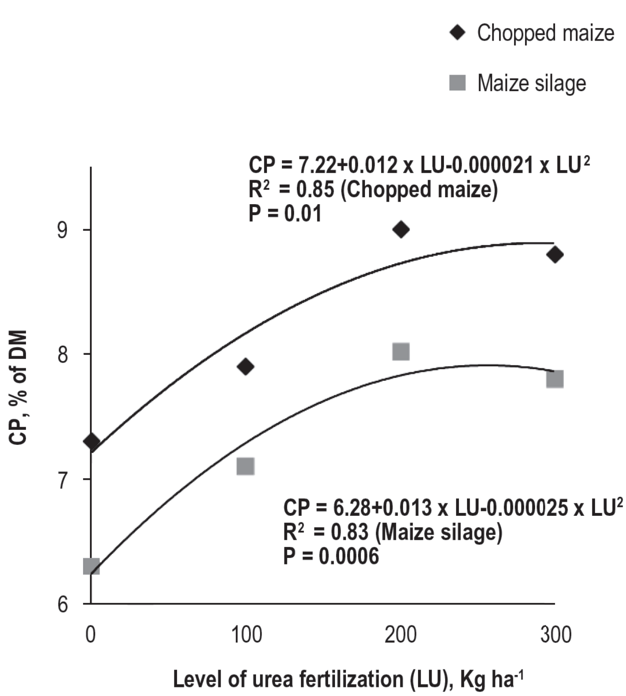

Figure 2 – Effect of urea fertilization on the crude protein content of chopped maize and maize silage – Palmeira das Missões, RS – Brasil – 2012
Source: (MARTINS et al., 2014)

To evaluate the effect of nitrogen fertilization on the structural and chemical changes of maize plants, correlation coefficients were calculated among the morphological characteristics of maize plants and the chemical composition of maize silage. The morphological characteristics that presented a significant correlation with the yield of natural matter of maize silage were PH (r = 0.61), EDS (r = 0.65), ED (r = 0.70), ELS (r = 0.55), CD (r = 0.69) and NEP (r = 0.60). Except for the ELS, these same morphological characteristics were also correlated with the yield of silage dry matter (Table 5).

The morphological characteristics of maize plants that had a significant correlation with the chemical composition of maize silage were ear diameter (with and without straw), cob diameter, number of rows per ear and plant height. The silage CP content was positively correlated with the plant height (r = 0.81),

Table 5 – Correlations coefficients among the yield and morphological variables of maize plants and the silage chemical composition – Palmeira das Missões, RS – Brasil – 2012

Item	EDS	ELS	ED	EL	NRE	AKR	CD	PH	NPP	NEP
SMP	0.65*	0.55*	0.70**	0.08	0.02	0.24	0.69**	0.61*	0.36	0.60*
DMP	0.62*	0.57	0.75**	0.18	0.04	0.37	0.70**	0.69**	0.23	0.57*
CP	0.57*	0.42	0.76**	0.03	0.36	0.53	0.80**	0.81**	0.08	0.59*
NDF	-0.36	-0.44	-0.21	-0.38	0.40	-0.09	-0.18	-0.28	-0.03	-0.37
ADF	-0.39	-0.14	-0.35	0.06	-0.64*	-0.36	-0.41	-0.07	-0.02	-0.02
TDN	0.39	-0.14	0.35	-0.06	0.64*	0.36	0.41	0.07	0.2	0.02
ME	0.34	0.15	0.33	-0.06	0.63*	0.38	0.38	0.08	0.005	-0.01
NE_L	0.43	0.13	0.42	-0.09	0.64*	0.37	0.45	0.16	0.01	0.06
NE_M	0.37	0.15	0.35	-0.03	0.61*	0.40	0.40	0.11	-0.01	0.005
NE_G	0.38	0.12	0.37	-0.09	0.62*	0.36	0.43	0.13	0.03	0.03
EDDM	0.39	0.15	0.35	-0.06	0.64*	0.36	0.41	0.07	0.02	0.02

SMP= silage mass production (natural matter); DMP = dry matter production; EDS = ear diameter with straw; ELS= ear length with straw; ED = ear diameter without straw; EL = ear length without straw; NRE= number of rows per ear; AKR= average number of kernels per row; CD = cob diameter; PH = plant height; NPP= number of plants per plot; NEP= number of ears per plot; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients; ME = metabolizable energy; NE_L = net energy for lactation; NE_M= net energy for maintenance; NE_G= net energy for gain; EDDM = estimate digestible of dry matter

*$P < 0.05$

**$P < 0.01$

ear diameter with straw (r = 0.57), ear diameter without straw (r = 0.76) and cob diameter (r = 0.80). However, the ADF content of maize silage was negatively correlated only with the number of rows per ear (r = -0.64). In contrast, the number of rows per ear was positively correlated with EDDM and the chemical characteristics of the energy parameters of the maize silage (TDN, ME, NE_L, NE_G, NE_M).

In the present study, it was possible to estimate the chemical characteristics of the maize silage based on the morphological characteristics of the maize plant. The CP content of the silage was estimated by PH and NRE using the following equation: CP = -12.44 + 5.871 × PH + 0.01814 × NRE^2 (R^2 = 0.89; $P < 0.0001$). According to stepwise method, to estimate the ADF content of the maize silage, the NRE was the only predictor variable used in the ADF= 41.48- 0.046 × NRE^2 (R^2 = 0.42; P = 0.02). The NKE, ELS and EL were used to estimate the silage NDF content: NDF = 587.93 - 0.78 × NKE - 11.67 × ELS - 0.47 × EL + 0.0000007 × NKE^3 + 0.006 × ELS^3 (R^2 = 0.92; P = 0.003). Additionally, the EDDM was estimated by the NRE value using the following equation: EDDM = 56.58 + 0.035 × NRE^2 (R^2 = 0.42; P = 0.02).

The chemical composition parameters related to the silage energy content were also estimated using the morphological characteristics of the maize plants by multiple regression equations. Thus, the equation that estimated the TDN content of the maize silage was TDN= 57.81 - 0.0319 × NRE^2 (R^2 = 0.42; P = 0.02). The parameters of ME, EL_L, EL_G, and EL_M of the maize silage were estimated by the following equations: ME= 2.09 + 0.0011 × NRE^2 (R^2 = 0.41; P = 0.02); NE_L = 1.31 + 0.000757 × NRE^2 (R^2 = 0.41; P = 0.02); NE_G = 0.67 + 0.00091 × NRE^2 (R^2 =0.39; P = 0.03); and NE_M = 1.39 + 0.0009 × NRE^2 (R^2 = 0.38; P = 0.03).

Discussion

The chemical composition of the maize silage was estimated by the morphological characteristics of the maize plants that were evaluated shortly before the ensiling process. The morphological characteristics that better estimated the contents of CP, NDF, ADF, TDN, ME, NE_L, NE_G, NE_M and EDDM were the PH, ear length (with and without straw), NRE and NKE. It is likely that these morphological characteristics were included in the model due to the correlation among them and to the levels of CP, fiber (NDF and ADF), EDDM and energy (TDN, ME, NE_L, NE_G, NE_M) of the maize silage.

The variable NRE was positively correlated with the energy and protein contents and negatively correlated with the ADF content of the maize silage. Therefore, the results of this study suggest that NRE may be used as a morphological characteristic for the prediction of maize silage quality, as regression equations estimated the energy, protein and fiber contents (ADF) of the maize silage. The determination of the maize silage chemical composition in the field is limited by the cost, time and/or lack of laboratories in certain geographical regions. The use of regression equations to estimate the chemical composition of silage using the maize plant morphological characteristics that were evaluated before the ensiling process may be an alternative method at the farm level. Additionally, the use of the tabulated values of the maize silage chemical composition can result in inaccurately formulated diets because the standard composition is an average result of several silages, and differences related to the genetics of the maize plant and the fertilization management is not considered.

The use of urea fertilization increased the yield of dry and natural matter and the energy and protein contents of the maize silage. However, an interaction between the urea fertilization and the inclusion of the microbial inoculant at the ensiling time was not observed in this study. The lack of interaction between nitrogen fertilization and the inclusion of microbial inoculants may be due to the low crude protein content of maize plant (mean of 8.26% CP in this study). The protein nitrogen can have a buffering effect, which reduces the rate of pH drop during the ensiling and changes the fermentative process (WOOLFORD, 1984). However, despite the urea fertilization increases the CP content of the plant and maize silage, it may be insufficient to reduce the pH drop and change silage fermentation, which results in the absence of interaction between nitrogen fertilization and the inclusion of microbial inoculants during the ensilaging process.

The urea fertilization of maize increased the yield of dry and natural matter of the maize silage. This result can be explained by the greater availability of nitrogen in the soil for plant uptake and, consequently, the greater availability of nitrogen and carbon for the maize phytomass and ear kernels. Based on the morphological characteristics that were evaluated in this study, the highest mass production of maize silage with nitrogen fertilization was primarily due to the increase in the plant height and to the increase in the diameter and length of the ear. Nitrogen fertilization increased the plant and silage CP contents in a quadratic form, most likely in response to the increased uptake and deposition of nitrogen and carbohydrates for plant reserves (BROUWER; FLOOD, 1995).

In the present study, nitrogen fertilization increased the EDDM and maize silage energy (TDN, ME, NE_L, NE_G, NE_M). The increase in the maize silage energy variables was positively correlated with the NRE, which can increase the number of kernels per ear. The nitrogen that is absorbed by plants combines with carbon skeletons to produce amino acids, resulting in proteins. At the stage of kernel filling, the energy (as starch) and protein are stored in the kernels (MARSCHNER, 1995). Therefore, the increased availability of soil nitrogen for plant absorption can increase the yield of kernels and, consequently, the silage energy and protein contents.

The ADF content of the maize silage in this study was negatively correlated with the NRE, which may be due to the increase in the number of kernels per ear. Corn kernels have low fibrous carbohydrate content; therefore, the increase in the kernel yield can reduce the ADF content in the maize silage. Acid detergent fiber is an indigestible or slowly digestible organic portion of the feed; therefore, it may be negatively correlated with the evaluable energy of the maize silage (NATIONAL RESEARCH COUNCIL, 1989).

The inclusion of the microbial inoculant only resulted in a tendency to reduce the dry matter losses during the ensiling process without changing the aerobic stability after opening the silo. This result disagrees with that reported by Ranjit and Kung Jr. (2000), who observed that silages inoculated with *Lactobacillus plantarum, Lactobacillus buchneri*, and a chemical preservative took longer to heat than did untreated silage when exposed to air. The successful use of inoculants for silage production depends not only on the strain of the bacterial inoculant but also on the natural population of lactic acid bacteria and the sugar content of the forage (SILVA et al., 2005). However, one limitation of this study was the lack of evaluation of other variables associated with silage fermentation characteristics, such as soluble carbohydrates, organic acids, $N\text{-}NH_3$ and pH. These important characteristics are indicative of the adequate preservation of the silage, as the aerobic deterioration decreases the concentration of lactic acid and non-structural carbohydrates (RANJIT; KUNG JR, 2000).

Conclusion

The maize silage chemical composition can be estimated using the height of the maize plants and the morphological characteristics of the maize ear before the ensiling process. The energy content of the maize silage increases linearly with nitrogen fertilization; however, the inclusion level of nitrogen for the maximum response of the silage protein content is 260 kg urea ha-1. The inclusion of microbial inoculants during the ensiling process does not affect the chemical and fermentative parameters of maize silage.

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