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Hydrogel Application Depth in Maize Under Water Stress

Profundidade de Aplicação de Hidrogel no Milho Sob Estresse Hídrico

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Abstract

The increasing demand for sustainable agricultural productivity is driving the use of hydrogels to optimize soil water. This study aimed to evaluate the effect of different hydrogel application depths on the initial development of maize (Zea mays L.) under water restriction. The experiment was conducted in a greenhouse, in a completely randomized experimental design, with four replications and four hydrogel deposition depths relative to the seed (0, 3, 7, and 10 cm), in addition to a control treatment without hydrogel. Plant height was evaluated at 7, 14, and 21 days after sowing (DAS), and at 21 DAS, root length and shoot and root dry matter were assessed. The collected data was subjected to analysis of variance using RStudio software, and when significance was observed, Duncan's test was performed at a 5% significance level. Figures were created using SigmaPlot 12.0 software. At 7 DAS, there was no significant difference between treatments. However, at 14 and 21 DAS, a depth of 3 cm promoted the best results in terms of plant height and dry matter accumulation in both shoots and roots. Application at 0 cm reduced root biomass, while depths of 7 and 10 cm were limited by the physical distance between the root and the wet zone. It was concluded that application at 3 cm is the most efficient management strategy, establishing an ideal balance between protection against desiccation and rapid access by the root system.

Keywords: Superabsorbent polymers. Water Retention. Water Deficit. Soil Management.

Resumo

A crescente demanda por produtividade agrícola sustentável impulsiona o uso de hidrogéis para otimizar a água no solo. Este estudo objetivou avaliar o efeito de diferentes profundidades de aplicação de hidrogel sobre o desenvolvimento inicial do milho (Zea mays L.) sob restrição hídrica. O experimento foi conduzido em casa de vegetação, em delineamento experimental inteiramente casualizado, com quatro repetições e quatro profundidades de deposição do hidrogel em relação a semente (0, 3, 7 e 10 cm), além de um tratamento controle sem hidrogel. Avaliou-se a estatura aos 7, 14 e 21 dias após a semeadura (DAS) e, aos 21 DAS, comprimento radicular e matéria seca da parte aérea e de raiz. Os dados coletados foram submetidos à análise de variância no software RStudio e, quando observado significância, procedeu-se o teste de Duncan a 5% de significância. A elaboração das figuras foi realizada no software SigmaPlot 12.0. Aos 7 DAS, não houve diferença significativa

entre os tratamentos. Contudo, aos 14 e 21 DAS, a profundidade de 3 cm promoveu os melhores resultados em estatura e acúmulo de matéria seca da parte aérea e radicular. A aplicação a 0 cm reduziu a biomassa radicular, enquanto as profundidades de 7 e 10 cm foram limitadas pelo distanciamento físico entre a raiz e a zona úmida. Concluiu-se que a deposição a 3 cm é a estratégia de manejo mais eficiente, estabelecendo um equilíbrio ideal entre a proteção contra a dessecação e o acesso rápido pelo sistema radicular.

Palavras-chave: Polímeros Superabsorventes. Hidroretentor. Déficit Hídrico. Manejo de Solo.

1 Introduction

The growing demand for sustainable agricultural productivity, especially in regions subject to water scarcity and climate uncertainties, has driven the adoption of innovative technologies to optimize water use. In this scenario, superabsorbent polymers, known as hydrogels, stand out for their ability to retain water in volumes hundreds of times greater than their dry weight, releasing it gradually as the soil water potential decreases (Piccoli *et al*., 2024). This dynamic not only mitigates the effects of water deficit but also improves the physical properties of the soil (Albalasmeh *et al*., 2022).

In corn cultivation (*Zea mays)* L.), a grass with high water requirements, the use of hydrogels has shown potential to enhance variables such as plant height, stem diameter and leaf area (Radian *et al*., 2022). In addition to increasing shoot size, the literature indicates that the polymer acts directly on root vigor, allowing the plant to sustain photosynthetic metabolism and biomass accumulation even under moderate stress (Alvarez *et al*., 2025).

The effectiveness of hydrogel, however, depends not only on the dosage applied, but also on its spatial location in the soil profile. The depth of incorporation determines the proximity of the polymer to the rhizosphere, influencing the kinetics of water absorption and nutrient interception (Yáñez - Chávez *et al*., 2014). A superficial application can subject the polymer to degradation or very rapid drying cycles, while a very deep application causes the water source to move away from the roots.

Recent studies suggest that hydrogel stratification modifies the architecture of the root system and the rhizosphere microenvironment (Yang *et al.*, 2024). However, despite its practical relevance, studies defining the appropriate depth of hydrogel incorporation to maximize the morpho-physiological variables of maize are still scarce. In this context, the present study aims to evaluate the effect of different hydrogel application depths on growth variables and the initial development of maize under water stress.

2 Material and Methods

The experiment was conducted in a greenhouse at the Federal Institute of Southern Rio Grande do Sul, Bagé Campus, in a completely randomized experimental design with five treatments and four

replications. The treatments consisted of a control treatment (without hydrogel application) and hydrogel applied at four different depths relative to the seed: 0, 3, 7, and 10 cm. The hydrogel was used at a dose of 60 kg ha^{-1} (chosen from previous studies) and was swollen before deposition to the soil, in a 1:5 ratio (liter:gram) of water and hydrogel, respectively, according to the manufacturer's recommendation.

The experiment was conducted in 0.5-liter pots using the corn cultivar SHS7010PRO3. Five seeds were added per pot for subsequent thinning, maintaining one plant per pot as the experimental unit. The pots were kept at field capacity until 7 days after sowing (DAS), and at the end of this period, no water was supplied to the plants until the end of the experiment.

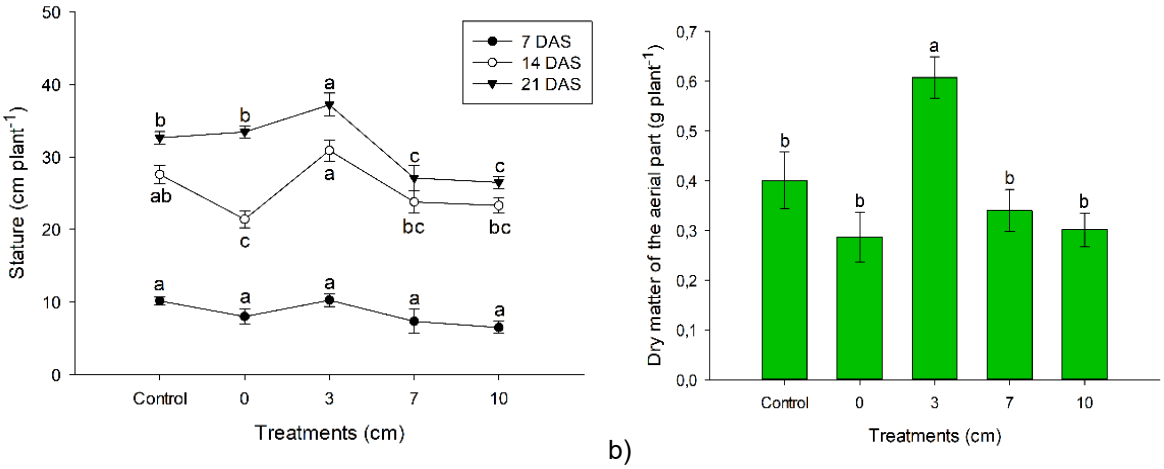
In this study, plant height was evaluated at 7, 14, and 21 days after sowing, and at 21 DAS (days after sowing), root length and shoot and root dry matter were assessed. The collected data were subjected to analysis of variance using RStudio software, and when significance was observed, Duncan's test was performed at a 5% significance level. The figures were created using SigmaPlot 12.0 software.

3 Results and Discussion

Analysis of plant height 7 days after sowing revealed no significant differences between treatments (Figure 1a). This result is consistent with the management adopted, since all experimental units were maintained at field capacity during the initial establishment period.

However, after irrigation was suspended, the depth of hydrogel deposition began to exert a decisive influence on vegetative vigor.

Figure 1 - Plant height at 7, 14, and 21 days after sowing and shoot dry matter of corn subjected to hydrogel application at different depths

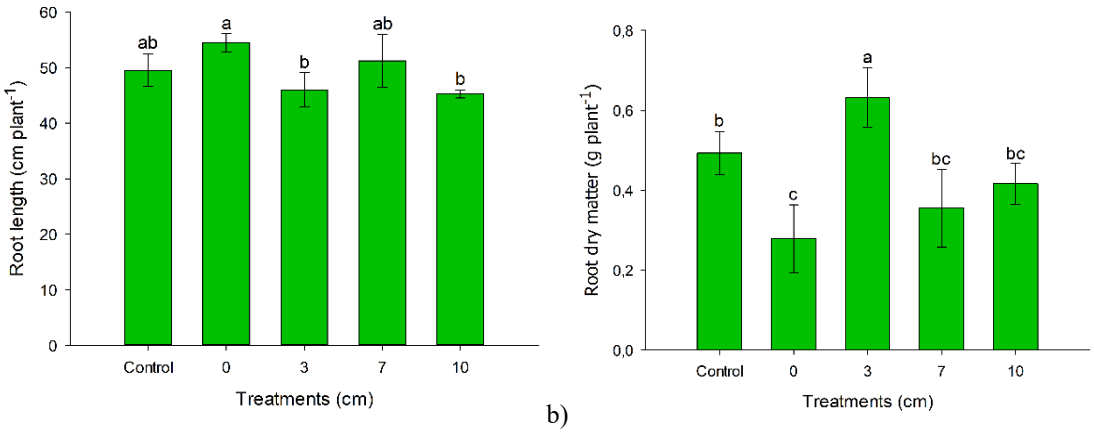


*Points and bars with different letters differ from each other by Duncan's test (p-value <0.05).
Source: research data.

At 14 and 21 DAS, the application of hydrogel at a depth of 3 cm promoted the greatest growth in height and the greatest accumulation of dry matter in the aerial part (Figures 1a and 1b). This superior performance suggests that a distance of 3 cm from the seed establishes an ideal "water comfort zone," allowing early interception of the polymer by the primary roots without the deleterious effects of excessive proximity.

The responses observed in the aerial part are a direct reflection of root morphology (Figure 2), since root development is closely linked to the growth and productivity of corn plants (Ohse; Mello; Santos, 2021; Pereira *et al.,* 2024). It was observed that the deposition of the hydrogel next to the seed (0 cm) resulted in the lowest root biomass (Figure 2b), despite a high root length (Figure 2a). Application at 0 cm may have generated an initial physiological signal of water abundance, discouraging investment in dense root biomass.

Figure 2 - Root length and dry matter of corn plants 21 days after sowing, subjected to hydrogel application at different depths



a) b)

*Columns with different letters differ from each other according to Duncan's test (p-value <0.05).
Source: research data.

However, with the progression of water deficit, the lack of a robust root structure limited the exploration of soil volume, forcing the plant to produce thinner roots to increase the absorption surface, which explains the high length with low dry mass. In addition, excessive moisture in direct contact with the seed can induce hypoxic or anoxic conditions, impairing initial respiratory metabolism and compromising the stand and subsequent vigor (Vieira; Carvalho, 2023).

Contrary to what was expected for drought conditions, the depths of 7 and 10 cm did not surpass the control treatment in terms of biomass accumulation (Figure 2b). Two factors physiological they can to explain this behavior:

- Temporal Deficit: The physical distance required more time for the root system to intercept the moist zone. During this interval, the seedlings may have suffered severe water stress that irreversibly compromised their growth potential (Song; Jing; He, 2019).

- Absorption Efficiency: Although roots have reached greater depths, effective absorption occurs mainly through root tips and absorbents (Yan *et al.,* 2022). As the root advances and ages, suberization and lignification processes reduce the water permeability of older regions, limiting the efficiency of hydrogels located in layers far from the base of the plant. Thus, the root tip, located in the elongation and differentiation zone, remains the main absorption region (Taiz *et al.,* 2024).

From a practical and field application standpoint, these results indicate that hydrogel application technology should be integrated into precision seeding techniques. The use of furrow openers that allow the polymer to be deposited in a parallel line slightly below (about 3 cm) the seed can prevent seed anoxia and ensure water supply during the heterotrophic-autotrophic transition.

This management strategy is a robust solution for planting in sandy soils or in regions with frequent dry spells, as it optimizes water use efficiency (WUE) and minimizes stand losses without excessively increasing the operational costs of deep incorporation. Thus, the effectiveness of hydrogel in corn cultivation is not just a matter of dosage, but of spatial synchrony between the active root absorption zone and the artificially created water reservoir.

4 Conclusion

The combined analysis of morphological variables allows us to conclude that the depth of hydrogel incorporation is a determining factor for the success of the technology in corn cultivation, surpassing in importance the simple presence of the polymer in the soil. Deposition of the hydrogel at a depth of 3 cm relative to the seed is the most efficient management strategy for the initial development of the crop, as it establishes a balance between protection against surface desiccation and rapid access by the primary root system.

On the other hand, application close to the seed (0 cm) and at greater depths (7 and 10 cm) proves ineffective: the former because it limits deep root exploration and the latter because it creates a temporal and physical distance that prevents the plant from mitigating water stress at critical stages, such as initial growth. Therefore, to optimize water efficiency and vegetative growth of corn under water restriction, it is recommended to stratify the hydrogel in subsurface layers close to the germination zone, ensuring that the water reservoir is positioned in the region of greatest physiological activity of the roots.

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