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Article

Biodegradable Cashew Gum Hydrogel in Mombasa Grass Pasture: A Sustainable Option for Agriculture

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Abstract: Hydrogels are water-absorbing polymers that can hydrate forage plants in the soil. The objective was to evaluate the replacement of synthetic hydrogels derived from petroleum by biodegradable hydrogels in Mombaça grass pastures (*Megathyrsus maximum*). The experimental treatments consisted of: No hydrogel (NH); Synthetic commercial hydrogel (CH), made from a synthetic polyacrylamide product; and Biodegradable test hydrogel (TH), obtained from cashew gum (*Anacardium occidentale*). The experimental design was randomized blocks with five replications and three treatments. Morphogenesis, production, chemical and mineral composition of the Mombaça grass pasture were assessed. The data was subjected to analysis of variance and mean comparison by the Snott-Knott test at 5% probability. Leaf elongation rate was 42.3 mm day^{-1} in the TH treatment, which was higher ($P<0.05$) than NH (35.0 mm day^{-1}). Green leaf mass yield was higher in TH in comparison to NH and CH. On the other hand, there was no effect of hydration on chemical composition. The mineral composition of Mombaça grass showed more Zn when TH was used. It can be concluded that biodegradable hydrogels can replace synthetic commercial hydrogels in pastures.

Keywords: chemical composition; *Megathyrsus maximus*; morphogenesis; organic hydrogel; planting gel; polymers; synthetic hydrogel

1. Introduction

Mombaça grass (*Megathyrsus maximus* cv. Mombaça) is a perennial forage plant that grows in both cespitose and clumpy ways. It is very productive when grown on fertile soils, but it does not tolerate waterlogging or prolonged periods of water deficit [1]. Prolonged water deficit is very damaging to the grass, as it minimizes leaf emergence and tissue expansion by the forage plant. It can also reduce tillering and affect nutrient absorption by the plant, even if the nutrient is available in adequate quantities in the soil. As a result, prolonged water deficit reduces grass productivity [2].

One strategy to reduce the effects of prolonged water deficit in the soil is to use products based on synthetic polymers, derived from petroleum, in solid powder form, which are water absorbers, being previously hydrated and then incorporated into the soil. In this case they are known as hydrogels. But in some situations this synthetic powder is incorporated directly into the soil, in which case it is called planting gel. When water is available, these commercial synthetic polymers can absorb more than 400 times their weight in water, releasing it slowly and gradually as the soil's humidity decreases [3].

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The hypothesis being tested is that the use of a natural hydrogel based on cashew gum (*Anacardium occidentale*) in the pasture will result in a chemical composition, morphogenic characteristics and productivity of the Mombaça grass that is similar to or better than the synthetic commercial hydrogel. The objective of this study is therefore to determine the chemical composition, mineral composition, morphogenic characteristics and productivity of Mombaça grass subjected to different hydration managements with hydrogels in pasture, as well as to evaluate the possibility of replacing the synthetic commercial hydrogel by a biodegradable hydrogel.

2. Material and Methods

2.1. Experimental location

The trial was conducted in the Federal University of Piauí (UFPI), at the Cinobelina Elvas campus (CPCE), in Bom Jesus, Piauí, Brazil, at geographical coordinates 09°04’28” South latitude, 44°21’31” West longitude and average altitude of 277 m. The experiment lasted from July 2021 to July 2022, when it was recorded average precipitation and temperature values of 700mm and 38°C, respectively.

The climate is classified as Aw (Tropical hot and humid, with dry seasons from spring to summer and rainy seasons from fall to winter) according to the Köppen classification. The region’s vegetation is the Cerrado, which is equivalent to the Brazilian savannah [5].

2.2. Experimental treatments

The treatments consisted of three ways of hydrating the Mombaça grass pasture: No Hydrogel (NH), where no hydrogel was added; hydration of the pasture soil with biodegradable Test Hydrogel (TH) based on Cashew gum; and hydration with synthetic Commercial Hydrogel (CH), based on polyacrylamide. TH and CH were applied at a level of 20 kg ha^{-1} to the Mombaça grass pasture. A randomized block design was adopted with five replications and three treatments.

2.3. Hydrogels used

The biodegradable TH obtained from cashew gum was produced through the copolymerization process and added nutrients. Each gram of TH contained 0.5% K_3PO_4, 67% K and 33% P. TH had a swelling capacity of 1100 g of H_2O g^{-1} of hydrogel, thermal stability at 439 °C and was non-toxic. TH was produced at UFPI, in the Materials Science Laboratory.

The CH used was a copolymer of acrylamide and potassium acrylate branded Hydroplan-EB (SAP)®, a commercial product. Both hydrogels were applied to the soil for planting and previously hydrated with 400 liters for each kg of hydrogel, following the manufacturer’s recommendations.

2.4. Experimental Units

The soil was classified as dystrophic red-yellow latosol associated with quartz sands [6], with a sandy loam physical characterization (clay: 220; silt: 50 and sand: 720 g kg^{-1}).

After sampling, the soil was dried and sieved through a 2-mm diameter metal mesh to remove impurities and a sample of this soil was taken for physical-chemical analysis following the methodology for determination of the soil chemical characteristics [7], which revealed the following results: 5.2 pH in water; 8.37 mg dm^{-3} phosphorus (P); 0.05 mg dm^{-3} potassium (K); 1.20 cmolc dm^{-3} calcium (Ca); 0.08 cmolc dm^{-3} magnesium (Mg); <0.50 cmolc dm^{-3} aluminum (Al); 2.30 cmolc dm^{-3} hydrogen + aluminum (H + Al); 1.33 cmolc dm^{-3} sum of bases (SB); 3.63 cmolc dm^{-3} CEC at pH 7.0 (T); 36.6% base saturation (V); and 27.3% aluminum saturation (M).

Correction fertilization was conducted in accordance with the recommendations for pasture planting made by [8]. Therefore, as the TH has 67% K and 33% P in its composition, a standardization fertilization was performed by applying the equivalent of these minerals in the NH and CH treatments.

To correct the potassium levels, potassium chloride (60% K_2O) was used as the potassium source, applying the equivalent of 40 kg ha^{-1} of K_2O. Single superphosphate (18% P_2O_5) was used as the phosphorus source, applying the equivalent of 90 kg P_2O_5 ha^{-1}. In addition, the equivalent of 100 kg of nitrogen ha^{-1} was applied in the form of urea (45% N). The fertilizers were diluted in water and applied separately to the pasture.

The evaluation period lasted for 60 days in a Mombaça grass pasture that had been established for five years, with two cycles of 30 days each to assess growth. At first, the pasture was cut to uniformity, with a residual height of 15 cm, removing the material from the experimental plots. Subsequently, CH and TH were applied in linear meters at the base of the clumps at a level of 20 kg ha^{-1}.

2.5. Evaluation of the morphogenic and production characteristics of the grasses

Assessments of morphogenic characteristics were conducted according to [9], using millimeter rulers, every three days, during the two harvest cycles, with 30 days in each cycle and an experimental period of 60 days. To assess morphogenesis, three tillers were drawn and marked with smooth plastic-coated wire of different colors. The number of leaves, leaf blade length, stem length, and leaf stage classification (expanding, expanded, senescent and dead) were monitored on each tiller. With this information, the following parameters were calculated: leaf appearance rate (LAR, leaves tiller^{-1} day^{-1}), by the number of leaves emerging per tiller divided by the number of days in the evaluation period; phylochron (PHY, days leaf^{-1} tiller^{-1}), which is the inverse of the leaf appearance rate; leaf elongation rate (LER, cm leaf^{-1} day^{-1}), by the sum of leaf blade elongation per tiller divided by the number of days of evaluation; stem elongation rate (SER, cm tiller^{-1} day^{-1}), by the sum of stem elongation per tiller divided by the number of days of evaluation; number of live expanded leaves per tiller (NLLe), which is the average number of fully expanded leaves per tiller, including sheared leaves; leaf lifespan (LLS, days), which is estimated by the equation LLS (day) = NLLe x PHY [9]; leaf senescence rate (LSR, cm tiller^{-1} day^{-1}), by the decrease in the length of the green part of the leaf blade, which is obtained from the difference between the initial and final measurements divided by the number of days of evaluation; final leaf length (FLL, cm), which is the average length of the live, fully expanded and uncut leaves in the tiller; and final stem length (FSL, cm), which is the average length of the stems.

The appearance rate was evaluated by counting the number of leaves that emerged per tiller, divided by the number of evaluation days (tiller leaves^{-1} day^{-1}); the elongation rate was obtained by adding up all the leaf elongation per tiller, divided by the number of days in the evaluation period (tiller mm^{-1} day^{-1}); leaf lifespan was obtained by counting the average number of elongating leaves per tiller; phylochron was obtained by the inverse of the rate of appearance of leaves (days); and the number of leaves per tiller was determined by counting the number of live leaves on three tillers in the pasture.

The production characteristics were assessed at the end of each cycle, as follows: plant height, which is measured from the ground to the last expanded leaf of the tallest tiller; and tiller population density (TPD), by counting the number of live tillers present in each clump. After the evaluations, the Mombaça grass was cut at a residual height of 15 cm. Green forage samples were taken to the laboratory and weighed on an electronic scale with precision of 1g.

Green mass samples were then separated into leaf blades, stems + sheaths and dead material (DM), then were weighed to obtain the leaf green mass yield (LGMY), then placed in identified paper bags and taken to an oven with forced air ventilation for 72 hours at 55°C, until reaching constant weight, in order to obtain the leaf dry mass yield (LDMY), which was converted to kg ha^{-1}.

2.6. Analysis of the chemical and mineral composition of the grasses

After pre-drying, samples of the forage dry biomass from each treatment were ground in a stationary "Thomas Wiley" knife mill with a 1.0 mm mesh screen for laboratory chemical analysis. The following chemical composition analyses were carried out according to [10]: determination of dry matter (DM) at 105°C (INCT-CA Method G-003/1), crude protein (CP) (INCT-CA Method N-

001/1), mineral matter (MM) (INCT-CA Method M-001/1), neutral detergent fiber (NDF) (INCT-CA Method F-002/1), acid detergent fiber (ADF) and organic matter (OM). All analyses were conducted at the Animal Nutrition Laboratory of UFPI in Bom Jesus/CPCE.

Macro and micronutrient analyses were conducted at the Soil and Plant Analysis Laboratory of UFPI/Cinobelina Elvas Campus. The following mineral contents were determined: phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), expressed in g kg^{-1}; iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu), expressed in mg kg^{-1}. Nitric-perchloric digestion was conducted and after digestion the phosphorus (P) content was determined by UV/VIS spectrophotometry at 660nm, by reading the intensity of the blue color of the phosphomolybdic complex produced by the reduction of molybdate with ascorbic acid in a Digital Light -UV-Visible spectrophotometer model IL-592 EVEN. The levels of potassium (K), calcium (Ca), magnesium (Mg) and zinc (Zn) were determined using atomic absorption spectrophotometry (AAS), model AA240FS VA-RIAN®. The methodology used to analyze the plant nutrients followed the standards described in [11].

2.7. Statistical analysis

The data were analyzed for analysis of variance of the main effects and the harvest cycles × hydrogel interaction. When the effect of interaction was significant, the factors were split using the Scott-Knott test to compare the means, considering a 5% significance level ($P \leq 0.05$). The statistical analyses were conducted using the SISVAR software version 5.0 [12].

3. Results

3.1. Morphogenesis

No effect of treatment ($P>0.05$) was found on SER, LSR, NLLe, LAR and PHY (Table 1). On the other hand, LAR was higher ($P<0.05$) in the Mombaça grass hydrated with TH (42.33 mm day^{-1}), differing from the NH treatment (30.53 mm day^{-1}).

Table 1. Morphogenic characteristics of Mombaça grass pasture under three forms of hydration.

Variables	Hydrogel (H)			Mean	*P-value*	SEM
	No	Commercial	Test			
LER (mm $tiller^{-1}$ day^{-1})	30.53b	35.00ab	42.33a	35.95	0.03	2.67
SER (mm $tiller^{-1}$ day^{-1})	0.26a	0.35a	0.60a	0.40	0.11	0.10
LSR (mm $tiller^{-1}$ day^{-1})	0.95a	1.01a	1.36a	3.36	0.36	4.22
NLLe (leaves $tiller^{-1}$)	8.27a	8.53a	9.33a	8.71	0.87	1.47
LAR (leaves $tiller^{-1}$ day^{-1})	0.257a	0.360a	0.495a	0.371	0.53	0.144
PHY (days $leaves^{-1}$ $tiller^{-1}$)	2.86a	4.55a	4.97a	4.13	0.51	1.32

LER: Leaf Elongation Rate; SER: Stem Elongation Rate; LSR: Leaf Senescence Rate; NLLe: Number of Expanded Live Leaves; LAR: Leaf Appearance Rate; PHY: Phylochron; Different lowercase letters in the row represent significance of $P<0.05$ for the use of Hydrogel (H). SEM: Standard Error of the Mean.

For the variables SER, LAR and PHY, the results were 0.60 mm $tiller^{-1}$ day^{-1}, 0.495 leaves $tiller^{-1}$ day^{-1} and 4.97 days $leaves^{-1}$ $tiller^{-1}$, respectively in treatment TH, while in treatment NH they were

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0.26 mm tiller^{-1} day^{-1}, 0.257 leaves tiller^{-1} day^{-1} and 2.86 days leaves^{-1} tiller^{-1}. LSR and NLLe showed averages of 3.36 mm tiller^{-1} day^{-1} and 8.71 leaves tiller^{-1}.

3.2. Structure and production characteristics

There was no significant difference between the heights of Mombaça grass, which ranged from 59 to 64.8 cm. On the other hand, there was isolated effect (P< 0.05) between hydration forms and harvesting cycles on LGMY. There was also effect of interaction (P< 0.05) between the forms of hydration and harvesting cycles on LDMY. It was found isolated effect between the forms of hydration on TPD, with a difference in the superiority of the test hydrogel when compared to the management without hydrogel, Table 2.

Table 2. Structural and production characteristics of Mombaça grass pasture under three forms of hydration.

Hydrogel	Cycles		Mean	SEM	*P - Value*		
	Cycle 1	Cycle 2			H	C	H×C
Plant Height (cm)							
No	64.8	64.2	64.5	1.32	0.23	0.62	0.29
Commercial	64.6	59.0	61.8				
Test	62.2	63.8	63.0				
Mean	63.8	62.3					
Leaf Green Mass Yield (kg ha^{-1})							
No	7,000.0	4,936.0	5,968.0B	232.17	<0.01	<0.01	0.84
Commercial	7,448.0	5,296.0	6,372.0B				
Test	8,664.0	6,161.0	7,412.0A				
Mean	7,704.0a	5,464.0b					
Leaf Dry Mass Yield (kg ha^{-1})							
No	2,617.4Ca	1,678.8Ab	2,338.9	81.55	0.16	<0.01	<0.01
Commercial	3,694.5Ba	1,966.5Ab	2,830.5				
Test	4,477.0Aa	2,060.4Ab	3,077.9				
Mean	3,596.3	1,901.9					
Tiller Population Density (TPD, tiller m^{-2})							
No	177.0	188.2	182.6b	9.76	<0.01	0.09	0.44
Commercial	169.6	219.4	194.5ab				
Test	231.0	243.4	237.3a				
Mean	192.6a	217.0a					

Different lowercase letters in the row represent significance of P<0.05 for the use of Hydrogel (H). Different uppercase letters in the column represent significance of P<0.05 for the Harvesting Cycle (C). SEM: Standard Error of the Mean.

3.3. Chemical and mineral composition

The use of hydrogels did not affect the chemical composition of Mombaça grass. The average DM content was 308.6 g kg^{-1}, CP was 71.8 g kg^{-1} DM, NDF was 707.6 g kg^{-1} DM, ADF showed 347.9 g kg^{-1} DM and MM showed 43.3 g kg^{-1} DM, Table 3.

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Table 3. Chemical composition of Mombaça grass pasture under three forms of hydration.

Variables	Hydrogel (H)			Mean	SEM	*P–Value*
	No	Commercial	Test			
DM (g kg)	310.6a	307.1a	308.1a	308.6	1.53	0.98
CP (g kg^{-1} DM)	69.5a	73.8a	72.3a	71.8	0.35	0.68
NDF (g kg^{-1} DM)	713.6a	691.5a	717.9a	707.6	0.83	0.11
ADF (g kg^{-1} DM)	349.3a	341.2a	353.4a	347.9	0.57	0.36
MM (g kg^{-1} DM)	42.2a	41.9a	46.0a	43.3	0.44	0.77

DM: Dry Matter; CP: Crude Protein; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; MM: Mineral Matter. SEM: Standard Error of the Mean. Different lowercase letters in the row represent significance of P<0.05 for the use of hydrogel (H).

In the evaluation of the mineral composition of the Mombaça grass under different hydration forms, there was effect (P<0.05) only on Zn, with an accumulation of 28.0 mg kg^{-1} for the hydration with TH. The macronutrients Mg, P and K showed averages of 4.5 g kg^{-1}, 4.0 g kg^{-1} and 331.0 g kg^{-1} respectively, while Cu showed 8.1 mg kg^{-1}, Mn 124.6 mg kg^{-1}, Fe 78.6 mg kg^{-1} and Zn 13.6 mg kg^{-1}, Table 4.

Table 4. Mineral composition of Mombaça grass pasture under three forms of hydration.

Variables	Hydrogel (H)			Mean	SEM	*P-Value*
	No	Commercial	Test			
Ca (mg kg^{-1})	42.6a	35.7a	35.2a	37.8	0.31	0.24
Mg (mg kg^{-1})	5.0a	4.5a	4.1a	4.5	0.07	0.72
P (mg kg^{-1})	3.5a	3.8a	4.7a	4.0	0.05	0.35
K (mg kg^{-1})	365.2a	334.0a	294.0a	331.0	4.07	0.49
Cu (mg kg^{-1})	1.1a	1.4a	17.0a	8.1	0.03	0.48
Mn (mg kg^{-1})	35.9a	34.1a	304.0a	124.6	0.59	0.80
Fe (mg kg^{-1})	19.3a	23.5a	193.0a	78.6	0.37	0.72
Zn (mg kg^{-1})	4.6b	8.3b	28.0a	13.6	0.11	0.02

Ca: Calcium; Mg: Magnesium; P: Phosphorus; K: Potassium; Cu: Copper; Mn: Manganese; Fe: Iron; Zn: Zinc. SEM: Standard Error of the Mean. Different lowercase letters in the row represent significance of P<0.05 for the use of hydrogel (H).

4. Discussion

4.1. Morphogenesis

The results from the pasture under different forms of hydration only showed effect on LER with the use of TH, which showed 42.33 mm leaf^{-1} day^{-1}, being superior to the NH management, but was statistically similar to the CH treatment, which is a synthetic product with the capacity to absorb 400 times its weight [13,14]. Therefore, this result shows that CH can be safely replaced by TH, as it is an organic and 100% biodegradable product with high water retention capacity [15]. In addition, CH was similar to NH management and did not influence any of the morphogenic variables evaluated.

However, there were no differences between hydration forms used in the Mombaça grass pasture for SER, LSR, NLLe and PHY, although these variables showed higher average values in the TH treatment. It can therefore be seen that TH favors the appearance and expansion of new leaves and may influence the other variables over the course of the harvest cycles, as the main characteristic of hydrogel is that it releases water gradually [16,17]. This can be seen in the LAR and NLLe values, which practically doubled in comparison to the NH management.

4.2. Structure and production characteristics

It was observed that hydration with TH and CH had different effects on LGMY. TH is favorable to the production of Mombaça grass and was superior to NH for the same variable. When comparing the harvest cycles, it can be seen that the second cycle had lower LGMY. This was because the water in the hydrogel was released in greater quantities in the first 30 days (the first cycle) [15], enhancing leaf elongation and the growth of the Mombasa grass. Therefore, more water available in the pasture led to greater LGMY, a fact that was observed in the morphogenic characteristics, in which LER performed better and is directly related to leaf growth and production.

It was found effect of interaction between cycles and forms of hydration on LDMY in the first harvesting cycle, which means that the first cycle had higher LDMY than cycle two. However, Mombaça grass had higher LDMY when using TH in both the first and second cycles. LDMY was lower when the hydrogels were not used.

TPD was higher in the TH treatment in comparison to NH. This suggests that the continued use of hydrogels will result in a stable LGMY, since the more tillers appear, the greater the production of the grass [18]. Also, a greater number of harvesting cycles is needed to stabilize TPD in the pasture under the effect of CH and TH, showing different responses to TPD between these hydrogels, as it is a very unstable variable.

4.3. Chemical and mineral composition

The lack of effect in the chemical composition analysis between the forms of hydration used in the Mombaça grass pasture shows that the hydrogels do not interfere with its composition, although changes may occur in the case of evaluations with other forage grasses. Although statistically the values between treatments were similar, there was an improvement in the levels of CP, NDF, ADF and MM with the use of TH. The NDF values are considered to be within the expected range for this forage species subjected to a 30-day rest period and a residual harvesting height of 15 cm [18,19]. For the other variables, the increase under the effect of TH is positive for the species.

While the micronutrients evaluated showed a relative increase in their levels, this may have been due to the fact that they are easy to mobilize through mass flow, in the direction of the water released by the hydrogel [20,21]. The micronutrient Zn was the only chemical element that showed a significant effect of the three forms of hydration. The Zn content observed was 28 mg kg^{-1} in the TH treatment, despite this micronutrient showing antagonistic absorption to phosphorus [22,23]. In addition, critical toxic levels of Zn in grasses occur when there is more than 110 mg Zn kg^{-1} of soil [24]. The results for the macronutrients Ca, Mg and K showed a decrease in content with the use of TH. For the concentration of Ca in Poaceae species, the maximum value found was 4.8 g kg^{-1} which corresponds to 0.48% in the *Eleusine indicae* species and a minimum of 0.6 g kg^{-1} equivalent to 0.06%

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in the *Aristida longifolia* species [23]. Potassium does not play a structural role in the plant, but it does contribute to its osmotic regulation. Under conditions of deficiency, potassium can move from the maturing organs to those that are growing. In the case of potassium deficiency in plants, the appropriate level for this nutrient is 10.0 to 14.0 g kg^{-1} [22]. As the values vary according to the organ analyzed, the species analyzed in this study have a high concentration of this nutrient according to the results.

The literature reports that phosphorus is one of the macronutrients that is little demanded in pasture for optimal growth of forage plants, and it varies depending on the forage species [8]. P can account for between 0.1 and 0.5% of dry matter, and the appropriate levels of this nutrient in Mombaça grass are between 1.0 and 2.3 g kg^{-1}, and the P content observed in this study is within these limits. [22] establish values of 0.11 to 0.30 g kg^{-1}. Low phosphorus concentrations in the cell cytoplasm reduces the activity of cytoplasmic proteins and minimize forage plant growth. When growth is paralyzed, the older leaves of the plants are deficient in phosphorus and at first show a dark green and bluish staining, caused by the higher relative concentration of chlorophyll, and purple tones can occur in the leaves and stem [22,23].

5. Conclusions

Cashew gum hydrogel shows potential for use in Mombaça grass pastures. It has advantages over conventional hydrogels and increases the rate of leaf elongation, green leaf production and stimulates tillering.

The biodegradable hydrogel made from cashew gum can replace synthetic commercial hydrogels in Mombaça grass pastures.

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