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Production efficiency of corn for forage at different growing densities and harvesting times

Eficiência produtiva de milho para forragem em diferentes densidades de cultivo e épocas de colheita

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Abstract

The experiment was conducted at the Animal Production Center (Núcleo de Produção Animal – NUPRAN) of the Center for Agrarian and Environmental Sciences of the Universidade Estadual do Centro-Oeste - UNICENTRO - CEDETEG Campus, Guarapuava, State of Paraná. This study aimed to evaluate biomass production, plant physical composition, chemical composition and dry matter contents of the plant and structural components of forage corn. The experiment was carried out in 5x5 factorial with five planting densities (80, 160, 240, 320 and 400 thousand plants ha^{-1}), harvested in 5 times (40, 50, 60, 70 and 80 days after planting). The harvesting time caused a statistical difference for all parameters, and the planting densities factor only caused statistical difference in leaf participation and dry biomass production. There was no interaction for any of the parameters evaluated. Forage corn, harvested in the vegetative stage, can be a great ally of the rural producer, since it presents high potential for food production with high nutritional value in a short period of time, and in significant amount with production of up to 14,720 kg ha^{-1} dry biomass reached at 80 days of cycle with 320 thousand ha^{-1}, freeing the soil for the production of another crop.
Key words: Neutral detergent fiber. Dry biomass production. Dry matter content.

Resumo

O experimento foi conduzido nas instalações do Núcleo de Produção Animal (NUPRAN) do Centro de Ciências Agrárias e Ambientais da Universidade Estadual do Centro Oeste - UNICENTRO - Campus

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CEDETEG em Guarapuava-PR. Este trabalho teve como objetivo avaliar a produção de biomassa, a composição física da planta, a bromatologia e os teores de matéria seca da planta e componentes estruturais do milho para forragem. O delineamento experimental foi em blocos inteiramente casualisados, em esquema fatorial 5x5, com cinco densidades de plantio (80, 160, 240, 320 e 400 mil plantas ha^{-1}), colhidas em 5 épocas (40, 50, 60, 70 e 80 dias após o plantio). O fator época de colheita apresentou diferença estatística em todos os parâmetros, e o fator densidades de plantio só apresentou diferença estatística em participação de folhas e produção de biomassa seca. Não houve interação em nenhum dos parâmetros avaliados. O milho forragem, cortado em período vegetativo, pode ser um grande aliado do produtor rural, pois apresenta alto potencial de produção de alimento com alto valor nutritivo em período reduzido de tempo, e em quantidade significativas com produção de até 14.720 kg há$^{-1}$ de biomassa seca alcançada aos 80 dias de ciclo com 320 mil ha^{-1}, liberando o solo para produção de outra cultura.

Palavras-chave: Fibra em detergente neutro. Produção de biomassa seca. Teor de matéria seca.

Introduction

Brazil is known for its potential in the production of food of animal origin, derived from cattle farming. The production of cattle generates great profits for the rural producer, but, for a greater increase in production, the problem of the seasonality of forage production must be overcome (ROCHA, 2007).

The great challenge of the researchers is the search for alternatives to produce quality pastures in a short time, allowing greater use for the producer, with greater meat and milk production, increasing their economic yield (PÍCCOLO, 2012).

According to Bergamaschi et al. (2004), corn belongs to the group of plants with C_4 photosynthesis, which presents a high productive potential. It presents in the initial phase of its development, a high capacity to produce large amounts of biomass per area, with high nutritional value (CAMPÊLO et al., 2007).

As it is a forage used in its egetative stage up to 80 days, corn tends to contain a high crude protein content (CP) and lower contents of NDF and ADF, different from what can be found in corn silages, which are around 8% CP, 47% NDF, 34% ADF (NEUMANN, 2001).

Due to its structural characteristics, corn grazing is impaired, and there may be many losses due to trampling of the animals, but the cutting and ready supply in the trough is, according to Hodgson (1990), an interesting technique, because it reduces the variability developed during grazing by selection of the animals, avoids manure in pasture sites and assists in parasite control.

The improvement in corn production completely depends on the duration of the period of interception of incident solar radiation, and on the efficient use of this radiation intercepted by the leaves and the adequate distribution of photoassimilates produced in the plant (ARGENTA et al., 2001). One of the factors that can alter forage corn quality is sowing density, since it directly affects the interception and efficiency of conversion of the radiation intercepted by the canopy. In corn, this latter factor is more significant than in other grasses due to morphological, anatomical and physiological characteristics (SANGOI, 2001).

In addition to improving forage quality, the increase in density can also increase the production of green (BV) and dry (BS) biomass per area. According to Alvarez et al. (2006), when the corn hybrids presented between 33 and 38% dry matter (DM), they observed a mean production of 13,903 kg ha^{-1} in 0.7 m spacing and 11,777 kg ha^{-1} with 0.9 m spacing.

The goal of the present study was to evaluate biomass production, plant physical composition, chemical composition and dry matter contents of the plant and its structural components of forage corn grown at different densities and different harvesting times.

Material and Methods

The experiment was conducted at the Animal Production Center (Núcleo de Produção Animal – NUPRAN) of the Center for Agrarian and Environmental Sciences of the Universidade Estadual do Centro-Oeste - UNICENTRO - CEDETEG Campus, Guarapuava, State of Paraná.

The climate of the region of Guarapuava is Cfb (subtropical mesothermal humid), without dry season, with fresh summers and moderate winters according to the Köppen classification, at altitude of approximately 1,100 m, average annual rainfall of 1,944 mm, annual minimum average temperature of 12.7°C, annual maximum average temperature of 23.5°C and relative humidity of 77.9%.

Corn was planted on October 25, 2012, in a no-till system, in succession to black oats (*Avena strigosa*), which was desiccated with an herbicide based on Glyphosate (commercial product Roundup Original®: 3.0 L ha^{-1}). At sowing, we used row spacing of 0.4 m, seed depth of approximately 4 cm and seed distribution per linear meter for final densities of 80, 160, 240, 320 and 400 thousand plants ha^{-1}.

The hybrid was sown manually in plots with a total area of 14 m^2 (2.8 x 5.0 m) and the internal useful area of 8 m^2 (2.0 x 4.0 m) of each plot was used for quantitative-qualitative evaluation. The fertilization consisted of 400 kg ha^{-1} fertilizer in the formulation 04-20-20 (N- N-P_2O_5-K_2O), and as topdressing, 25 days after planting, 160 kg ha^{-1} N, as urea (45-00-00).

The management of the corn crop, up to 20 days after plant emergence, included weed control practices using an herbicide based on *Atrazine* + *Simazine* (commercial product Siptran®: 6 L ha^{-1}), as well as control of fall armyworm (*Spodoptera frugiperda*) with the insecticide based on Lambda-cyhalothrin (commercial product Karate®: 150 mL ha^{-1}), by means of a technical visit to the crops. Corn plant thinning was performed manually 15 days after emergence (DAE), adjusting the plant population according to the factor under study.

Analyses were performed for dry biomass production, structural physical composition of the plant, dry matter content of the plant and the chemical characteristics of LG6036 PRO forage corn hybrid cultivated at five planting densities (80, 160, 240, 320 and 400 thousand plants ha^{-1}). The corn plants of the different treatments were evaluated at 40, 50, 60, 70 and 80 days after emergence to determine the dry matter content of the plant and its structural components, and in each evaluation whole plants were harvested from a 5 m planting row contained in the useful area of each plot, harvested manually at 20 cm from the ground.

The adoption of this practice allowed determining the percentage composition of the anatomical structures of the plant by segmentation of the components: stem and leaves. The productive potential of dry matter (kg ha^{-1}) was also determined by relating the individual plant weight and plant population per unit area.

Samples of the whole plant of each treatment were obtained in a homogeneous and representative way; weighed and pre-dried in a forced air oven at 55°C to constant weight for determination of the dry matter content (DM), ground in a Wiley mill with a 1 mm mesh sieve. In the pre-dried samples, analyses were performed for total dry matter (DM) in the oven at 105ºC, crude protein (CP) by micro Kjeldahl method, mineral matter (MM) by incineration at 550ºC (4 hours), according to AOAC (1995). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were also determined, according to Van Soest et al. (1991) and Goering and Van Soest (1970), respectively.

The experiment was conducted in a 5x5 factorial completely randomized block design with four replications, consisting of five planting densities (80, 160, 240, 320 and 400 thousand plants ha^{-1}), combined with five harvesting times 40, 50, 60, 70 and 80 days after emergence. The collected data were tested by analysis of variance, with a comparison of the means at the significance level of 5% by Tukey's test, through the statistical software SAS (1993). Data were also subjected to polynomial regression analysis, considering the evaluation period (days after emergence and plant density), using the "proc reg" procedure of SAS (1993).

Results and Discussion

The expected and observed rainfall as well as the maximum and minimum temperatures in the experimental period of corn cultivation are illustrated in Figure 1, showing that there was a large variation in rainfall between what was expected for the period and what actually occurred in the 10-day period of corn cultivation.

Figure 1. Precipitation observed and expected in (mm), minimum and maximum temperature per 10-day period during the experimental period.

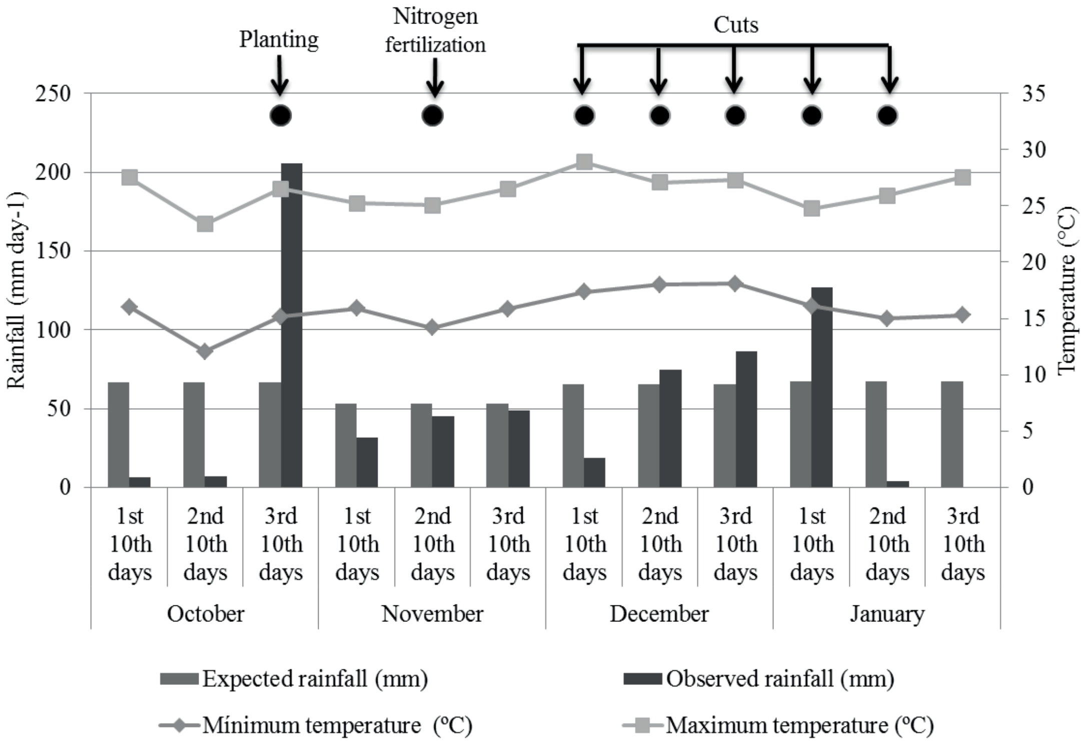

Table 1 lists the mean dry matter content of the whole plant, as well as the percentage of leaves in the plants and the production of dry biomass, in the five harvesting times and in the five different planting densities.

The dry matter content of the plant in the evaluation of different harvesting times presented a statistical difference (P > 0.05) and an average increase of 0.15% at each day from 40 to 80 days of the cycle, with a small reduction in the second harvest. Neumann et al. (2017) evaluated the same experiment in another agricultural year and found lower values in relation to the increase in dry matter contents, with 0.10% each day of advancement in the cycle.

The reduction of the values from the first to the second evaluation can be justified by the climatic behavior during the experimental period, which presented a low rainfall incidence before the first harvest as shown in Figure 1, causing the plants to undergo dehydration. For Bergamaschi et al. (2004), water scarcity can directly affect the composition of the plant and its development. After the first cut, a higher rainfall occurred and with this the water content of the plants increased, explaining the reduction of DM contents. As for the different densities, no statistical difference was detected, presenting mean values of 13.13% in the whole plant, whose values were close to 14.23 found by Neumann et al. (2017) when used the same densities.

Table 1. Mean content of dry matter of the plant (DM), plant leaf percentage (PLP) and dry biomass production (DMP) of forage corn grown with different population densities, according to the evaluation dates.

Population density (plants ha^{-1})	Days after plant emergence					Mean
	40 days	50 days	60 days	70 days	80 days	
	Dry matter content of the plant, % (DM)					
80 thousand	9.76	8.70	14.70	15.09	16.80	13.01
160 thousand	10.97	9.01	13.26	15.54	15.73	12.90
240 thousand	12.08	9.33	13.22	17.82	14.64	13.42
320 thousand	12.01	9.55	12.89	15.46	16.83	13.35
400 thousand	12.31	9.08	13.43	15.09	14.90	12.96
Mean	11.43	9.13	13.50	15.80	15.78	
Regression equation[1]	DM = 3.9031 + 0.15376D (CV: 16.49%; R^2: 0.5071; P<0.0001)					
Regression equation[2]	DM = 13.13% (CV: 23.5%; R^2: 0.0003; P=0.8732)					
	% leaves in the plant (PLP)					
80 thousand	87.5	87.8	47.6	45.6	38.3	61.3
160 thousand	85.5	87.1	54.2	50.4	46.3	64.7
240 thousand	87.7	88.8	51.8	54.1	49.0	66.3
320 thousand	88.0	84.4	56.0	56.4	44.6	65.9
400 thousand	89.1	88.9	61.8	56.7	48.8	69.1
Mean	87.6	87.4	54.3	52.6	45.4	
Regression equation[1]	PLP = 136.907 – 1.191D (CV: 14.6%; R^2: 0.7598; P<0.0001)					
Regression equation[2]	PLP = 60.476 + 0.021P (CV: 29.6%; R^2: 0.0148; P=0.2285)					
	Dry biomass production, kg ha^{-1} (DMP)					
80 thousand	1000	2320	6073	7009	8298	4940
160 thousand	1362	3213	7919	10192	9416	6420
240 thousand	1748	4087	10498	12458	11106	7979
320 thousand	2311	4607	9296	12401	14720	8667
400 thousand	2339	5375	9148	13533	13273	8734
Mean	1752	3920	8587	11119	11363	
Regression equation[1]	DMP = -6613.30 + 237.19D (CV: 41.8%; R^2: 0.5310; P<0.0001)					
Regression equation[2]	DMP = 4668 + 12.29P (CV: 58.18%; R^2: 0.0913; P=0.0022)					

* CV: coefficient of variation
[1] D = days after emergence of the plants, ranging from 40 to 80 days;
[2] P = population density, ranging from 80 thousand to 400 thousand plants ha^{-1}.

In the percentage of leaves of the plant, there was a significant difference (P > 0.05), both for harvesting times and between planting densities, presenting a linear decreasing behavior of 1.19% for each day of the evaluation cycle and an increase of 2.0% per 100 thousand plants increase in the stand. Neumann et al. (2017) observed the same behavior, but with each day of the cycle there was a reduction of 1.0% and for every 100 thousand plants included in the canopy, the percentage of leaves increased by 2.9%.

The stem: leaf ratio of the plants at the vegetative stage directly impacts the nutritive value and consumption of forage. According to Beleze et al. (2003), the higher participation of stem and the consequent decrease of the leaves evidences the advance of the phenological stage of the plant due to the displacement of substances to define the height of the plant. In turn, the increase of leaves due to the plant population increase is due to the greater competition for space given the interception of the radiation that causes the plants to alter their morphology, depending on the arrangement that they were distributed (ARGENTA et al., 2001).

The production of DM presented a significant difference ($P > 0.05$), with a linear increase from 237.19 kg ha^{-1} per day of cycle evaluation. Regarding planting densities, the production of DM was also linear increasing from 12.29 kg ha^{-1} per thousand plants increase in the planting stand. The results of the present study are lower than those reported by Neumann et al. (2017), which presented an increase of 291.40 kg ha^{-1} and 29.45 kg ha^{-1} more DM for every one thousand plants added in the canopy.

According to Amaral Filho et al. (2005), corn productivity increases as plant density increases until an ideal density is reached and from this there is a decrease in productivity due to the greater competition among plants for nutrients.

For regions in the southern Brazil that have severe winters, it would be possible in the same area with a cut at 80 days, to make two cuts a year, and the production would be greater than 22.5t dry biomass. This is superior to the dry biomass produced by other grasses as reported in Poczynek et al. (2016), who analyzed the production of different forages, including Estrela roxa (17.3 t ha^{-1}), Coast-cross (15.8 t ha^{-1}), Tifton 68 (21.0 t ha^{-1}), Jiggs (21.3 t ha^{-1}), Hemartrhia roxinha (13.5 t ha^{-1}), Quicuio (15.7 t ha^{-1}) and Tifton 85 (17.4 t ha^{-1}), in a similar period of production time.

Table 2 lists the values of crude protein (CP) and mineral matter (MM) of corn plants according to the date of evaluation in five different population densities. The behavior of the two parameters was similar with the advance of the crop in the evaluation days, with a linear decrease of 0.17% and 0.11% dry matter, respectively. As for different densities, there was no significant difference ($P > 0.05$) for both periods, presenting mean values of 10.20% and 6.09% CP and MM, respectively.

Neumann et al. (2017) found CP values with a reduction of 0.12% with each day of advancement in the cycle and reported for density, difference of 0.35% CP per 100 thousand plants added. For MM, they reported a reduction of 0.12% each day.

Campêlo et al. (2007) reported that hydroponic corn on elephant grass substrate produced mean CP contents of 15.30% and MM of 1.57%. The difference in CP can be explained as a function of the harvesting time, which in the case of hydroponic corn is more precocious. However, the difference in MM is due to the form of cultivation and the density of planting that is higher, with less availability of minerals for each plant.

Table 3 lists the percentages of NDF and ADF in the dry matter of corn plants according to the date of evaluation in five different population densities.

The NDF and ADF contents presented a quadratic behavior during the cycle, with maximum values of participation in the composition of the plant, on day 66 of the cycle for the two parameters. Neumann et al. (2017) obtained an increasing linear trend, with increase of 0.11% each day for NDF and 0.14% for ADF.

Table 2. Values of crude protein (CP), mineral matter (MM) and dry matter digestibility of the corn plant grown with different population densities, according to the evaluation dates.

Population density (plants ha^{-1})	Days after plant emergence					Mean
	40 days	50 days	60 days	70 days	80 days	
	% Crude protein of the plant (CP)					
80 thousand	13.49	12.59	9.41	6.48	7.33	9.86
160 thousand	13.90	12.53	9.35	8.02	7.85	10.33
240 thousand	12.93	13.18	9.21	8.33	6.42	10.01
320 thousand	13.86	13.07	9.44	7.38	7.17	10.19
400 thousand	13.30	12.46	8.84	8.26	7.58	10.09
Mean	13.49	12.77	9.25	7.69	7.27	
Regression equation[1]	CP = 20.405 – 0.170D (CV: 15.3%; R^2: 0.7084; P<0.0001)					
Regression equation[2]	CP = 10.20% (CV: 38.33%; R^2: 0.0001; P=0.9278)					
	% Mineral matter of the plant (MM)					
80 thousand	7.84	7.84	6.09	4.78	3.98	6.10
160 thousand	7.31	7.48	6.23	4.94	4.66	6.13
240 thousand	8.66	7.68	6.44	4.68	3.69	6.23
320 thousand	9.08	7.39	5.15	4.25	4.04	5.98
400 thousand	7.53	7.53	5.61	5.16	4.28	6.02
Mean	8.08	7.58	5.90	4.76	4.13	
Regression equation[1]	MM = 12.532 – 0.107D (CV: 14.4%; R^2: 0.7529; P<0.0001)					
Regression equation[2]	MM = 6.09% (CV: 29.0%; R^2: 0.0006; P=0.8042)					

* CV: coefficient of variation
[1] D = days after emergence of the plants, ranging from 40 to 80 days;
[2] P = population density, ranging from 80 thousand to 400 thousand plants ha^{-1}.

Table 3. Values of Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) of the forage corn plant grown with different population densities, according to the evaluation dates.

Population density (plants ha^{-1})	Days after plant emergence					Mean
	40 days	50 days	60 days	70 days	80 days	
	% NDF in the plant					
80 thousand	59.50	63.49	71.85	71.40	67.31	66.71
160 thousand	59.65	65.18	71.67	74.11	69.19	67.96
240 thousand	62.24	63.81	70.60	71.72	66.75	67.03
320 thousand	62.39	64.43	71.97	72.38	68.78	67.99
400 thousand	63.42	65.30	71.01	72.75	68.41	68.18
Mean	61.44	64.44	71.42	72.47	68.09	
Regression equation[1]	NDF = 4.497 + 1.988D – 0.015D^2(CV: 3.9%; R^2: 0.6940; P<0.0001)					
Regression equation[2]	NDF = 67.57% (CV: 6.97%; R^2: 0.0080; P=0.3766)					
	% ADF in the plant					
80 thousand	36.21	38.97	48.48	46.67	40.26	42.12
160 thousand	34.68	39.66	46.11	47.63	44.24	42.46
240 thousand	36.37	39.80	43.05	46.02	41.11	41.27
320 thousand	36.21	38.02	47.24	45.96	42.14	41.92
400 thousand	37.36	39.95	45.97	46.05	44.54	42.77
Mean	36.17	39.28	46.17	46.47	42.46	
Regression equation[1]	ADF =-20.359 + 1.983D – 0.015D^2(CV: 7.1%; R^2: 0.6118; P<0.0001)					
Regression equation[2]	ADF = 42.11% (CV: 11.5%; R^2: 0.0005; P=0.8214)					

* CV: coefficient of variation
[1] D = days after emergence of the plants, ranging from 40 to 80 days;
[2] P = population density, ranging from 80 thousand to 400 thousand plants ha^{-1}.

The different planting densities did not significantly alter the mean contents of NDF and ADF (P > 0.05), with values of 67.57% NDF and 42.11% ADF in the five densities. Campêlo et al. (2007) in a study with hydroponic corn on elephant grass substrate produced mean content of NDF of 55.99% and ADF of 32.42%.

In cultivation of hydroponic corn, Müller et al. (2005) observed that the increase in density from 0.5 kg m^2 to 1.5 kg m^2 and 3 kg m^2 planting resulted in an increase in CP content of the plant. In relation to the fiber content, they observed a reduction according to density increase, 81.6%, 77.3% and 64.9% NDF, and 56.7%, 49.7% and 42.5% ADF, respectively, showing that the planting density has a great impact on the NDF and ADF of the plant. According to the researchers, this is due to the fact that with higher planting density, the plant has a smaller stem diameter, with consequent less thickening of the cell wall, which results in better quality food. They also showed that this increase of the fiber is due to the development of the corn plant in its cycle, because there is more deposition of components of the cell wall to enable growth, also proven by the decrease in the percentage of leaves.

Conclusions

Forage corn, cut in the vegetative stage, can be a great ally of the rural producer, since it has the potential to produce food with high nutritive value in a short period of time, and in significant amount, with dry biomass production at 80 days of cycle, with up to 320 thousand ha^{-1}, freeing the soil to produce another crop.

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