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HYDROGEL ASSOCIATED WITH SOIL IN A SEMI-ARID ENVIRONMENT

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Abstract
The hydrogel is becoming more and more indicated for agricultural use, as they have the potential to increase the water storage capacity in the soil and, consequently, reduce the amount and frequency of irrigation. However, these advantages can be lost when using specific types of fertilizer or short watering shifts. Given this, the objective was to evaluate the real efficiency of the hydrogel when submitted to different fertilizer and irrigation shifts, in the cultivation of sweetsop trees. For this purpose, a Randomized Complete Block Design (RCBD) with a 3x3x2 factorial scheme was used, corresponding to three fertilizer solutions: A1 – urea + elemental sulfur + phosphoric acid, A2 – ammonium sulfate + phosphoric acid, and A3 – only water; three irrigation shifts: 1, 3 and 6 days; and two doses of hydrogel: 0.0g (control) and 5g per plant. The relative and absolute growth rates were calculated weekly from the height and diameter data of the sweetsop trees. 77 days after the transplantation some data were collected, namely: fresh leaf mass – FLM, dry leaf mass – DLM, fresh stem mass – FSM, dry stem mass – DSM, specific leaf area – SLA and total leaf area – TLA. The conclusion of this research is that there are no beneficial effects of adding hydrogel to the soil when it is added with mineral fertilizer, regardless of the irrigation shift. Besides considering variables such as soil density and the mode of application, research must consider the application of the hydrogel under conditions similar to those presented in this study to be unfeasible.

Keywords: Hydrogel Viability; Water-saving, Perennial Crops; Hydride Retaining Polymers

Introduction

Some limitations are imposed on the plant growth by the soil due to different reasons, among which are the nutrient surplus or the lack of it; low level of oxygenation and hydric restriction [1-3].

The hydric shortfall in the Brazilian semiarid northeastern region is one of the main limiting factors to agricultural production, which is principally caused by two aspects: the semiarid climate with its high temperature and reduced level of rain for long periods [4], and problems with the availability of water for agricultural practices.

To have an idea [5] claim that the low level of rain between 2009 and 2017 caused 155 dams, which are monitored by governmental agencies, to be little recharged. At the end of 2017, those dams were storing only 7,28% of their total capacity impacting negatively on the state's agricultural production.

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In this context, the farmers' principal strategy to ensure the success of their agricultural production despite a long time with no rain is the irrigation. As a consequence, this strategy places agriculture on the top of the rank of activities that use water the most in Ceará [5], surpassing even the service of human and industrial supply.

However, this worldwide trend has fostered the development of technology including the production of the hydrogel, also known as water-retaining polymer, for agricultural uses. Such polymers are crosslinked chains consisting of different materials, among which are the acrylate and acrylamide [6, 7]. They create a gel in the soil capable of increasing the soil capacity to store and release water for plants for long periods and, consequently, it reduces the amount of water, the irrigation frequency and the water stress in crops [8-10].

Despite the great potential of the acrylamide hydrogel, which is the most affordable for agricultural purposes, research point out a reduction of its efficiency when they are added to the soil with specific kinds of mineral fertilizer. Bowman *et al.* [11] for instance, found negative effects in the hydrogel absorption capacity when it is added with a sulfate solution. On the other hand, the same result was not true when the urea nitrogenous fertilizer had been used. Monovalent ion seems to reduce the water absorption by hydrogel by 75% whereas bivalent or trivalent ion reduces that by 90% [12].

However, there are controversies about the efficiency of the hydrogel when it is added with fertilizer and watering shifts, mainly, in sweetsop trees (*Annona Squamosa* L.), which is a fruit that develops well in the Brazilian northeastern conditions and has a great acceptance in reason of its tasteful flavor and the possibility to be consumed whether *in natura*, industrialized or as an exported product [13]

The raised issues are meaningful since that for an efficient and economically feasible productive handling is essential not only providing efficient water conditions for the plants but also, and mainly, delivering proper nourishment. In turn, it makes fertilizing techniques and watering handling to be unavoidably carried out simultaneously.

In view of that, this research aims to evaluate the real hydrogel efficiency when different types of fertilizer and irrigation shifts are applied, through the growth rate and other biometric parameters of the sweetsop tree, which has been disseminated to increase the family income in the agricultural space of the semiarid region of Ceará.

Material and methods

The experiment was carried out in a greenhouse at the Instituto Federal do Ceará – IFCE, Sobral, which is in the semiarid region in Ceará (3° 41' S and 40º 20' W), 240 km far from the capital, Fortaleza.

A randomized complete block design with a 3x3x2 factorial scheme was used corresponding to three fertilizer solutions: A1 – urea + elemental sulfur + phosphoric acid, A2 – ammonium sulfate + phosphoric acid, and A3 – only water; three watering shifts: 1D – daily watering, 3D – watering every three days, and 6D – watering every six days; and two doses of hydrogel: NH – no hydrogel (0.0g, control) and WH – with 5g of hydrogel per sweetsop tree. The treatments were spread along four blocks, totalizing of seventy-two experimental units.

Sweetsop tree seedlings with six months of age and different growth patterns were used. This way, the seedlings similar in size were gathered together to form the four blocks that form the experimental design.

The setup process was carried out on April 2019, using three parts of topsoil for the cultivation of the sweetsop trees, all the parts removed from an area in UVA, Sobral, CE, which according to the classification conducted by Embrapa (2011) is called brunisolic soil, currently classified as Luvisol, in addition to a part of washed sand (purchased at a construction store in

Sobral/CE). The chemical characteristics of the Luvisol used were pH of the water = 8.0; 487.76mg·kg^{-1} of P; 31.58g·kg^{-1} of M.O.; 13.9cmolc·kg^{-1} of CTC; 100% of V; and 11.3; 1.5; 0.665 and 0.435cmolc·kg^{-1} of Ca2+, Mg2+, K+ and Na+, respectively, and clayey textural class.

After the homogenization process, the mixture was sieved in a 4mm mesh sieve. After that, the seedlings, one at a time, were moved in 20dm³ vases. The addition of 5g of the hydrogel Forth® was made in half of the volume of the recipients while the seedlings were being moved. For its addition in soil, a 20cm depth hole was made in the middle of the recipient. Then, 5g of hydrogel were diluted in 800mL of water and poured into the hole. At last, the seedlings were placed in the hole in a way that the hydrogel permeated the roots.

Only 22 days after the transplant, the process of watering shifts started. Watering was performed due to the need for restoration of the crop's evapotranspiration to located systems. The watering took place based on the daily evaporation measured in a mini gauge evaporimeter according to [14]. For the 1D treatments, the total evaporated irrigation lamina is added daily. For the 3D and 6D treatments, the applied value is the sum of the evaporation in the mini gauge evaporimeter for three and six days, respectively.

The fertilization process followed an adjusted recommendation made [14, 15] for the foundation with 85g·plant^{-1} P_2O_5 and 45g·plant^{-1} K_2O, added with the introduction of nitrogen with 50g·plant^{-1} in the form of nitrate (NO_3^-) and ammonia (NH_3) over the A1 and A2 treatments, respectively. This process is conducted by fertigation dived into six fortnightly application.

The preventive controlling method against pests and diseases used alternative means as recommended [16]. The climate was monitored not only by the mini gauge evaporimeter but also by a *Ville-de-Paris* rain gauge and a hygrometer whose data used to be collected daily at 9 a.m.

To evaluate the efficiency of each treatment, a tape measure and a graduated ruler were handled to determine the height of the plant (HP) and, for the stem diameter (SD), a digital caliper. After that, the absolute growth rate (AGR) was determined by dividing the height collected at 77 days after the transplant by the total of evaluation weeks, which are 11, which had the AGR as result em mm^{-1} for the height. The same happened to the determination of AGR for the stem diameter.

As for the relative growth rate (RGR), the height at 77 days after the transplant was subtracted from the height at day 0 and then multiplied by 11 (total of weeks between the measures collection) in both variables.

At the end of the experiment (exactly 77 days after the transplant), there was the determination of destructive biometric variables. At first, all the leaves from the useful plants for each treatment were removed and immediately taken to the laboratory (in paper bags) to be weighed and to determine their fresh leaf mass – FLM. The stem from each useful plant was then cut close to the ground, using scissors, and stored into paper bags and also weighed as soon as possible to collect the fresh stem mass – FSM.

After weighing, 05 (five) leaves from each useful plant in each treatment were photographed using a (Ciber-shot 16,1 megapixels) camera. Later, they were used in the determination of the specific leaf area – SLA using the software ImageJ. The total leaf area – TLA was specified by multiplying the average value of five leaves area of each plant by the total quantity of leaves in each plant.

The samples with leaves and stems had been individually stored in greenhouses that had forced air circulation until they reached a steady weigh. Then, they were weighed to collect their dry leaf mass – DLM and dry stem mass – DSM.

The variable data underwent the Kolmogorov-Smirnov test and presented a normal distribution ($p > 0.05$). Then, the analysis of variance (ANOVA) was conducted by the F test ($p < 0.05$) and as soon as the treatments had presented a meaningful effect, it was carried out the Tukey's range test ($p < 0.05$). The analyses were conducted in the software Sisvar [17].

Results and discussion

In order to evaluate the effects of the studied factors, it is presented an overview of the analysis of variance (Table 1) to the absolute growth rate (AGR) and the relative growth rate (RGR) of the plants height and their stem diameter. According to Table 1, there were not meaningful effects in the interaction among the variables in question. However, there was an isolated effect in the fertilizing process ($P < 0.05$) for both the stem's height and diameter.

Table 1. An overview of the analysis of variance (ANOVA) for the absolute growth rate (AGR) and the relative growth rate (RGR) of the sweetsop tree height, its stem's diameter and the number of leaves

Source of Variation	LF	MEAN SQUARE			
		HEIGHT		STEM DIAMETER	
		AGR	RGR	AGR	RGR
Hydrogel (F1)	1	0.60152 ns	1.72608 ns	0.00847 ns	0.00281 ns
Fertilization (F2)	2	9.74585 *	14.15510 **	0.35299 **	0.27337 **
Watering shifts (F3)	2	4.33401 ns	4.39543 ns	0.01244 ns	0.01091 ns
INT. F1xF2	2	0.98934 ns	0.08419 ns	0.00864 ns	0.03760 ns
INT. F1xF3	2	6.77229 ns	4.07135 ns	0.02067 ns	0.01036 ns
INT. F2xF3	4	0.60629 ns	0.65676 ns	0.02152 ns	0.01153 ns
INT. F1xF2X F3	4	1.20973 ns	1.99410 ns	0.00707 ns	0.00501 ns
TREATMENT	17	3.03227 ns	3.39657 *	0.05367 **	0.04314 **
BLOCKS	3	37.95732 **	0.27274 ns	0.14371 **	0.00915 ns
RESIDUE	51	247.180	150.895	0.022207	0.01524
CV%		22.73	49.09	13.58	55.89

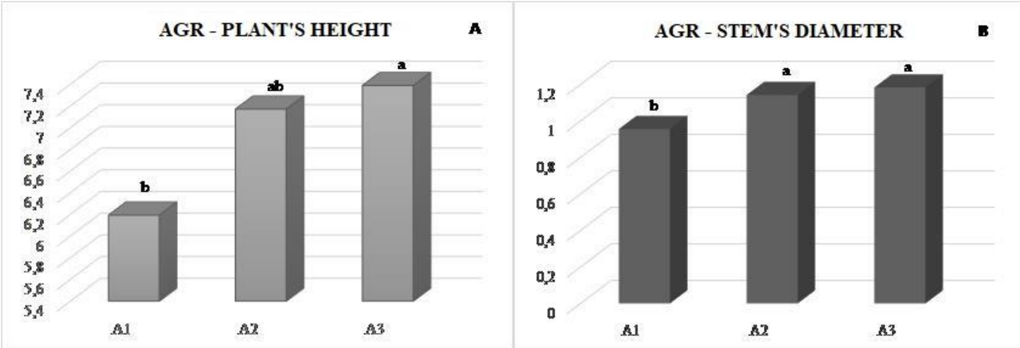
Obs: nm – not meaningful according to the F test;
*, **, *** - meaningful at 5%, 1%, and 0,1% of significance by the F test, respectively; CV – Coefficient of Variation; LF – Level of Freedom; AGR – Absolute Growth Rate; RGR – Relative Growth Rate

Considering the AGR's mean squares for the stem's height and diameter, it was realized that, for both of these variables, the fertilization A1, the one made up of urea + elemental sulfur + phosphoric acid, had the lowest value when compared to the A2 treatment (ammonium sulfate + phosphoric acid) and A3 (only water), which did not present difference between themselves.

As for the height, the plants that underwent the A3 treatment were 16.2% higher in AGR terms than those from A1 and, those that underwent the A2 fertilization were 13.6% higher than those from A1. Regarding the stem's diameter, the growth rates were higher, 19.2% and 16.3%, respectively, in the A3 and A2 treatments compared to A1.

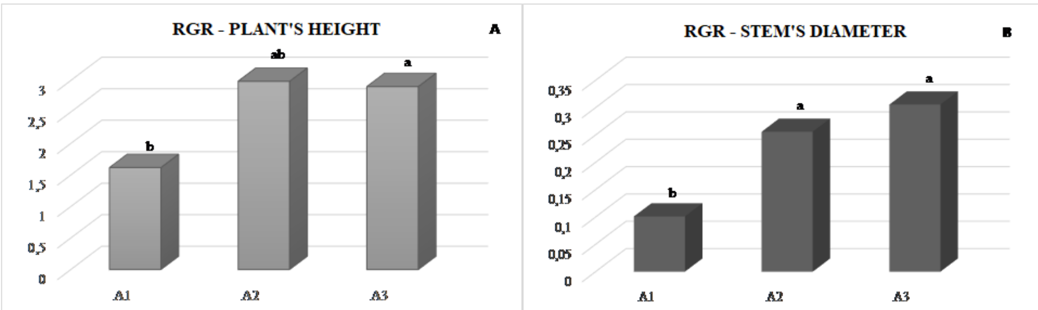
Concerning the RGR, the variable that best presents the growth of the plant's height and its stem's diameter, the previous trend stayed the same. However, the growth among the treatments doubled or even triplicated in specific cases.

About height, the plants submitted to the A3 treatment were 44.3% higher in RGR terms than those from A1 and the plants that underwent the A2 fertilization were 45.8% higher in the same terms. For the stem's diameter, the RGR growth rates were 67.0% and 60.5% in the A3 and A2 treatments, respectively, in comparison with the A1.



* Averages followed by the same lower-case letter do not differ according to Tukey's range test (P<0,05)

Fig. 1 – Plant's height (A) and stem's diameter (B) absolute growth rate (AGR) of sweetsop trees submitted to different fertilization methods: A1 – urea + elemental sulfur + phosphoric acid; A2 - ammonium sulfate + phosphoric acid; A3 – only water



* Averages followed by the same lower-case letter do not differ according to Tukey's range test (P<0,05)

Fig. 2. Plant's height (A) and stem's diameter (B) relative growth rate (AGR) of sweetsop trees submitted to different fertilization methods: A1 – urea + elemental sulfur + phosphoric acid; A2 - ammonium sulfate + phosphoric acid; A3 – only water

Although it is unusual for fertilized substrates to have lower growth rates than non-fertilized substrates, it is necessary, in this research, to consider some issues that may justify completely such results or at least in parts.

In the fertilized treatments (A1 and A2), although the recommendation had been followed, there were variations in the sources of the fertilizer. This is quite relevant since each kind of fertilizer presents a specific chemical nature and the interaction with the soil is different in each case. In addition to it, fertilizers present different saline levels and potentials to affect the pH [18]. Once the soil salinity and pH are affected, the entire dynamics of water and nutrient uptake can change and, consequently, the nutrition of plants.

Different from the A2 treatment, the A1, which presented the worst results in all variables presented up to now, used the elemental sulfur as the sulfur source (S) and urea for the supply of nitrogen (N). While in the A2, ammonium sulfate was used to deliver S and N. Both of the experiments had the phosphoric acid as the phosphorus source.

It is at large known that sulfur causes the soil to be acidic and it may be boosted with the use of phosphoric acid. In soil, a low pH (acidic) may cause the unavailability of nutrients, including N and P, which are essential macronutrients to make plants grow, besides increasing the availability of aluminum (Al), which is toxic for plants [19]

Furthermore, urea was added in the A1 treatment, which although widely used in agricultural practices [20] it may have low efficiency of N, due to ammonia volatilization losses (NH_3) and its toxic effect on the plants at the beginning of their growing period.

Still concerning urea, another hypothesis is that the hydrogel presents in the soil made the diffusion of NH_3 (gas) difficult, making it stays longer in the plants' root zone, consequently causing them to be intoxicated and affecting the nutrition of the plants in the A1 treatment.

In the case of the absence of hydrogel effects, it is still necessary to consider two factors. The first one is regarding the greatest impact of fertilization in the plants' development in comparison with water stress, once the water total volume that had been lost through evapotranspiration was completely restored, even in the sweetsop trees with watering shifts of 6 days. This way, the water stress was not enough to impact, in a more pronounced way, the growth in comparison with fertilization.

Kögler and Söffker [1] state that low water stress (less than 2,7 days) does not affect the relationship between the use of water and the growth of corn stalks. They also highlight in their research that plants can even be directed to have adaptive behavior, which can be manipulated in the form of training with intended stress sequences and would allow the control of plant growth and water use.

The second factor that must be considered is concerning the natural chemical composition of the soil, its density and the application method. In their study, Lejcu *et al.* [21] analyzed the water absorption capacity by hydrogel in types of soil with different levels of density (1.3, 0.9 and $0.5 g \cdot cm^{-3}$) and application depths (1.3, 0.9 and $0.5 g \cdot cm^{-3}$). With this, they found that the loads limit the water absorption by hydrogel by up to 94.3% and also reduce the prolonged polymer swelling. In this case, likely, conventional methods of applying hydrogel directly to the soil and at depth are limiting its efficiency. This may also explain the significant differences in the efficiency of these polymers in laboratory tests (no interaction with soil) and field tests [22].

The ANOVA results for FLM, DLM, FSM, DSM, SLA and TLA are shown in Table 2 below. For these variables, no meaningful interaction effect happened but there was an isolated effect in watering shifts and fertilization.

The sweetsop trees' FLM and DSM were influenced by both watering shifts and fertilization separately. FSM and DSM were influenced by the watering shifts only, whereas the TLA was affected by the fertilization process. The hydrogel influenced none of the described variables and the SLA was not affected by any of the studied factors.

Table 2. An overview of the analysis of variance (ANOVA) for Fresh Leaf Mass – FLM; Fresh Stem Mass – FSM; Dry Leaf Mass – DLM; Dry Stem Mass – DSM; Specific Leaf Area – SLA and Total Leaf Area – TLA

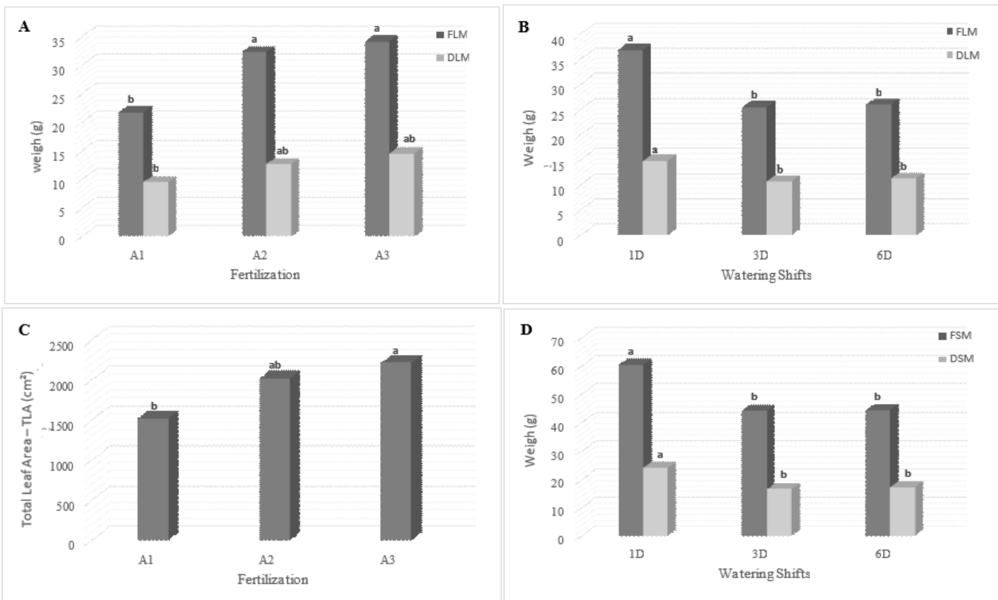
Source of Variation	LV	MEAN SQUARE					
		FLM	FSM	DLM	DSM	SLA	TLA
Hydrogel (F1)	1	121.65ns	379.11ns	9.92ns	6.20ns	1100.71ns	3600.85ns
Fertilization (F2)	2	811.91*	736.20ns	114.94**	119.46ns	607.90ns	2342419.78*
Watering shifts (F3)	2	740.47*	1538.14**	91.50*	304.38**	956.69ns	1393678.08ns
INT. F1xF2	2	51.21ns	116.20ns	8.83ns	1.17ns	108.68ns	472892.84ns
INT. F1xF3	2	177.38ns	394.80ns	25.41ns	26.57ns	219.82ns	765883.72ns
INT. F2xF3	4	24.99ns	369.32ns	2.61ns	53.30ns	183.56ns	53576.72ns
INT. F1xF2X F3	4	181.14ns	278.08ns	20.00ns	48.27ns	222.39ns	421968.65ns
TREATMENTS	17	265.18ns	502.32ns	34.22ns	77.39ns	382.98ns	697384.24ns
BLOCKS	3	21.03ns	802.97ns	9.95ns	264.71**	969.07ns	34123.43ns
RESIDUE	51	164.17	289.70	18.95	42.59	753,25	679751,40
CV%		43.58	34.2	35.53	33.72	17.47	43.07

Obs: nm – not meaningful according to the F test; *, **, *** - meaningful at 5%, 1%, and 0.1% of significance by the F test, respectively; CV – Coefficient of Variation; LF – Level of Freedom

Mean values of FLM and DLM are consistent with the results of AGR and RGR, since they show that plants submitted to fertilization A1, have lower values of these variables, while in fertilizations A2 and A3, there were no significant differences.

Among the plants under the A3 and A1 fertilization, there was a reduction of 36.4% in FLM. For the dry mass, the reduction of the plants from A1 fertilization compared to those from A3 was 34.4%, although both are not statistically different (Fig. 3A). In the total leaf area – TLA the growth rate between A3 and A1 was 31.6% (Fig. 3C).

When the watering shifts were analyzed, the plants that were watered every 24 hours (1D) presented an increase of 30.9% and 28.2% in the variables FLM and DLM, respectively, in comparison with those watered every 3 days (3D). A difference of 2.1% and 5.5% in FLM and DLM between the 3D (watered every 3 days) and 6D (watered every six days) plants, respectively, was noticed, not so significant value (Fig. 3B).



* Averages followed by the same lower-case letter do not differ according to Tukey's range test (P<0.05)

Fig. 3. Fresh and Dry Leaf Mass of sweetsop trees submitted to different types of fertilizer (A) and watering shifts (B); Total Leaf Area (C) and Stem's Dry and Fresh Mass of sweetsop trees submitted to different methods of watering shifts (D)

The same trend happened to the SDM with an FSM increase of 26.6% between the 1D and 3D treatment plants and 31.0% at the MSC. Increases in FSM and DSM from plants submitted to 3D and 6D watering shifts were not significant (Fig. 3 D).

Just like in this research [23] verified a triple interaction among fertilization, hydrogel (doses ranging between 1 and $3g \cdot L^{-1}$) and (daily and alternate) watering shifts in specimens of *Adenium obesum*. Furthermore, the evaluated hydrogel doses were not enough to promote good development of the seedlings, but the fertilization, in turn, was responsible for delivering good results concerning the seedlings' development and quality. The conclusion of the authors is that the use of hydrogel associated with substrates irrigated on alternate days did not favor the production of seedlings.

The absence of hydrogel effects in the enhancement of the trees biometric variables has been reported in the research of [24] during the evaluation of seedlings from Tamboril. In that work, the polymer (the same used in this study) did not cause benefits, even at the highest dose tested ($6.0 g \cdot L^{-1}$).

Conclusion

Based on the biometric variables evaluated in this research, the conclusion is that there is no beneficial effect when adding hydrogel to the soil when it is added with mineral fertilizer, regardless of watering shifts.

However, evidence suggests that the intrinsic characteristics of the soil and the recommended form of applying the polymer contribute negatively to these results, so that other studies are necessary, with changes in the variables, to conclude the unfeasibility of using hydrogel under conditions similar to those presented here.

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