Bromatological quality and productivity of hydroponic maize forage cultivated in different substrates

Qualidade bromatológica e produtividade de forragem hidropônica de milho cultivado em diferentes substratos

Calidad bromatológica y productividad del forraje de maíz hidropónico cultivado en diferentes sustratos

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Abstract

The objective of this work was to evaluate the productivity and the chemical quality of hydroponic corn forage grown on different substrates. The experiment was conducted at the Federal Institute of Science and Technology of Roraima – Campus Novo Paraíso, in the municipality of Caracaraí, Roraima, Brazil. The experiment was carried out in a randomized block design, with five sowing rates (treatments) and four replications. Hybrid corn seeds 2022 were used, sown on a double-sided canvas. When germination started, fertigation with nutrient solution was carried out. The evaluation occurred on the 10th day after sowing and included determination of plant height (cm) and roughage productivity (kg m^2 and t ha^{-1}) and bromatological analyses (% N, PB, FDA, NDF and NDT). For bromatological analyses, corn plants were collected, dried in an oven at 65 ºC and then crushed. The productivity of natural forage (k m^2 and t ha^{-1}), plant height and the neutral fiber content (NDF) of hydroponic corn were higher at the sowing rate of 2.5 kg m^2. These variables were influenced by the sowing rate and type of substrate, but resulted in a lower crude protein content. The results show that sugarcane bagasse was a suitable substrate for hydroponic corn, which is justified by the fact that it presents fewer moisture losses, avoiding the loss of nutrients in the nutrient solution. At a sowing rate of 1.0 kg m^2, the forage produced had a higher content of nitrogen, crude protein and total digestible nutrients, which are important for animal nutrition.

Keywords: Forage; Hydroponic; Productivity; Substrate; Supplementation.

Resumo

Objetivou-se avaliar a produtividade e a qualidade bromatológica da forragem hidropônica de milho cultivada sobre diferentes substratos. O experimento foi conduzido no Instituto Federal de Ciência e Tecnologia de Roraima – *Campus* Novo Paraíso, no município de Caracaraí, Roraima. O experimento foi realizado em delineamento em blocos casualizados, com cinco taxas de semeadura (tratamentos) e quatro repetições. Utilizaram-se sementes de milho híbrido 2022, semeada sobre uma lona dupla face. Iniciada a germinação, procedeu-se à fertirrigação com solução nutritiva. Para a avaliação, determinou-se a altura da planta (cm) e a produtividade de volumoso (kg m^2 e t ha^{-1}) e efetuando-se as análises bromatológicas (% N, PB, FDA, FDN e NDT). Para tais análises, foram coletadas plantas de milho, secadas e posteriormente trituradas. A produtividade de forragem natural (k m² e t ha^{-1}), a altura das plantas e o teor de fibra neutro (FDN) de milho hidropônico foram maiores na taxa de semeadura de 2,5 kg m². Essas variáveis foram influenciadas pela taxa de semeadura e o substrato, porém com menor teor de proteína bruta. Os resultados mostram que o bagaço de cana-de-açúcar foi o substrato adequado para milho hidropônico, justificado pelo fato de o mesmo apresentar menos perdas de umidade, evitando a perdas dos nutrientes da solução nutritiva. À taxa de semeadura de 1,0 kg m², a forragem produzida apresentou maior teor de nitrogênio, proteína bruta e nutrientes digestíveis totais, que são importantes para a nutrição animal.

Palavras-chave: Forragem; Hidroponia; Produtividade; Substrato; Suplementação.

Resumen

El objetivo fue evaluar la productividad y la calidad bromatológica del forraje hidropónico de maíz, cultivado en diferentes sustratos. El experimento se condujo en el Instituto Federal de Ciencia y Tecnología de Roraima - Campus Novo Paraíso, en el municipio de Caracaraí-Roraima. El experimento se realizó en un delineamiento de bloques al azar, con cinco tasas de siembra (tratamientos) y cuatro repeticiones. Se utilizaron semillas de maíz híbrido 2022, sembradas sobre una lona doble cara y, cuando comenzó la germinación, se llevó a cabo la fertirrigación con solución nutritiva. La evaluación ocurrió el 10º día después de la siembra, se determinó la altura de la planta (cm), la productividad del voluminoso (kg m^2 y t ha^{-1}) y los análisis bromatológicos (% N, PB, FDA, NDF y NDT). Para las evaluaciones bromatológicas, se recolectaron plantas de maíz, secadas en un horno a 65 ºC y luego trituradas. La productividad del forraje natural (k m² y t ha^{-1}), la altura de las plantas y el contenido de fibra neutra (NDF) de maíz hidropónico fueron mayores en la tasa de siembra de 2.5 kg m². Esas variables fueron influenciadas por la tasa de siembra y el tipo de sustrato, pero con un menor contenido de proteína cruda. Los resultados mostraron que el bagazo de caña de azúcar fue el sustrato adecuado para el maíz hidropónico, hecho que se justifica por el mismo presentar menos pérdidas de humedad, evitando la pérdida de los nutrientes de la solución nutritiva. En la tasa de siembra de 1.0 kg m², el forraje producido presentó un mayor contenido de nitrógeno, proteína cruda y nutrientes digestibles totales, que es importante para la nutrición animal.

Palabras clave: Forraje; Hidroponia; Productividad; Sustrato; Suplementación.

1. Introduction

In Brazil, the area of cultivated and native pastures occupies about 180 million hectares, but the supply of pasture has been decreasing. (Rocha et al., 2014). The growing reduction of pasture areas in Brazil, mainly due to the degradation process, environmental issues, the replacement of pastures with agricultural crops and the climatic seasonality, has led producers to seek new food supplementation technologies that enable, efficiently, the increase of animal production, guaranteeing its development. (Rocha et al., 2014).

The cultivation of hydroponic forage began in Brazil in the 1990s, with the purpose of serving as food for horses (Fraga et al., 2009), with corn being the most used forage. After that time, numerous researches were developed in order to make this technique an alternative to obtain roughage with high protein value. Corn (*Zea mays L.)* is the second most produced crop in Brazil and one of the main crops grown in the world, with a purpose ranging from human and animal consumption to the supply of bioenergy (Simão, 2016).

An agricultural technology that has been widespread in Brazil is hydroponics, which consists of growing vegetables in the absence of soil. This technique has aroused growing interest due to the great challenge of increasing food and fiber production, exploring the same area of soil, water resources and climatic conditions without resulting in environmental impacts. (Araújo et al., 2008). In addition, in general, hydroponics is an economically accessible and profitable technology.

Recently, the hydroponic technique was adapted for the production of roughage to serve as food for cattle, sheep, goats, horses, rabbits and birds; in times of drought, with scarcity of good quality forage, with lower production cost than the use of silage and concentrates, and with a high nutritional value, mainly in proteins, due to the phase in which the plants are harvested and made available for animal feed (Araújo et al., 2008; Piccolo, et al., 2013). Hydroponic fodder can be used in situations where conventional fodder cannot be grown due to any adverse conditions. (Naik et al., 2017).

Residues from agricultural production or from the processing of agricultural products play a fundamental role in restoring nutrients to the soil, being used as soil cover or in the composting process. Thus, these residues, which often constitute an environmental problem, can be used as a substrate in the production of hydroponic forage.

Hydroponic forage as an animal supplement can provide good results for the production of milk and meat, as it is a result of the germination process of cereal seeds (corn, wheat sorghum, oats and other species), which develop in a short period, 10 to 20 days, capturing energy from the sun and assimilating the minerals contained in the nutrient solution. (Araújo et al., 2008).

The study of the chemical and chemical composition of foods is the starting point for understanding the physiological processes responsible for the transformation of complex compounds to the formation of products of animal origin, mainly due to the availability of energy and other nutrients (Geron et al., 2014). Fibrous foods, a source of structural carbohydrates (hemicellulose and cellulose), are the main energetic substrates used by microorganisms present in the digestive tract of ruminant animals (Van soest, 1967). Dietary fiber represents the fraction of structural carbohydrates contained in food, which are slow to digest. Depending on its composition, it can limit the consumption of dry matter (DM) and energy by the animal, however, for the animal to have an adequate digestion of dry matter and other nutrients, it is necessary that the diet contains a small amount of fiber and that it is of good quality, therefore, rich in hemicellulose and pectin. (Nussio, Campos & Lima, 2010).

According to Fraga et al. (2009), the average forage production is 25 to 35 kg m2 of hydroponic forage, whose average cost of a kilo of ready forage is approximately US $ 0.02, which can be significantly reduced if the producer has seeds on the property. The productivity of green mass per year for hydroponic fodder is approximately 700 t ha^{-1}, for a period of 360 days, whereas, for the same period, irrigated elephant grass produces 200 t ha^{-1} (Fraga et al., 2009).

Results obtained by Araújo et al. (2008) evaluating the productivity and protein content of hydroponic green maize forage grown on sugarcane bagasse (*Saccharum sp*.), In Goytacazes' Fields, RJ, obtained a productivity of 34.41 kg m^{-2} fresh matter, corresponding to 344.1 t ha-1, with a crude protein content of 11.89%. Manhães et al. (2011), evaluating the yield of the BR 106 corn variety in the production of hydroponic green forage, using sugarcane bagasse (*Sacchurum sp*.) As substrate, observed productivity of 20.6 kg m^{-2} and 4.0

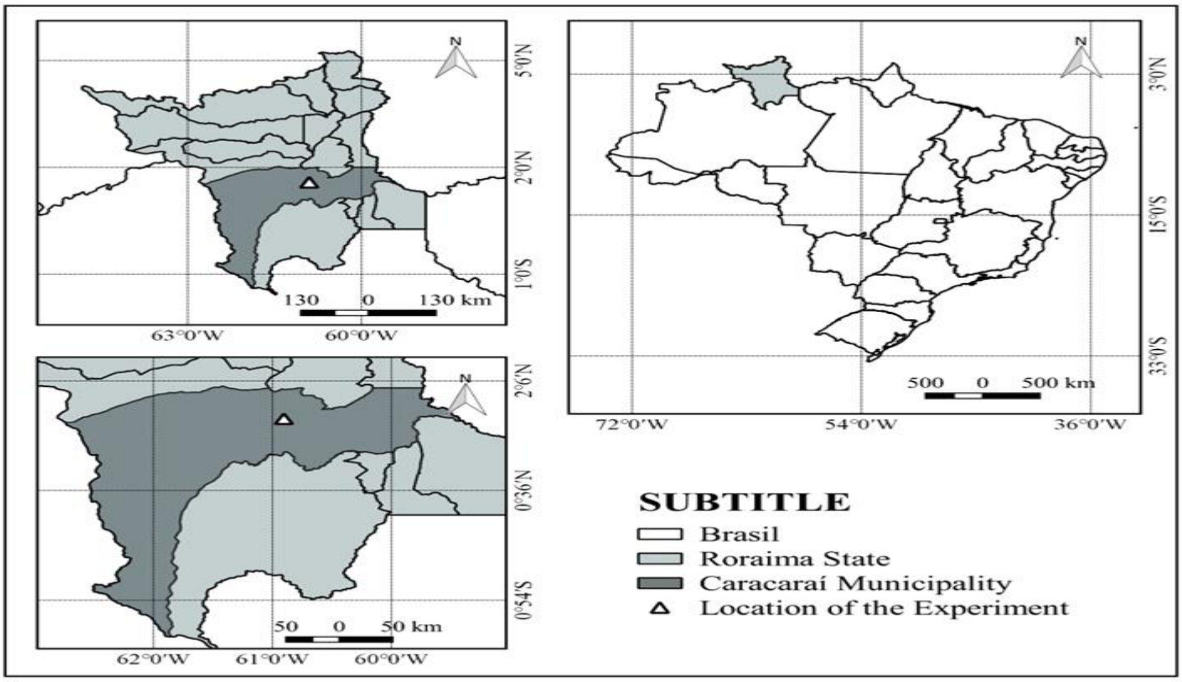
kg m^{-2} of fresh and dry matter, respectively, of corn forage and crude protein content of 18.26%. These results demonstrate the potential of roughage production and the good quality of forage produced by this technique in relation to the production of roughage in the field.

In this sense, the objective was to evaluate the productivity of hydroponic forage grown on the substrates of sugarcane bagasse and corn stubble, with five sowing rates, identifying the appropriate amount of seeds per m², the ideal harvest age, productivity per m² and its chemical quality (N content, crude protein, acid detergent fiber, neutral detergent fiber and total digestible nutrient content).

2. Materials & Methods

This is an exploratory research with a quantitative nature. The experiment was conducted in the field, at the Federal Institute of Science and Technology of Roraima - *New Paradise Campus*, in the municipality of Caracaraí - Roraima, at the geographical coordinates 1o 15 '01.46 N' 'and 60º 29' 12.30 W ", at a altitude of 83.09 m (Figure 1). The experiment was installed in a greenhouse using two substrates, sugarcane bagasse and corn forage, being grown with hybrid corn seeds BRS 2022, in a randomized block design, with five treatments (sowing densities: 0, 5, 1.0, 1.5, 2.0 and 2.5 kg m²) and 4 repetitions, for each substrate.

Figure 1. Location of the study area in the municipality of Caracaraí, south of Roraima.



Source: Authors.

The beds, with a useful area of 1 m² and spaced 0.5 m apart, were randomly distributed in the area, on top of double-sided polyethylene canvas (15 microns). The substrates used were obtained from IFRR, New Paradise Campus, from agricultural cultivation areas. The sugarcane bagasse, after extracting the juice, and the corn straw were crushed in forage, resulting in particles of 1-2 cm in size.

The treatments were prepared with a 2-3 cm layer of substrate and irrigated with water for 24 hours before planting. The corn seeds from the treatments were weighed and placed in containers with water for 24 hours for pre-germination.

The plants were fed with a hydroponic fodder nutritive solution, with the following concentrations: calcium nitrate (15.5% N, 18.5% Ca, 25% CaO), potassium nitrate (12% N, 45% K_2O, 1,2% S), monoammonium phosphate - MAP (12% N, 61% P_2O_5), magnesium sulfate (9% Mg, 11% S), Fe (0.06%), B (0.041%), Cu (0 , 04%), Mn (0.04%), Mo (0.009%), Ni (0.008%) and Zn (0.001%). During the first three days after planting, irrigation was performed only with water (5 L/m^2/ day, in two waterings). Germination started, fertigation was performed as follows: at 7 am and 5 pm - watering with 3 L of the nutrient solution per m² of bed in the morning; and at 5 pm - watering with 2 L of the nutrient solution per m² of bed in the afternoon. This procedure was repeated for 6 days, and the use of the nutrient solution was suspended one day before harvest, to remove salts from the forage.

The harvest was carried out on the 10th day after sowing. At harvest time, plant height (cm) and forage production (kg m²) were determined. Forage samples were taken, which were packed in paper bags for drying in an oven at 65 ° C for 72 h, and later grinding in a Willer mill. For the analysis, the samples were separated according to the density of the seeds (0.5; 1.0; 1.5; 2.0 and 2.5 kg m²).

The crude protein content (% CP) was indirectly determined from the total nitrogen value (N), which was determined by the Kjeldahl method, which is based on three steps: digestion, distillation and titration. After determining the N, the PB content is estimated by multiplying by the conversion factor of 6.25, considering that the proportion of N in plant proteins is equal to 16%. (Campos et al., 2004).

The levels of neutral detergent fiber (NDF) and acid detergent fiber (FDA) in hydroponic corn were obtained by the conventional method described by Van Soest (1963) and Van Soest (1967), respectively. The percentages of neutral detergent fiber (NDF) and acid (FDA) at the base of the DM were obtained by difference between the weighings, NDF or FDA (%) = [(C - B) x 100] / A, where A was the weight of the sample in grams, B, the weight of the container (glass crucible or F57 filter) and C, the weight of the container plus the residue (FDN or FDA). The content of total digestible nutrients (NDT) of roughage was obtained by the equation proposed by Chandler (1990) mentioned in the NRC (1996): % NDT = 87.84 - (0.70 x% FDA).

The results obtained were subjected to analysis of variance and the means of the substrates were compared using the Tukey test ($P < 0.05$), using the SISVAR statistical program (Ferreira, 2014).

3. Results and Discussions

The averages and coefficients of variation obtained for natural forage weight (kg m^2), plant height (cm), N (g kg), PB (%), NDF (%) and FDA (%) contents, evaluated at 10 days after sowing, for the substrates sugarcane bagasse and corn straw, were influenced ($P < 0.05$) by the sowing density (Table 1 e 2).

The production of natural forage (kg m^2) was 34 and 18.73 kg, respectively, for planting in sugarcane bagasse and corn straw substrate, corresponding to 340 and 187.3 t ha^{-1}, respectively. The amount of natural forage produced with hydroponic corn per area was influenced by the sowing rate and type of substrate. The results obtained from natural forage productivity (kg.m^2), with sugarcane bagasse substrate, were superior to those obtained by Manhães et al. (2011), who, evaluating the yield of the BR 106 corn variety in the production of hydroponic green forage using sugarcane bagasse as a substrate, obtained productivity of 20.6 kg m^{-2}. Araújo et al. (2008) obtained for hydroponic corn grown on sugarcane bagasse a productivity of 34.41 kg m^2, which corresponds to 344.1 t ha^{-1}, corroborating the values obtained in this work. In addition to the experiment being carried out in a greenhouse with better plant development, the temperature at work by Araújo et al. (2008) is close to that of this work, and the results are also closer than those obtained by Manhães et al. (2011), who carried out the experiment at a lower temperature, with influence on the quality of forage.

These results show that sugarcane bagasse is an adequate substrate for hydroponic corn. This is justified by the fact that it presents less moisture losses, avoiding loss of nutrients in the nutrient solution.

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Table 1. Evaluation of natural forage productivity (kg m²) and (t ha-¹), plant height (cm), N content (g kg), crude protein (% CP), neutral detergent fiber (% NDF), detergent fiber acid (% FDA) and total digestible nutrients (% NDT) of hydroponic corn grown over sugarcane bagasse, with 10 days after sowing.

Treatment	Weight (kg m²)	Prod. (t ha)	Height (cm)	N (g kg)	PB (%)	FDN (%)	FDA (%)	NDT (%)
Sowing rate (0.5 kg m^2)	12.6 e	238 c	23.8 e	51.7c	32.3 c	54.82 d	38.96 d	60.56 b
Sowing rate (1.0 kg m^2)	13.9 d	245 b	24.5 d	53.9a	33.7 a	54.25 e	38.80 e	60.68 a
Sowing rate (1.5 kg m^2)	18.2 c	247 b	24.7 c	52.4b	32.7 b	55.98 c	42.23 a	58.28 e
Sowing rate (2.0 kg m^2)	18.5 b	258 b	25.8 b	52.4b	32.8 b	59.00 b	42.13 b	58.35 d
Sowing rate (2.5 kg m^2)	20.5 a	340 a	34.0 a	40.2d	25.1 d	59.77 a	41.65 c	58.68 c
CV (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,0

Means followed by equal letters in the same column, do not differ (P <0.05) by the Tukey test. Source: Authors.

Table 2. Evaluation of natural forage productivity (kg m²) and (t ha-¹), plant height (cm), N content (g kg), crude protein (% CP), neutral detergent fiber (% NDF), detergent fiber acid (% FDA) and total digestible nutrients (% NDT) of hydroponic corn grown over corn stubble, with 10 days after sowing.

Treatment	Weight (kg m²)	Prod. (t ha)	Height (cm)	N (g kg)	PB (%)	FDN (%)	FDA (%)	NDT (%)
Sowing rate (0.5 kg m^2)	11.2 d	112 c	28.25 c	51.70 c	32.31 c	55.52 e	41.31 e	60.56 b
Sowing rate (1.0 kg m^2)	12.6 c	126 b	28.90 c	53.93 a	33.71 a	57.01 d	42.43 d	60.68 a
Sowing rate (1.5 kg m^2)	16.2 b	162 b	35.25 b	52.40 b	32.75 b	62.34 c	45.42 c	58.27 e
Sowing rate (2.0 kg m^2)	16.7 b	167 b	38.55 a	52.43 b	32.77 b	62.66 b	46.34 b	58.35 d
Sowing rate (2.5 kg m^2)	18.7 a	187 a	38.55 a	40.23 d	25.15 d	63.59 a	46.44 a	58.68 c
CV (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Means followed by equal letters in the same column, do not differ (P <0.05) by the Tukey test. Source: Authors.

Regarding plant height (cm), the treatments differed as follows: the higher the sowing rate, the greater the height. This fact is justified by the higher density of plants, which makes them compete for light for their photosynthetic metabolism (Tables 1 and 2). The height of the plants in the two substrates (sugarcane bagasse and corn straw) varied from 23.8 to 38.8 cm, differing between the sowing densities. Araújo et al. (2008), working with the sugarcane bagasse substrate, obtained height within the variations of this work, with 28.7 cm being their highest height.

As for the nitrogen content, there was no difference between the two substrates, however the values differed in relation to the sowing rate: the higher the sowing rate, the lower the N content (Tables 1 and 2). Fraga et al. (2009), working with the substrates of sugarcane bagasse and rice straw, obtained higher levels of nitrogen from plants grown in sugarcane bagasse than in those cultivated in rice straw.

In relation to crude protein (% CP), the type of substrate did not influence its content (P <0.05), but the seeding density (Tables 1 and 2). The values of crude protein (% CP) obtained in this work varied between 25.1 and 33.71%, being higher than those reported in the literature. Araújo et al. (2008), evaluating the productivity and protein content of hydroponic green maize forage grown on sugarcane bagasse (*Saccharum sp*.), In Goytacazes' Fields - RJ, obtained a crude protein content of 11.89 %. Manhães et al. (2011), evaluating the yield of the BR 106 maize variety in the production of hydroponic green forage using sugarcane bagasse (*Sacchurum sp.)* As substrate, obtained a crude protein content of 18.26%.

The variables N content (g kg) and CP content (%) showed a statistical difference regarding the sowing rate, and the treatment with 1.0 kg of seeds per m² obtained higher levels in relation to the other treatments analyzed. Araujo et al. (2008); Santana et al. (2020), found that, on average, the sowing densities of 1.0 to 2.5 kg m² of corn resulted in 11.88% of CP. In turn, Crevelari (2011), using sugarcane bagasse as a substrate, obtained crude protein content of around 5.9 and 6.7% for corn seeding density of 1.5 and 2.0 kg m², respectively, fertigated with dilutions of vinasse.

According to Locatelli (2016), the use of the Hoagland and Arnon nutrient solution resulted, on average, in crude protein (% CP) 1.2 times higher than the average of plants irrigated with water or with the FAO solution. This indicates that the mineral composition of the Hoagland and Arnon solution favored the growth of the aerial part of the plants, resulting in a higher concentration of nitrogen and crude protein.

The levels of neutral detergent fiber (NDF) and acid detergent fiber (FDA) were proportional to the sowing rate: the higher the sowing rate, the higher the levels of NDF and FDA (Tables 1 and 2). The FDA is part of the cell wall of forages, and the part less digestible by ruminal microorganisms, consisting basically of lignin and cellulose. (Salman et al., 2010). Matos and Teixeira (2016), working with hydroponic corn with rice husk substrate, obtained FDA above 52.69%, higher than the value obtained in this study, which was 46.44% with corn straw substrate. However, according to Rocha et al. (2014), the FDA levels are influenced by rice husk, which has a high content of these elements and can even impair the nutritional quality of the forage.

Amorim et al. (2001) found values lower than those of this work: 35.4, 39.6 and 34.6% in dry FDA phytomass in hydroponic corn forage produced on hydrolyzed sugarcane bagasse substrate, grass and chicken litter, respectively.

According to Campelo et al. (2007), the very high fiber content is an undesirable characteristic in the forage. These authors concluded that the use of rice husk, compared to the use of chopped elephant grass, as a substrate in the hydroponic cultivation of corn, resulted in lower quality forage, as it increased the fiber content.

4. Final Considerations

It was concluded that the amount of natural forage (kg m²) and the height of plants (cm) produced from hydroponic corn by area were influenced by the type of substrate and by the sowing density.

At a sowing rate of 1.0 kg m², the forage produced showed higher levels of nitrogen and crude protein, which are important for animal nutrition.

However, it should be considered that there are several nutrient solutions on the market for hydroponics and corn seeds (cultivars and hybrids), which can influence the results. It is important to evaluate the nutritional solutions and the types of seeds; and new experiments to confirm the nutritional quality of the forage.

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