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Use of Hydrogel and Carnauba Bagasse Coverage in Water Management of Corn in the Semiarid Region

Uso de Hidrogel e Cobertura com Bagana de Carnaúba no Manejo Hídrico do Milho no Semiárido

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Abstract
Water deficits can harm corn grain productivity. The use of water-retaining polymer aims to increase the efficiency of water use and reduce the impacts of water restrictions. Covering the soil with carnauba bagana maintains water and reduces soil temperature. The objective was to evaluate the influence of using hydrogel and carnauba bagana as soil cover on alleviating water deficit and on the growth and production of corn in the semi-arid region of Piauí. The design used was in randomized blocks, in a factorial scheme (4x2) formed by the combination of four doses of hydrogel (0; 50; 100 and 200% of the recommended dose) and the presence or absence of carnauba bagana, with four replications. The variables evaluated were plant height, stem diameter, dry mass of the aerial part,

number of ears per plant, number of grains per ear, number of rows per ear, number of grains per row, average ear length, average diameter of the ear and cob, productivity, temperature and humidity. The dose of 30 kg ha^{-1} of hydrogel provided higher values in the number of ears per plant and humidity. The carnauba bagana provided improvements in the number of grains per ear, average ear diameter, productivity, temperature and humidity. The dose of 30 kg ha^{-1} (0.27 g pot^{-1}) of hydrogel, which corresponds to 200% of the dose recommended by the manufacturer, is recommended under the study conditions. Carnauba bagana can be a viable alternative for producers in the region.

Keywords: Plant Cover. Water-Retaining Polymer. Soil Moisture. *Zea mays* L.

Resumo

O déficit hídrico pode trazer prejuízos à produtividade de grãos de milho. O uso do polímero hidroretentor visa aumentar a eficiência do uso da água e diminuir os impactos da restrição hídrica. A cobertura do solo com bagana de carnaúba proporciona a manutenção da água e diminuição de temperatura no solo. Objetivou-se avaliar a influência do uso de hidrogel e bagana de carnaúba como cobertura de solo na atenuação do déficit hídrico e no crescimento e produção de milho no semiárido piauiense. O delineamento utilizado foi em blocos casualizados, em esquema fatorial (4x2) formado pela combinação de quatro doses de hidrogel (0; 50; 100 e 200% da dose recomendada) e presença ou ausência da bagana de carnaúba, com quatro repetições. As variáveis avaliadas foram: altura de planta, diâmetro do caule, massa seca da parte aérea, número de espiga por planta, número de grãos por espiga, número de fileiras por espiga, número de grãos por fileira, comprimento médio da espiga, diâmetro médio da espiga e do sabugo, produtividade, temperatura e umidade. A dose de 30 kg ha^{-1} de hidrogel proporcionou maiores valores no número de espiga por planta e umidade. A bagana de carnaúba proporcionou melhorias no número de grãos por espiga, diâmetro médio da espiga, produtividade, temperatura e umidade. A dose de 30 kg ha^{-1} (0,27 g $vaso^{-1}$) de hidrogel, correspondente a 200% da dose recomendada pelo fabricante é a recomendada nas condições de estudo. A bagana de carnaúba pode ser uma alternativa viável para os produtores da região.

Palavras-chave: Cobertura Vegetal. Polímero Hidroretentor. Umidade do Solo. *Zea mays* L.

1 Introduction

Maize (*Zea mays* L.), a member of the Poaceae family, is an annual plant of great global agricultural importance (Silva *et al.*, 2020b). In Brazil, it stands out due to its high yield potential and wide use in both human and animal nutrition, as well as serving as a raw material for industry (Torres *et al.*, 2020). Furthermore, it adapts to different environments, allowing it to be cultivated throughout the country (Silva *et al.*, 2021a).

In the 2022/2023 season, maize production was estimated at 125.8 million tons, representing an 11.2% increase compared to the previous season (CONAB, 2022). The Northeast region achieved favorable results in maize production during the 2021/2022 season, reaching around 11 thousand tons, a 25% increase compared to the preceding season. States such as Maranhão, Piauí, and Bahia represent the Northeast in national maize production, ranking among the ten largest maize-producing states in Brazil (CONAB, 2022).

Water availability is one of the most crucial factors for the successful completion of a plant's life cycle, while also being the most limiting factor for plant development (Araújo Junior *et al*., 2019), particularly for maize, which has a significant water demand (Cavalcante Junior *et al*., 2018; Silva *et al*., 2021b). Water deficit, caused by low water availability, can lead to considerable losses, especially by reducing grain and biomass yield (Guimarães; Rocha; Paterniani, 2019).

In this context, water-retaining polymers or hydrogels have emerged as products with great agricultural potential, aiming to increase water and nutrient use efficiency and mitigate the effects of water stress (Kraisig *et al*., 2018; Carvalho *et al*., 2022; Rodrigues *et al*., 2023). Hydrogels function as soil conditioners, retaining moisture and gradually releasing it to plants, in addition to reducing root dehydration, which allows crops to develop even under water deficit conditions (Mendonça; Querido; Sousa, 2015; Silva; Fischer Filho; Fuzzo, 2021). This becomes even more relevant in semi-arid regions, characterized by scarce and irregular rainfall (Marengo; Torres; Alves, 2016).

Mamann *et al*. (2017) observed the positive effect of hydrogel on nutrient uptake and on the production of grains and biomass in wheat crops. This indicates that the polymer has beneficial effects on grasses, suggesting a strong potential for its application in maize cultivation in semi-arid regions.

Carnauba straw, a byproduct of carnauba palm leaves, is a promising alternative as mulch in the northeastern semi-arid region. When used as mulch, carnauba straw plays a fundamental role, bringing benefits such as improved soil conservation, increased nutrient availability, enhanced water retention, and reduced soil temperature (Nascimento *et al*., 2021; Silva *et al*., 2020a).

Moreover, the use of this residue as soil cover is justified by its easy availability in the region and by the characteristics of the semi-arid climate in Piauí, where water deficit is a common occurrence. It also offers environmental benefits, as it is often discarded in nature when not used by farmers, leading to environmental damage (Santos *et al*., 2023).

Given the above, this study aimed to evaluate the effects of hydrogel and carnauba straw mulch on the growth and productivity of maize under water deficit conditions in the semi-arid region of Piaui, Brazil.

2 Material and Methods

The experiment was conducted from July to November 2024 at the Pinhões property, located in São João da Varjota, Piauí, Brazil (6°55'15"S, 41°51'28"W, altitude 303 m). According to the Köppen climate classification, the region has a BSh-type climate, characterized as hot semi-arid within the Caatinga biome, with low and irregular rainfall. Annual precipitation averages approximately 600 to 700 mm (Alvares *et al*., 2014).

A randomized block design was used, arranged in a 4 × 2 factorial scheme, consisting of the combination of four hydrogel doses (0, 50, 100, and 200% of the recommended dose) and the presence or absence of carnauba straw mulch, with four replicates, totaling 32 experimental plots. Each experimental unit consisted of an 18-liter pot. The ideal dose (100%) was based on the manufacturer's recommendation (15 kg ha^{-1}). Subsequently, calculations were performed to determine the amount to be applied per pot, which corresponded to 0, 0.0675, 0.135, and 0.27 g pot^{-1}, equivalent to field doses of 0, 7.5, 15, and 30 kg ha^{-1}, respectively. The hydrogel was incorporated into the soil at the time of sowing.

Before setting up the experiment, a composite soil sample was collected from the 0–20 cm layer. After sampling, the soil was sent to the laboratory for chemical and particle size analysis, following the procedures described by Teixeira *et al.* (2017). The characteristics of the soil used are presented in Table 1.

Table 1 - Chemical and particle size characterization of the soil

pH	**P**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Al^{3+}**	**H+Al**	**SB**	**T**	**m**	**V**	**O.M.**
H_2O	mg dm^{-3}	-------------------------$cmol_c dm^{-3}$---------------------							----------%------------		
6.71	96.2	5.65	1.42	0.38	0.0	1.68	7.45	9.14	0.0	81.6	1.83

Hydrogen potential (pH), Phosphorus (P), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Exchangeable Aluminum (Al^{3+}), Potential Acidity (H^++Al), Sum of Bases (SB), Cation Exchange Capacity (T), Aluminum Saturation (m), Base Saturation (V), and Organic Matter (OM).
Sand: 79.9%; Silt: 8.2%; Clay: 11.9%.
Source: Research data.

According to the soil analysis results, there was no need for acidity correction with lime, since the pH was high and the base saturation exceeded 60% (Table 1). Fertilization followed the recommendation proposed by Cavalcanti *et al.* (2008), with applications of 30 kg ha^{-1} of N, 20 kg ha^{-1} of P_2O_5, and 20 kg ha^{-1} of K_2O, which were incorporated into the soil. Due to the sandy texture of the soil, the nitrogen applied as topdressing was split into two applications: the same amount used at planting was reapplied at the V4 growth stage and again at V8. The sources of nitrogen, phosphorus, and potassium were urea (45% N), single superphosphate (18% P_2O_5), and potassium chloride (60% K_2O), respectively. These values were converted to the appropriate amounts for 18-liter pots, resulting in applications of 0.6 g of urea, 1.0 g of single superphosphate, and 0.3 g of potassium chloride per pot.

The carnauba straw was obtained from an ornamental plant store in the city of Picos-PI, and the seed used was the hybrid AG1051 by BAYER. Sowing was carried out at a density of three seeds per pot. Immediately afterward, for the treatments receiving carnauba straw, the soil surface was covered with a 2 cm thick layer of this residue, corresponding to approximately 288 g per pot (Rezende; Silva; Lino, 2024).

Irrigation began during this period and was carried out manually once a day, applying 900 mL of water per pot, equivalent to 70% of the field capacity. Throughout the experiment, any emerging weeds were removed manually. Seven days after emergence, thinning was performed, leaving only one plant per pot.

At the flowering stage, irrigation was suspended for five days to induce water stress, since according to Magalhães and Durães (2006), water deficits of four to eight days during the flowering stage in maize can cause productivity losses of over 50%, making this the most sensitive stage to water restriction.

At 105 days after germination, the following variables were evaluated: plant height (PH, cm), stem diameter (SD, mm), shoot dry matter (SDM, g pot^{-1}), number of ears per plant (NEP), number of grains per ear (NGE), number of rows per ear (NRE), number of grains per row (NGR), average ear length (AEL, cm), average ear diameter (AED, cm), average cob diameter (ACD, cm), yield (Y, kg ha^{-1}), soil temperature (T, ºC), and soil moisture (M).

pH was measured in centimeters using a tape measure, from the soil surface to the base of the first ear. SD was measured with a digital caliper, 2 cm above the soil. T for each pot was measured with a "TP 101" portable spike-type thermometer, with a scale from -50 to 300 ºC and accuracy of 0.1 ºC. The electrode was inserted into the soil at three different points per pot, and the average was calculated. M was measured with a portable moisture meter ("Terra Solo" brand), with a dimensionless scale ranging from 0 to 10, where values closer to 0 indicate drier soil and values closer to 10 indicate moister soil. The two prongs were inserted into the soil at three different points per pot, and the average was calculated.

Each plant was then cut at the soil level and placed into paper bags. The samples were then placed in a forced-air oven at 65 ºC for 72 hours to determine SDM. NEP, NGE, NRE, and NGR were determined by direct counting. AEL and AED were measured using a digital caliper, with AED measured at the midpoint of each ear. Y was determined by threshing the ears, weighing the grains, and drying them in a forced-air oven at 105 ºC for 24 hours to adjust the moisture content to 13%. After this adjustment, the grains were weighed again to calculate yield.

The obtained data were subjected to preliminary tests for normality and homoscedasticity. Once the assumptions were met, data were analyzed using analysis of variance (ANOVA) via the F-test ($P<0.05$) to evaluate the individual and interactive effects of hydrogel doses and carnauba straw soil cover. Means for the hydrogel dose factor were compared using polynomial regression, and means for the soil cover factor were compared using Tukey's test at a 5% significance level. The statistical analysis was performed using Sisvar® software, version 5.8 (Ferreira, 2011).

3 Results and Discussion

According to the analysis of variance (ANOVA), there was an individual effect of hydrogel doses on the number of ears per plant (NEP) and soil moisture (U), and an effect of carnauba straw on the number of grains per ear (NGE), average ear diameter (AED), yield (Y), soil temperature (T), and soil moisture (U) (Tables 2 and 3).

Table 2 - Plant height (PH), stem diameter (SD), number of ears per plant (NEP), number of grains per ear (NGE), number of rows per ear (NRE), and number of grains per row (NGR) of corn, in response to hydrogel doses (D) and carnauba straw (B)

Source of Variation (SV)	PH (cm)	SD (mm)	NEP	NGE	NRE	NGR
Hidrogel (H)	0.99^{ns}	0.23^{ns}	0.03^{*}	0.70^{ns}	0.97^{ns}	0.59^{ns}
Straw (B)	0.14^{ns}	0.15^{ns}	0.06^{ns}	0.04^{*}	0.48^{ns}	0.05^{ns}
H x B	0.87^{ns}	0.53^{ns}	0.47^{ns}	0.52^{ns}	0.69^{ns}	0.52^{ns}
Block	0.49	0.05	0.11	0.29	0.72	0.38
CV(%)	9.05	4.37	40.15	89.22	14.49	89.10

*Significant at 5% probability by F test; ns: not significant.CV: Coefficient of variation.
Source: research data.

Table 3 - Average ear length (AEL), average ear diameter (AED), average cob diameter (ACD), shoot dry mass (SDM), corn yield (YLD), and soil temperature (T) and moisture (M), in response to hydrogel doses (H) and carnauba straw (S)

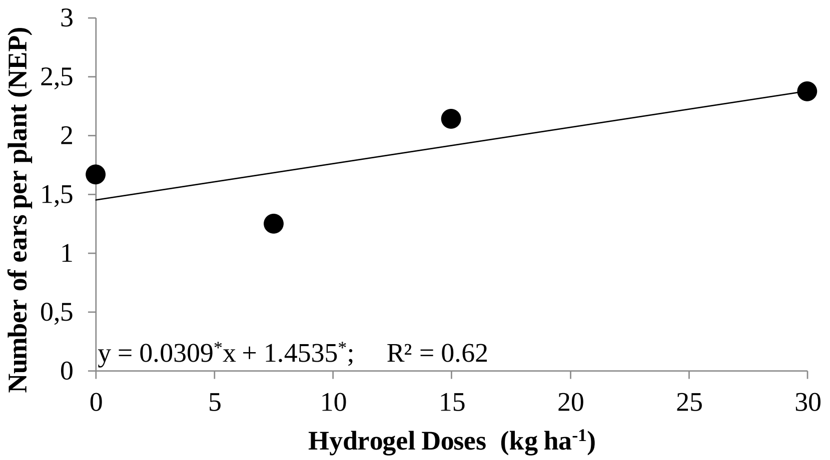
	AEL	AED	ACD	SDM	YLD	T	M
	-------------cm-------------------			-g vaso^{-1}-	kg ha^{-1}	ºC	
Hidrogel (H)	0.83^{ns}	0.36^{ns}	0.31^{ns}	0.75^{ns}	0.43^{ns}	0.96^{ns}	0.04^{*}
Straw (B)	0.74^{ns}	0.02^{*}	0.27^{ns}	0.37^{ns}	0.03^{*}	0.00^{*}	0.00^{*}
H x B	0.48^{ns}	0.41^{ns}	0.81^{ns}	0.20^{ns}	0.61^{ns}	0.96^{ns}	1.00^{ns}
Block	0.56	0.15	0.75	0.25	0.37	0.00	0.55
CV(%)	21.20	17.35	12.03	13.08	63.92	4.27	5.83

*Significant at 5% probability by F test; ns: not significant. CV: Coefficient of variation.
Source : research data.

3.1 Effect of hydrogel

Regarding NEP, the dose of 30 kg ha⁻¹ resulted in the highest value for this variable, reaching 2.38 (Figure 1).

Figure 1 - Number of ears per plant (NEP) of corn as a function of hydrogel doses



Source : research data.

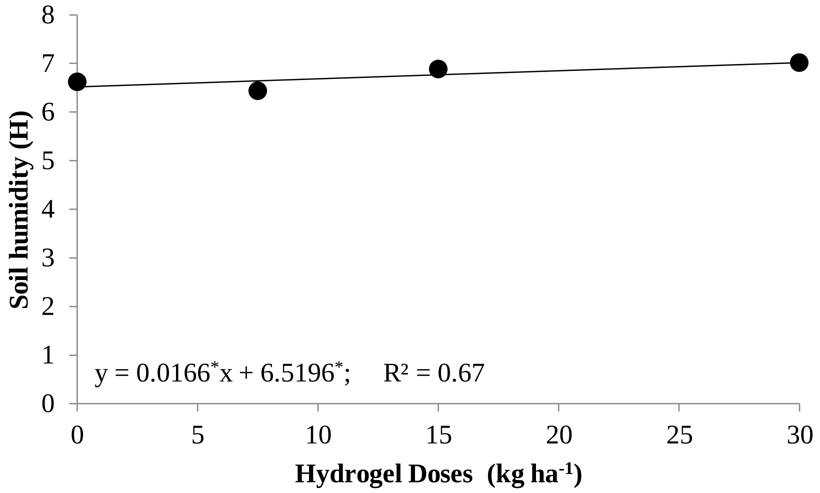
The increase in this variable with the use of hydrogel can be explained by its ability to act as a soil colloid conditioner, reducing nutrient leaching and improving water availability in the soil, thereby facilitating plant absorption, as the water is gradually released (Abobatta, 2018; Navroski *et al*., 2016; Rodrigues; Paiva Sobrinho; Luz, 2024).

Some studies have reported a positive effect of hydrogel application on increasing the number of ears per plant (NEP) in maize (Jamwal; Dawson; Kashyap, 2023; Paradkar; Mahajan, 2022) and wheat (Kumar *et al*., 2019; Mahla; Wanjari, 2017; Tripathi *et al*., 2023). This positive response of NEP to the application of the water-retaining polymer likely results in greater vegetative development of maize.

Nitrogen is a key macronutrient for maize cultivation and is an essential component of chlorophyll. In adequate concentrations, this element enables maize plants to perform their photosynthetic functions, promoting plant growth and productivity (Gojon, 2017; Marques *et al*., 2020).

For the variable soil moisture (U), the 30 kg ha⁻¹ dose provided the highest average, which was 7.01 (Figure 2).

Figure 2 - Soil moisture (U) in maize cultivation as a function of hydrogel doses



Source: research data.

This result can be explained by the fact that hydrogel helps retain water in the environment, reducing water loss through evaporation and favoring the occurrence of metabolic processes in the crop (Prevedello; Loyola, 2007; Rodrigues; Paiva Sobrinho; Luz, 2024). Silva *et al.* (2024) state that the greater the water retention by the hydrogel, the higher the soil moisture values, which directly relates to the higher doses used in this study.

3.2 Effect of carnauba bagasse

According to Table 4, carnauba bagasse resulted in higher average values for number of grains per ear (NGE), average ear diameter (DME), yield (PD), and soil moisture (U), and a lower average value for soil temperature (T).

Table 4 - Mean values of the variables affected by the presence or absence of carnauba bagasse as soil cover

Carnauba Bagasse	**NGE**	**DME (cm)**	**PD** (kg ha^{-1})	**T** (ºC)	**U(%)**
Presence	35.20a	2.95a	1261.35a	32.34b	7.34a
Absence	16.14b	2.49b	555.32b	34.82a	6.10b
CV(%)	89.22	17.35	63.92	4.27	5.83

NGE = Number of grains per ear; DME = Average ear diameter (cm); PD = Yield (kg ha^{-1}); T = Soil temperature (°C);U = Soil moisture (%). Means followed by the same letter in the column do not differ statistically from each other by Tukey's test at 5% probability.
Source: research data.

The use of vegetative cover on the soil surface enhances the performance of agricultural crops (Paço *et al*., 2019). This explains the influence of carnauba bagasse on the number of grains per ear (NGE) compared to its absence. In a study conducted by Oliveira *et al*. (2018), based on the chemical composition of carnauba bagasse, the residue has a high C/N ratio, with a high organic carbon content and nutrients such as potassium, calcium, sulfur, and iron, making it a nutritional source for demanding crops like maize. Moreover, it can retain up to 56.20% of water (Almeida *et al*., 2020).

These NGE values are similar to those found by Araújo, Araújo Filho and Maranhão (2017), who reported that NGE values in treatments with carnauba bagasse were higher than in treatments without it.

Regarding the variable DME (average ear diameter), this increase due to the use of carnauba bagasse is directly related to grain filling (Favarato *et al*., 2016). This effect can be attributed to the greater moisture retention and temperature reduction provided by the vegetative cover, leading to increased production of photoassimilates and nutrient transport for grain filling, resulting in larger ear diameters (Torres *et al*., 2020).

As for yield (PD), the use of carnauba bagasse provided a higher average value compared to the absence of this residue. This likely occurred due to the low availability of water during critical periods of maize development, such as the flowering stage, which is a major factor contributing to low yield (Silva *et al*., 2007).

Since the number of ovules is established around flowering, water deficit during this phase causes significant yield loss due to the reduction in the number of seeds (Embrapa, 2021). However, the presence of carnauba bagasse mitigated this factor, as it provides more water for a longer period (Gonçalves *et al*., 2020).

Similar results were found in the study by Araújo, Araújo Filho, and Maranhão (2017), where the use of carnauba bagasse positively influenced maize yield, with an average of 662.7 kg ha^{-1} when using carnauba bagasse as soil cover, compared to 165.6 kg ha^{-1} without it.

The positive influence of carnauba bagasse on soil temperature (T) can be explained by the cover's ability to reduce thermal amplitude, acting as a thermal insulator (Duarte *et al*., 2014). This indicates that using this residue helps protect the soil from most solar radiation, reducing gas exchange between soil and atmosphere and allowing lower soil temperatures (Sousa *et al*., 2017).

In a study conducted by Nascimento *et al*. (2021), the use of carnauba bagasse on the soil surface in maize cultivation reduced soil temperature by about 5ºC compared to its absence, a result similar to that found in the present study.

The higher soil moisture (U) values associated with the use of carnauba bagasse can be explained by the cover's ability to retain water, protect, and cool the soil, ensuring more stable moisture levels (Almeida *et al*., 2020).

Findings by Nascimento *et al*. (2021) support the present study, as they observed that treatments using carnauba bagasse in maize cultivation had higher soil moisture than treatments without cover, which showed moisture reduction, likely due to the lack of soil protection from solar radiation.

These results support the use of carnauba bagasse as a mulch for maize development in the semi-arid region of Piaui. Gonçalves *et al*. (2020) state that carnauba bagasse, abundant in the northeastern semi-arid region - a place of irregular rainfall and high temperatures - is highly important for local agriculture due to its efficiency in water use.

Indeed, the individual or combined use of hydrogel and carnauba bagasse has positive effects on maize cultivation under water deficit conditions, offering a viable alternative for water management in this crop in semi-arid regions.

4 Conclusion

The application of 30 kg ha^{-1} of hydrogel (0.27 g per pot), equivalent to 200% of the manufacturer's recommended dose, provides the best results for soil moisture and the number of ears per plant.

The application of carnauba bagasse increases maize yield under water deficit conditions, indicating its potential as a management strategy for farmers in the region.

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