

# Physical attributes of a Quartzarenic Neosol treated with hydrogel

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**Abstract:** This study aimed to evaluate the effect of different doses of hydrogel on the physical attributes of sandy-textured soil in a semi-arid region. To this end, sandy-textured soil was mixed with hydrated hydrogel in a two-liter vase in the laboratory under normal temperature conditions between 25°C and 27°C. The experiment was conducted in randomized blocks with five doses of hydrogel (0.0, 0.6, 1.2, 2.4, and 4.8 g L<sup>-1</sup>) with four replications over nine weeks. The polymer used was a commercial hydrogel based on cross-linked potassium polyacrylate. At the end of the experiment, soil density, particle density, total soil porosity, soil granulometric analysis, and water-dispersed clay were analyzed after nine weeks of applying the hydrogel doses to the soil. The results showed that the hydrogel altered the physical attributes of the soil, such as soil density and total porosity, there was a statistical difference between the dose and the absence of hydrogel. The sand, silt, and clay fractions were impacted, as well as the degree of flocculation. Therefore, there is evidence that the application of hydrogel to sandy soils contributes to an improvement in their physical attributes, especially in soil density, total porosity, and degree of flocculation of these soils, thus favoring a better permeability of agricultural soils and contributing to gas exchange occurring more efficiently in the soil system.

**Keywords:** hydrogel, water storage, soil physical quality, semi-arid.

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## 1 Introduction

The soils of the Ibiapaba plateau are predominantly sandy-textured, such as Quartzarenic Neosols (Menezes et al., 2024). This type of soil has a lower capacity to retain water and nutrients compared to clay-textured soils, requiring more appropriate management for agricultural use and reducing nutrient losses, as well as improving the efficiency of crop irrigation. Among the soil management alternatives, the polymer in the form of hydrogel can increase water retention in the soil,

providing better conditions for the crop to achieve higher growth rates (Fawibe et al., 2019) and, above all, improving the physical conditions of the soil.

Hydrogels are polymers composed of three-dimensional structures of intertwined hydrophilic macromolecules or polymers, which, when absorbing water, even in large volumes, can maintain their structure without dissolving (Peppas et al., 2000; Sabadini, 2015). These water repellents can absorb from 400 to 1600 times their original weight in volume of water (Ahmed, 2015; Suresh et al., 2018), the amount depending on the structure and arrangement of the polymer (Riad et al., 2018). According to Ghobashy et al. (2018), the expansion action of a hydrogel is a transition from a solid state to a fluid where interfaces interact to form a gel, also

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known as a hydrogel. According to Saad et al. (2009), synthetic polymers are marketed as soil conditioners, and can reduce the number of irrigations and the water deficit of cultivated plants, especially in sandy soils.

With the growing demand for food and increasing crop areas worldwide, as well as in semi-arid climate regions, hydrogels are being applied in agriculture more frequently in recent years to improve soil properties to increase water use efficiency, increase soil productivity and contribute to global food security (Mi et al., 2017; Menezes et al., 2024). Various studies have been carried out to study these products to assess their ability to condition soils, mainly as products that retain and make water available to cultivated plants (Willingham and Coffey, 1981; Wallace, 1987; Sayed et al. 1991).

The use of hydrogels in the soil or substrate has been shown to increase water retention, reduce nutrient losses through percolation and leaching, contribute to better aeration, aggregate formation and soil drainage, thus saving water, improving the soil physical conditions and increasing crop productivity (Lamont and O'Connell, 1987; Hüttermann et al., 1999; Abedi-Koupai et al., 2008; Tohidi-Moghadam et al., 2009).

Other authors, such as Carvalho and Amabile (2006), report that superabsorbent polymers are products that play a role in improving the physical, chemical, and biological properties of the soil, making them an important strategy for plant development. As mentioned by Reynolds et al. (2002), the physical quality of the soil is fundamental to its sustainability because, according to Arshad et al. (1997), physical characteristics have a significant impact on root development, water and nutrient retention capacity and availability, gas exchange, and soil biological activity.

In an experiment carried out by Pontes Filho et al. (2018), which analyzed four doses of hydrogel diluted in distilled water with an increase in

carnauba 'bagana' (*Copernicia prunifera*) in monkfish (*Enterolobium contortisiliquum*) seedlings. This author showed that the introduction of *Copernicia prunifera* 'bagana' with the addition of hydrogel favored the development of this vegetation in the size and diameter of the *Enterolobium contortisiliquum* seedlings.

These results confirm that the use of hydrogels in the soil expands the possibilities of their use in combination with plant residues, increasing the chances of plants surviving under drought stress, as well as considerably reducing the frequency of irrigation due to the water storage and supply capacity of these materials (Dimitri et al., 2013).

This study aimed to evaluate the effect of different doses of hydrogel on the physical attributes of sandy-textured soil in a semi-arid region.

## 2 Material and methods

The experiment was carried out from April to June 2024 in the Multifunctional Agricultural and Environmental Engineering Laboratory at the UNINTA Faculty in the municipality of Tianguá, located on the Ibiapaba plateau in the state of Ceará, Brazil. The climate is classified as mild semi-arid hot tropical, whose classification is BSh according to Alvares et al. (2014) with an average temperature ranging from 22°C to 29°C and an average annual rainfall of 941.2 mm from January to May (IPECE, 2017).

The soil was collected at a depth of 0 – 20 cm in a transitional area of green belt and Carrasco with a sandy aspect, whose classification of the area is Quartzarenic Neosol (EMBRAPA, 2018), equivalent to Entisols (Quartzipsamments).

The hydrogel polymer used was a commercial hydrogel based on cross-linked potassium polyacrylate. The polymer has a particle size of 0.2 to 0.8 mm in diameter and is white. When mixed with water, it forms a gelatinous substance with a pH varying between 7 and 8, after hydration and total expansion, forming a gel.

The impact of the hydrogel on the physical attributes of the sandy loam soil was evaluated using a two-liter pot experiment. To this end, the sandy loam soil was mixed with various doses of hydrogel (0.0, 0.6, 1.2, 2.4, and 4.8 g L<sup>-1</sup>). The mixtures were left for nine weeks, after which the soil was collected for the following evaluations: soil and particle density, total porosity, granulometric analysis, and water-dispersed clay, before and after the hydrogel treatments, according to the following methodology:

a) Soil density: this was determined from samples with preserved structure collected in cylinders of known volume, and dried at 105 °C until constant mass (Blake and Hartge, 1986b).

b) Particle density: this was determined using the volumetric flask method, using a sample with an unpreserved structure. In this procedure, the principle is to determine the volume of alcohol used to complete a 50 mL volumetric flask containing 20 g of oven-dried fine soil (Blake and Hartge, 1986a).

c) Total soil porosity: obtained from soil and particle density, according to the equation below:

$$pt = \left[ 1 - \left( \frac{Ds}{Dp} \right) \right] \quad (1)$$

where,  $pt$  is the porosity (cm<sup>3</sup> cm<sup>-3</sup>), and  $Ds$  and  $Dp$  are the soil and particle densities (g cm<sup>-3</sup>), respectively.

d) Particle size analysis: the pipette method was used to determine soil texture (Gee and Bauder, 1986) based on the USDA system. Sodium hydroxide (NaOH) 1 mol L<sup>-1</sup> was used to chemically disperse the particles. Sand was quantified by sieving, and clay by the pipette method. The silt was quantified by difference, considering the initial soil sample minus the sum of sand and clay (Gee and Bauder, 1986).

e) Water-dispersed clay: determined using the procedure adopted in the particle size analysis, distinguished from it by not using the chemical dispersant and disregarding the sand and silt fractions.

For the soil+hydrogel mixture, pots of known

volume were used, taking a soil mass of 2.0 kg for the hydrogel mixture corresponding to the doses 0.0, 0.6, 1.2, 2.4, and 4.8 g L<sup>-1</sup>, conducted in a randomized complete block design (RCBD) with four replications, after nine weeks, the samples were collected for analysis of the physical attributes.

The data was subjected to the Shapiro-Wilk test to verify normality, the F test, and analysis of variance (ANOVA) using a randomized block design using SISVAR software (Ferreira, 2019). Statistical differences between the means of the treatments were calculated using the SNK test. Mean differences were considered significant when  $p \leq 0.05$ , presented as graphs.

### 3 Results and discussion

Figure 1 shows the physical attributes of particle density ( $Dp$ ), soil density ( $Ds$ ), and total porosity ( $pt$ ). These attributes, except particle density, can be positively altered through the use of a soil conditioner, such as hydrogel, which has the capacity to improve aggregation and other physical aspects of the soil. As explained by Kiehl (1979), particle density ( $Dp$ ) is defined as the ratio between the mass of a soil sample and the volume occupied exclusively by its solid particles. This parameter describes the volume occupied by the solid components of a soil sample, excluding the influence of porosity.

Based on the values obtained for particle density ( $Dp$ ), there was no statistical difference in  $Dp$  values when compared to the control, with the value of approximately 2.5 g cm<sup>-3</sup> being the same regardless of the dose of hydrogel applied, the values did not differ statistically between the treatments, the behavior of which is due to the mineralogical nature of the soil type (predominance of quartz particles). In research carried out by Patel et al. (2024), these authors found different values for particle density under the application of different doses of hydrogel. The highest value found was 2.64 g cm<sup>-3</sup>, which corresponds to the treatment with no added hydrogel. The lowest value for particle density was found for

the treatment in which  $25 \text{ g kg}^{-1}$  of hydrogel was applied. As a result, particle density decreased as the doses of polymer applied increased.

As for soil density ( $D_s$ ), there was a statistical difference, meaning that the hydrogel had a positive influence on this physical attribute of the soil. Figure 1 shows that the lowest soil density value was found in the treatment with a hydrogel dose of  $4.8 \text{ g L}^{-1}$ , while the highest density was observed in the control treatment, with a value close to  $1.4 \text{ g cm}^{-3}$ . This behavior clearly showed that the higher the dose of hydrogel, the lower the soil density. Similar results were found by Kumar et al. (2018) in an experiment with corn, where they found a decrease in soil

density with the addition of hydrogel. Oliveira Neto et al. (2024) also observed a linear reduction in soil density ( $1.24 \text{ g cm}^{-3}$ ) for a hydrogel concentration of  $3 \text{ g dm}^{-3}$ .

Buckman and Brady (1983) define soil density as the amount of soil mass present per unit volume, maintaining the natural arrangement of the soil. Thus, this attribute is important for inferring whether there is soil compaction, and it also provides information on the functionality of the soil system. Therefore, hydrogel as a soil conditioner is relevant for cropping systems and improving the functionality of the soil system.

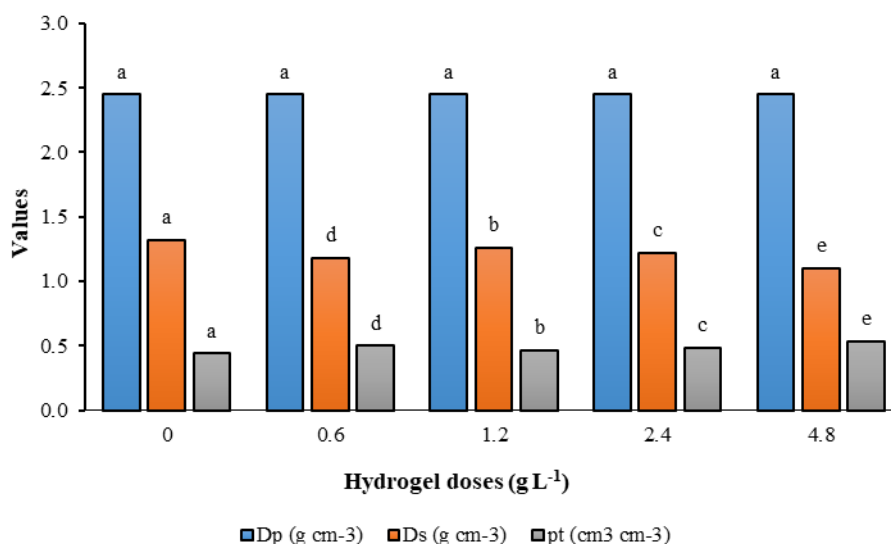


Figure 1 Average values for particle density (Dp), soil density (Ds), and total porosity (pt) of soil subjected to different doses of hydrogel. Equal letters do not differ statistically by the SNK test at 5% probability.

With regard to total porosity, it is possible to see that there was a statistical difference between the treatments (Figure 1). The lowest porosity value was found in the treatment that did not receive hydrogel. On the other hand, when  $4.8 \text{ g L}^{-1}$  of the polymer was applied, there was an increase in the volume of the soil's pore spaces, indicating better soil aeration and permeability. This data is extremely important, as pores are characteristic of soil with a better porous arrangement and a good capacity for water infiltration and gas exchange in the soil.

Similar values were found by Patel et al. (2024), who reported that porosity increased in parallel with the increase in the levels of hydrogel applied to the

soil. In the experiment carried out by Kumar et al. (2018), the data obtained for total porosity followed the same reasoning. This fact reinforces that the use of hydrogel can be useful as a soil conditioner, since there was an improvement in soil density and porosity.

According to the data presented in Figure 2, which shows the granulometric fractions of the soil, referring to the percentage of sand, clay, silt, water-dispersed clay, and the degree of flocculation of the clays, it is possible to see differences in the results for the different treatments and parameters tested.

It was noted that the lowest percentages of sand were found in the control treatment and the treatment with the highest dose of the polymer when  $4.8 \text{ g L}^{-1}$

was applied, which did not differ according to the SNK test at 5% probability. The highest percentage of sand, around 85%, was observed with the application of 0.6 g L<sup>-1</sup> of hydrogel, showing that the hydrogel influences the soil fractions.

For the clay fraction, there was a statistical difference between the control treatment and the treatment starting at 1.2 g L<sup>-1</sup>. With the application of

4.8 g L<sup>-1</sup> of hydrogel, there was a considerable increase in the clay fraction compared to the control. This behavior is possibly due to the presence of the polymer itself since this product is also made up of particles the size of the clay fraction, whose swelling time in the soil material favors the flocculation of clays and improves soil aggregation processes.

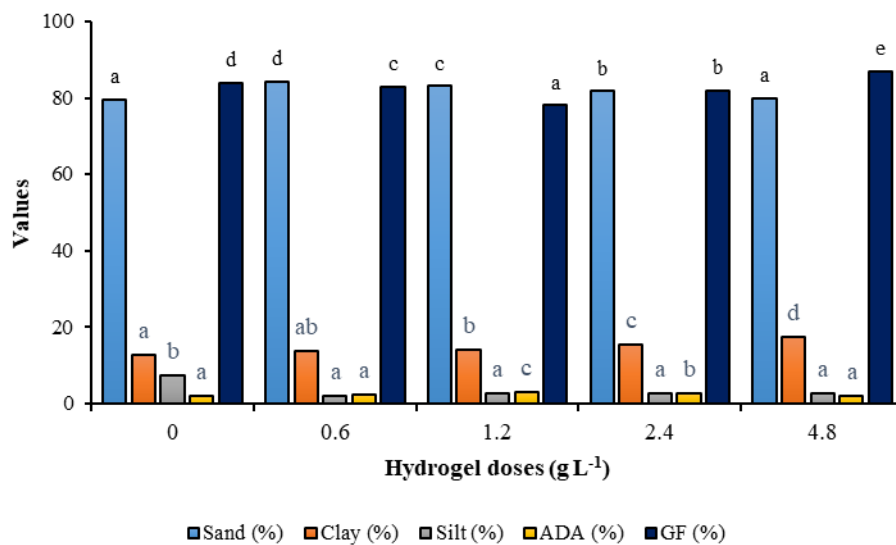


Figure 2 Average values for sand, clay, silt, water-dispersed clay (ADA) and degree of clay flocculation (GF) in soil subjected to different doses of hydrogel.

Note: Equal letters do not differ statistically by the SNK test at 5% probability.

When analyzing the silt values, it can be seen that there was a difference between the treatments. The highest percentage found for this particle size fraction was in the treatment in which no doses of hydrogel were applied. It can be seen, however, that when the hydrogel was added, the percentage of silt decreased for the different doses (0.6, 1.2, 2.4, and 4.8 g L<sup>-1</sup>), statistically showing the same values in these treatments. It can therefore be seen that the hydrogel does not influence the silt fraction.

Another attribute analyzed was water-dispersed clay (ADA). According to Figure 2, the lowest value found for this variable was in the control treatment and the treatment with the highest dose, which are statistically equal. The highest percentage of water-dispersed clay (3.1%) was found with the application of 1.2 g L<sup>-1</sup> of hydrogel. According to Mota et al. (2015), soils with high levels of water-dispersed clay cause problems in the physical and structural quality

of the soil, as well as becoming susceptible to erosion. However, in this study, the dose of 4.8 g of polymer did not statistically influence the ADA compared to the control.

Considering that water-dispersed clay is related to aggregation between the particles, there is evidence that the hydrogel provided a slight aggregation of the sandy soil, as reflected in the improvement in soil density and total porosity. According to Santos et al. (2010), water-dispersed clay is an attribute that influences the degree of flocculation, which influences the aggregation of soil particles, thus becoming an important attribute in the field of soil conservation. The highest value of degree of flocculation (GF) was observed in the highest dose of hydrogel with 87%, differing from the other treatments, which means that there was a slight improvement in the structure of the sandy-textured soil, however, the value of 87% is expected for a soil

with this texture, as in these soils there are few flocculating elements.

It is important to understand this characteristic since water-dispersed clay analyses have been widely used in studies evaluating soil structural conditions, bearing in mind that the higher the ADA values, the lower the aggregate stability and resistance of the soil to disintegration (Dontsova et al., 2009).

From the scatter plot, it can be seen that the Component explains 61.13% of the variability in the data, while Component 2 explains 37.78%, totaling 98.91% of the total variations in the soil attributes analyzed under hydrogel doses. Therefore, it can be considered that the two-dimensional perceptual map presented is suitable for assessing the relationships between soil attributes, as it explains a large part of the variability in the data since, in this type of analysis, an explanation greater than 50% is sought in the first two Components.

Figure 3 shows the relationship between the doses of hydrogel (D1, D2, D3, D4, and D5) and the soil's physical attributes ( $Dp$ ,  $Ds$ ,  $pt$ , Sand, Clay, Silt, ADA, and GF) in each quadrant of the principal components graph. The sand was found to have a strong influence, correlating positively with Component 1. Thus, considering that dose D2 ( $0.6 \text{ g L}^{-1}$ ) is located in the same quadrant, it suggests that the application of hydrogel correlates positively with the presence of sand in the soil. On the other hand, clay (%) is the main component in the lower right quadrant, with a strong negative influence on Component 2 and a moderate negative correlation on Component 1. This behavior shows that the D4 ( $2.4 \text{ g L}^{-1}$ ) and D5 ( $4.8 \text{ g L}^{-1}$ ) doses of hydrogel indicate a correlation between the clays present in the soil, meaning that hydrogel-treated soils interact with clays.

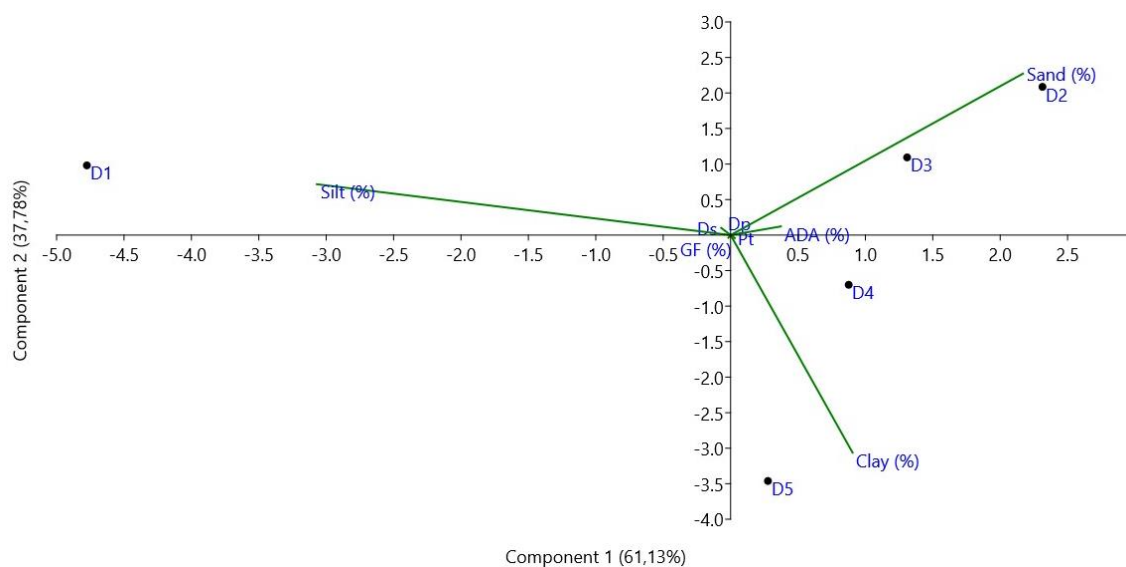


Figure 3 Scatter plot for the first two components of the different variables analyzed in the physical attributes of the soil under hydrogel doses

Note: The variables are particle density ( $Dp$ ), soil density ( $Ds$ ), total porosity ( $pt$ ), sand, silt, clay, water-dispersed clay ( $ADA$ ), and degree of flocculation ( $GF$ ).

Dose D1 (control) appears in isolation in the upper left quadrant (Figure 3) without a close correlation with the other physical attributes of the soil analyzed, which may indicate that the presence of hydrogel in the soil directly influences the other physical attributes. In this same quadrant, the percentage of silt (%) shows a negative correlation with Component 1. It can be seen that this variable is

associated with the doses close to the central point; this behavior indicates a moderate correlation with the doses. In this context, it can be seen that most of the attributes ( $Dp$ ,  $Ds$ ,  $pt$ , ADA, and GF) and doses of hydrogel (D3 and D4) are close to the central point. This suggests that these doses do not correlate strongly with any of the individual variables but have a more balanced and distributed relationship with

these soil physical attributes.

## 4 Conclusions

We are applying hydrogel to sandy loam soil led to positive changes in soil density, total porosity, and degree of clay flocculation.

The hydrogel in the soil shows a positive association with the percentage of sand and clay in the soil, as well as more moderate relationships with the other physical attributes of the soil. However, in this research, it was not possible to define an ideal dose of hydrogel, but doses of 0.6 to 4.8 g L<sup>-1</sup> of hydro retentive polymer can be recommended for sandy loam soils to improve physical attributes.

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