



Bromatological composition and dry matter production of corn hydroponic fodder

Júlio César Silva Almeida¹, Jean Kaique Valentim^{2*}, Dawson José Guimarães Faria³, Cassia Maria Silva Noronha³, Jonatan Mikhail Del Solar Velarde⁴, Janaina Palermo Mendes², Rita Therezinha Rolim Pietramale² and Henrique Momo Ziemniczak²

¹Departamento de Zootecnia, Instituto Federal de Minas Gerais, Bambuí, Minas Gerais, Brasil. ²Departamento de Zootecnia, Universidade Federal da Grande Dourados, Rua João Rosa Góes, 1761, 79825-070, Dourados, Mato Grosso do Sul, Brasil. ³Departamento de Zootecnia, Instituto Federal de Minas Gerais, Varginha, Minas Gerais, Brasil. ⁴Departamento de Zootecnia, Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brasil. *Author for correspondence. E-mail: kaique.tim@hotmail.com

ABSTRACT. The objective was to evaluate sowing density influence on hydroponic corn fodder bromatological composition, harvested in different ages raised on grass mix substrate. The experimental design used was completely randomized with six replications for each treatment, using 2.0 m² plots (1.0 x 2.0 m). The densities were distributed into factorial array (4x4), consisting in four sowing densities (1.0, 1.5, 2.0 and 2.5 kg m⁻²) and four cutting ages (10, 15, 20 and 25 days). The dry matter content (DMC) and production (DMP) and crude protein (CP), acid detergent fiber (ADF), Fiber neutral detergent (FND) and ethereal extract (EE) were analyzed each cutting age. In terms of DMP (kg m⁻²), EE (%) and DMC (kg m⁻²), it is recommended to use the density 1.0 kg m⁻² with cutting age of 25 days. Regarding CP (%) the best result was at 15 days of cut and density 2.5 kg m⁻² and the values for FND (%) and ADF (%) were higher at 25 days at 2.0 kg density 2,0 kg m⁻². The choice of both best harvesting age and density will depend on what is desired of the nutritional forage (CP, EE, NDF, ADF, DMC and DMP) as well its destination, since very close values were found in all analyzes, regardless of density and age of harvest analyzed.

Keywords: densities; sowing; cutting; hydroponics; productivity.

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Introduction

Livestock production has been challenged to establish capable techniques to produce efficiently, at low prices, and with high quality standards in competitive and sustainable systems. In the pastures off-season, there is always a need for food supplementation for the animals. According to Campêlo et al. (2007) in most regions, to complement animal nutrition, us common to use as alternatives sugar cane, hay or silage. However, due to prolonged drought or greater consumption, or even by other greater losses than planned, there is a need to supplement forage, aiming not to lose weight or produce due to nutritional deficits in the animals (Coutinho, Athayde, Rodrigues, and Coura, 2017).

According to Santos, Manfron, Haut, and Dourado Neto (2006), the hydroponic fodder production an option, especially corn, because its cycle is fast, the development is independent of several factors such as environmental, agroclimatic or topographic conditions, and finally, this crop presents low cost and has high production of green mass. Hydroponics is the cultivation of plants with nutrient solution, in the absence or presence of natural or artificial substrates (Maucieri et al., 2019).

Hydroponic forage cultivation is a technology for the production of vegetal biomass, obtained through the germination and plant initial growth from viable seeds (Gutiérrez & Camacho, 2019). Therefore, the main objective of this technology is to supply animals' nutritional needs, especially during dry or cold seasons of the year, where low yields and reduced forage quality of native species fall short of nutritional requirements (Müller et al., 2005). According to Sambo et al. (2019) with this technique, significant water saving is observed in relation to irrigated systems, an increasingly limiting resource and key element of productivity, production and rural development.

The use of less expensive substrates and nutrient solutions that are easily accessible to farmers, is essential and economically viable for foraging hydroponic crops (Paulus et al., 2015). On the other hand, because it is a technological innovation, even if simple, it lacks information on the quality of its products although it is already in use by farmers, who use their production as an option to complement food programs when available fodder is not sufficient for entire periods with insufficient forage (Campêlo et al., 2007).

In this context, the present study aimed to verify the of sowing density influence on hydroponic corn fodder bromatological composition harvested in different ages, raised on grass mix substrate.

Material and methods

The experiment was conducted at Minas Gerais Federal Institute campus, Bambuí - MG. The municipality of Bambuí is located approximate at 20°00'23 " south latitude, 45°58'37 "west longitude geographical coordinates, with 706 m.a.m.l.s, with an average annual temperature of 22.5°C, ranging from a minimum of 14, 6°C and maximum of 28,5°C with climate classified as tropical.

Hydroponic corn was cultivated in an open system, disposed in east/west direction. 48 experimental units were installed in beds of two square meters, with the plastic-coated surface extended on the ground with a 2.5% gradient, and the borders limited by 6 cm high bamboo guides staked on the ground.

A 4 x 4 factorial scheme was used, consisting of four sowing densities (1.0, 1.5, 2.0 and 2.5 kg m⁻² of seeds) and four harvest ages (10, 15, 20 and 25 days), arranged in a completely randomized design, with six replicates in each treatment.

The quality of maize seed gained given the degree of purity (98%) and germination (99%). For this, the seeds were placed in 200 l drums for the pre-germination process, consisting of submersion in water for 24 hours. After this period, drain the water of the water and the seeds were at home for over 48 hours. The purchased corn seed quality was evaluated before the experiment.

The sowing was done manually and as uniformly as possible in the evening period, with corn seeds (*Zea mays*, L) not selected, without chemical treatment, on a four-centimeter substrate layer composed of grass mixture (*Brachiaria decumbens/Tifton-85*). The nutritive solution was composed of vinasse from Total Agroindústria Canavieira S/A (Bambuí – MG) industry. In the analysis performed by this industry, this nutritive solution was constituted in mg L⁻¹ by: N = 360; P = 140; K = 3.170; Ca = 1290; Mg = 500; Fe = 30; Cu = 1.0; Zn = 2.0; Mn = 6.0 and pH 5.4. For fertigation, the vinasse was diluted 1:9 in water.

The nutrient solution, in the vinasse case, was conditioned in a water box with a capacity of 1000 L. Both the application of nutrient solution and the water irrigation systems, were performed through irrigators once a day with 3 L m⁻². Immediately after sowing, irrigation was initiated with pure water during the first three days and then with vinasse.

For green matter production evaluation (kg m⁻²), a square of wood with an area of 0.04 m² (20 x 20 cm) was used. All hydroponic forage, whole plant with root, non-germinated seeds and grass mix, used as substrate, contained within this square were harvested and then weighed in a digital scale.

After weighing 100 grams sub samples were placed in a forced circulation oven at 60°C for 72 hours to estimate the hydroponic forage dry matter content (DMC). The dry matter production (DMP) of the hydroponic forage was estimated by multiplying the yield of green matter by the DMC.

The analyses bromatology's were performed at the Animal Nutrition Laboratory of the Veterinary School, at Minas Gerais Federal University. The neutral detergent fiber (NDF) and the acid detergent fiber (ADF) followed the methodology of according Van Soest, Robertson, and Lewis (1991) and crude protein (CP) and ethereal extract (EE) according Silva and Queiroz (2002). The data obtained from the analyses were analyzed through the Statistical Analysis System (SAS, 2012) statistical package, and the normality of the residues was verified using the Shapiro-Wilk test and the variances compared by the Levenes Test. Subsequently, the data were submitted to variance analysis by the Mixed procedure (PROC MIXED) to verify if there was an interaction effect between the factors and their isolated effects. For all analyses, the level of 5% significance was used.

Result and discussion

No interaction ($p > 0.05$) between sowing densities and hydroponic corn cutting ages was found in the present study (Table 1).

Table 1. Probability of significance (p-value) at the 5% level between sowing density (kg m⁻²), harvesting age (days) and their interaction.

Parameters	DMP (g)	DMC (%)	CP (%)	NDF (%)	ADF (g)	EE (%)
Density (kg m ⁻²)	0.045	0.008	0.034	0.023	0.021	0.006
Harvest age (days)	0.025	0.043	0.067	0.009	0.0076	0.05
Density x Harvest age	NS	NS	NS	NS	NS	NS

NS = Not significant.

The means obtained for PB, EE, FDN, FDA, MS and PMS for complete fodder, substrate + roots and aerial part of corn plants are presented in the tables below. Dry matter (DMP) values were higher ($p < 0.05$) at 1.0 kg m⁻² density for 20 and 25 harvest days, when compared to the other densities (Table 2).

Table 2. Dry matter content of complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m⁻²) and harvest ages (days).

Density (kg m ⁻²)	Harvest age (days)			
	10	15	20	25
1.0	26.40 bC	28.60 aB	22.32 Ad	35.23 aA
1.5	31.05 aA	16.27 cC	16.10 dC	18.05 cB
2.0	18.84 dA	16.66 cB	18.13 cA	14.04 dC
2.5	21.37 cB	21.90 Bb	19.51 bC	23.59 bA

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

The data obtained in relation to the amount of dry matter are in accordance with that found in the literature. The concept of dry matter is related to the mass of the product subtracted from the water mass. Dry matter intake for ruminant animals is essential for performance improvements. The fiber of high degradability, present in the dry matter of food acts as substrate for ruminal microorganisms that digest food (Morais, Nepomuceno, & Almeida, 2017) transforming plant protein into animal protein, be it meat or milk, in addition, a low amount of MCD in fodder can make it difficult to sting due to a higher percentage of water. This fact also directly interferes with the consumption of ruminant animals (Alves et al., 2016).

Fiber is essential for ruminants and even if it is supplied in small amounts in the animal diet, this content has its importance with regard to ruminal microbiota. The minimum amount of fiber is necessary to have adequate concentrations of microorganisms in the rumen in order to promote the fermentation process, saliva production and ruminal movements (Silva et al., 2016). Fraga, Ferrari, Garcia, Leite, and Tannous (2009) verified values of 22.50, 21.73 and 18.51% of DMP for corn fertigated produced with rice husk, elephant grass and bovine manure substrates, respectively. Thus, the DMP contents in this work are very close to the values found in the literature.

Araújo, Coelho, Cunha, and Lombardi (2008) verified that hydroponic corn fodder dry matter production harvested at 10 days and fertirrigated with nutrient solution did not have affect ($p > 0,05$) seeding densities. These data corroborate with those obtained in the current research. Gutiérrez and Camacho (2019) in studies with hydroponic forage of oats, reported that harvest ages greater than 10 days would not be convenient for this production system, due to dry phytomass reduction, since there were decreasing values in hydroponic forage oat crop at 7, 11 and 15 days of 3.26; 2.95 and 2.27 kg m⁻² of DMC, respectively, showing results diverging to those found in this work with corn.

CP data were higher ($p < 0.05$) at 2.5 density kg m⁻² at 15; 2.0 kg m⁻² at 25 and 1.5 kg m⁻² at 20 harvesting days, and at the density of 1.0 kg m⁻², harvesting ages did not differ statistically ($p > 0.05$) from each other (Table 3).

Table 3. Crude Protein (CP) of the complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m⁻²) and harvest ages (days).

Density (kg m ⁻²)	Harvest age (days)			
	10	15	20	25
1.0	9.50 bA	9.89 bA	9.52 aD	9.10 cA
1.5	10.46 aB	9.79 bC	11.42 aA	10.74aB
2.0	10.38 aB	9.75 bB	8.78 cC	11.37 aA
2.5	9.89 abB	11.49 aA	10.49 bB	10.14 bB

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

In similar studies, Müller et al. (2005) found CP content of 12.1% at 10 days and 13.3% at 20 days, in corn tillage of soil using the same substrate in the current research. Araújo, Oliveira, Coura, and Bandeira (2008) verified that on average 1.0 to 2.5 kg m⁻² sowing corn densities resulted in CP content of 11.9%. While Manhães et al. (2011) in similar research, found for corn fodder harvested at 10 and 17 days, 10.25% and 15.00% CP content with a kg m⁻² density. Bezerra, Melo, Fernandes, Andrade, and Santos (2008) obtained CP content around 5.9 and 6.7% when the corn sowing density was 1.5 and 2.0 kg m⁻² and sugarcane bagasse as substrate.

Considering this, feed supplementation with corn hydroponic forage has a higher protein value, ranging from 8.78 to 11.42% in terms of CP, than other forages commonly used by cattle farmers, ranging from around 6 and 7% (Faria, Morenz, Paciullo, Lopes, & Gomide, 2018), and may be considered an excellent option for ruminant feeding.

In order to study the production of corn hydroponic fodder installed on elephant grass substrate, Araujo, Coelho, Cunha and Lombardi (2008) obtained 11.7% CP at 16 days and 13.1% CP at 22 days.

NDF content was higher ($p < 0.05$) at kg m⁻² density of 2.5 with 15 days; 2.0 kg m⁻² at 25 days; 1.5 kg m⁻² at 15 days and 1.0 kg m⁻² at 10 days of harvest, with 48.6; 61.23; 49.74 and 50.08% NDF content, respectively. The lowest values were found ($p < 0.05$) at 1.0 kg m⁻² with 25 days, and 2.5 kg m⁻² with 10 days of harvest (Table 4).

Table 4. Neutral detergent fiber content (NDF) of the complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m⁻²) and harvest ages (days).

Density (kg m ⁻²)	Harvest age (days)			
	10	15	20	25
1.0	50.08 aA	45.67 bB	37.87 cC	27.2 dD
1.5	44.39 cB	49.74 aA	43.39 bB	43.4 cB
2.0	48.31 bB	43.25 cD	46.79 aC	61.2 aA
2.5	38.72 dD	48.60 aA	43.08 bC	44.7 bB

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

The food intake of ruminants is regulated by several factors, as Zanine and Macedo Júnior (2006) reports, such as: food (fiber, energy density, volume), animal (weight, production level and physiological status) and feeding condition (food availability, frequency of feeding, among others), this control of consumption involves hunger and satiety stimuli, which operate through various neurohumoral mechanisms directly linked to the fiber content of the diet. Zanine and Macedo Júnior (2006) also report that to measure potential food consumption, the ideal system should divide food into fractions that limit consumption due to "filling" or specific density, from those that limit consumption due to energy density.

The effect of "filling" the diet can be expressed in terms of NDF, the determination of food filling units are highly correlated with the cell wall concentration of plants (Valença et al., 2016). According to Van Soest (1965), at NDF levels equal to or greater than 70%, there is a limitation in food consumption by the physical effect of filling the rumen, thus the results presented are satisfactory in order to minimize this effect.

Paulino, Oliveira, Gionbeli & Gallo (2014) report that the minimum level of NDF needed for ruminal smooth functioning, especially in diets with high energy is 35%, so the levels found in the present study were feasible for use. In a study by Müller et al. (2005), higher NDF contents were observed at 17 days, regardless the densities studied in relation to fodder harvested at 10 days, using elephant grass as substrate. In a study carried out by Flôres (2009), NDF content was higher at 17 days, showing that this fact is consequence of plant maturity, because with the advancement of the cycle, there is an increase in lignin content and increase and thickening of the cell wall in the tissues of the plant, mainly due to the decrease in leaf/stem ratio.

In studies carried out by Alves et al. (2011), working with hydroponic corn produced at a density of 2 kg m⁻² with sugarcane bagasse substrate, and obtained 77.3% for NDF, higher content to those found in this work, which emphasizes the substrate influence on bromatological composition, since the sugarcane bagasse has higher NDF contents than grass mix. Thus, it can be said that this fact was a consequence, also, because of the plant maturity, corroborating the present study, where in the density of 2 kg m⁻² in the cutting age of 25 days there was a higher percentage of FF (61.2%).

Data of acid detergent fiber (ADF) were higher ($p < 0.05$) at 2.0 kg m⁻² sowing density with 25 days; 1.0 kg m⁻² at 10 and 15 days, and 2.5 kg m⁻² at 15 days of harvest, but did not differ statistically from each other (Table 5).

Table 5. Fiber content in acid detergent of the complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m^{-2}) and harvest ages (days).

Density (kg m^{-2})	Harvest age (days)			
	10	15	20	25
1.0	27.80 aA	25.44 bB	18.86 cC	13.21 cD
1.5	23.95 cB	27.36Aa	22.66 aC	23.3 bBC
2.0	25.22 bB	22.91 cC	24.17 bB	36.49 aA
2.5	19.96 dC	27.23 aA	22.64 bB	22.64 bB

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

In the case of corn hydroponic forage, DMP of 47.63 and 51.43% were found at 10 and 20 days, respectively, due to the high AFD observed on elephant grass substrate. In a study developed by Rocha et al. (2007) evaluating fertirrigated corn with rice straw as substrate and harvested at 17 days, 72.54% of NDF and 50.76% of ADF were found, allowing significant differences in composition of the forages which difference is due probably to each substrate characteristics.

All the results found in this study were lower than those recommended by Mertens (1994), which states that the lower its content (around 30% or less), the higher the DMP consumption by the animal. These low values were due because the forage precocity and, were also, assumed to be influenced by the substrate used.

Santana, Bianchi, Morita, Isepon, and Fernandes (2010) observed 48.4% of ADF for hydroponic corn forage, and 61.45% for hydroponic corn forage. This value is lower than those found in this work at several densities and harvest ages, except for 2.0 kg m^{-2} sowing density with to 25 days of harvest.

The hydroponic corn forage using grass mix as substrate in the current study, presented low ADF levels, this result is very important because it is considered the indigestible and inhibitory part of the digestibility of forage plants (Humphreys et al., 2006).

Data of ethereal extract (EE) were higher ($p < 0.05$) at 1.0 kg m^{-2} sowing density with 20 and 25 days; 1,5 kg m^{-2} at 20 days and 1.0 kg m^{-2} at 20 days of harvest, in relation to the others, showing no relation between density and age of harvest (Table 6).

Table 6. Ethereal Extract Content (EE) of the complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m^{-2}) and harvest ages (days).

Density (kg m^{-2})	Harvest age (days)			
	10	15	20	25
1.0	1.81 aB	1.93 aB	2.43 aA	2.62 aA
1.5	1.91 aB	1.40 bC	2.47 aA	1.94 bB
2.0	2.10 aA	1.85 aAB	1.45 bC	1.59 bBC
2.5	2.02 aA	1.62ab B	2.13 aA	1.91 bAB

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

Paulino, Possenti, Lucena, Vedove, and Souza (2004) studied hydroponic corn forage bromatological compounds using three solution compositions as treatments, resulting in 3.76; 3.95 and 4.11% of EE in with 2.0 kg m^{-2} sowing density harvested at 20 day using tifton hay as substrate. Values above those found in this work. It is assumed that these values diverge due to the use of different environmental causes, as substrates and nutrient solutions used in each cultivation.

It was found higher DMP at the density of 1.0 kg m^{-2} with 25 days; 2.5 kg m^{-2} at 15 days and 1.5 kg m^{-2} at 10 days of harvest, even though they did not differ statistically between each other, and in relation to the other treatments (Table 7). This large divergence of results in DMP depicts the non-relation between density and age of harvest, in the conditions of the current research.

The choice of both best harvesting age and density will depend on what is desired of the nutritional forage (CP, EE, NDF, ADF, DMC and DMP) as well its destination, since very close values were found in all analyzes, regardless of density and age of harvest analyzed. DMP from corn hydroponic fodder was influenced by seed density ($p > 0.05$). This behavior was observed by Alves et al. (2011), when evaluating the hydroponic corn forage using densities of 1.0; 1.5; 2.0 kg m^{-2} in guandu (*Cajanus cajan L.*) substrate.

Araujo et al. (2008) obtained 11.7% and 13.1% PB levels in the dry matter at 16 and 22 days, respectively, in hydroponic corn growth with elephantgrass substrate. Araújo et al. (2018) obtained 35.4; 39.6 and 34.6%

of FDA; 32.1; 29.4 and 28.6% of hemicellulose and 31.3; 31.4 and 31.6% of cellulose in dried corn phytomass produced on hydrolyzed sugar cane, grass and chicken bed substrates, respectively.

According to Santana et al. (2010), the enlarge the sow density may result in a significant increase ($p < 0.05$) of protein content in hydroponic corn forage, as a function of the number of seeds since they are present in larger amount. However, this effect was not observed in the present study, since the values found were not consistent with this assertion.

Table 7. Production of dry matter of complete forage of hydroponic corn (corn + substrate) as a function of sowing density (kg m^{-2}) and harvest ages (days).

Density (kg m^{-2})	Harvest age (days)			
	10	15	20	25
1.0	1.32 dC	3.12 bB	2.65 cB	5.01 aA
1.5	4.09 aA	2.43 cC	3.20 bcB	3.42 bB
2.0	2.64 cB	2.75 bcB	3.67 abA	2.66 cB
2.5	3.45 bC	4.38 aAB	3.98 aBC	4.69 aA

Means followed by the same uppercase letters in the same row and lowercase in the same column do not differ statistically ($p > 0,05$) from each other by the Tukey test.

Conclusion

In terms of dry matter content (kg m^{-2}), dry matter production (kg m^{-2}) and ethereal extract (%) it is recommended to use the sowing density of 1.0 kg m^{-2} and harvest the corn fodder at the age of 25 days, because in this situation, those bromatological values were greater than the others. Regarding crude protein (%) the best result was obtained where corn was harvested at 15 days of age with a density of 2.5 kg m^{-2} . The values for neutral detergent fiber (%) and acid detergent fiber (%) were higher where harvested at 25 days of age and with a sowing density of 2.0 kg m^{-2} . Combining animal productivity and forage quality it is recommended to use the density of 2.5 kg m^{-2} and harvest age at 25 days aiming at better productive efficiency.

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