

GUAR GUM–BASED SUPERABSORBENT COMPOSITE FOR IMPROVING SOIL WATER RETENTION UNDER DRYING CONDITIONS

Musarrat Khan

Department of Chemistry, Jai Narain Vyas University, Jodhpur, Rajasthan, India

Research Article

ABSTRACT

Superabsorbent polymers can temporarily store water within soil and may reduce the rate of moisture depletion during drying. The present study evaluates the soil-water retention behavior of a prepared for the present study guar gum–g-poly(acrylic acid) superabsorbent composite (SAC1) under controlled laboratory drying conditions. A Jodhpur soil described in the experimental record as black loamy soil was amended with SAC1 at 0.5, 1.0 and 2.0% (w/w), and water content was monitored as a function of drying time. The 0.5% treatment decreased from approximately 1.00 to 0.09 g g⁻¹ over about 13 h, with $R^2 = 0.988$. The 1.0% treatment decreased from approximately 1.40 to 0.10 g g⁻¹, with $R^2 = 0.982$, whereas the 2.0% treatment decreased from approximately 1.60 to 0.30 g g⁻¹, with $R^2 = 0.997$. In untreated soil, the initial stage of evaporation was reported to last approximately 5–6 h, whereas the soil–SAC1 mixtures showed measurable drying behavior over approximately 13 h. These results indicate that incorporation of SAC1 delayed moisture depletion and increased the measured water retained in the soil mixture under the tested drying conditions. The 2.0% treatment showed the highest residual water content among the concentrations investigated; however, this should not be interpreted as an agronomic optimum because plant-available water, crop response, salinity, repeated wet–dry cycling and field performance were not evaluated. The findings support further investigation of guar gum-based superabsorbent composites as soil-water management materials.

Keywords: guar gum; superabsorbent composite; soil water retention; drying behavior; soil amendment; water conservation; agricultural hydrogel

I. INTRODUCTION

Water availability is a major constraint to agricultural production in dry and semi-arid environments. Rapid evaporation and drainage can reduce the period during which soil moisture remains available to plants, particularly in coarse-textured soils. Superabsorbent polymers (SAPs) have therefore been investigated as soil amendments because their hydrophilic, cross-linked networks can absorb water and retain it within swollen polymer domains. Their performance in soil, however, depends on polymer chemistry, application rate, soil texture, pore space, water quality and the surrounding soil environment. Recent studies have demonstrated that SAP-amended soils can exhibit slower moisture loss, while also showing that water retention and plant availability are not necessarily equivalent parameters.

Polysaccharide-based SAPs are of particular interest because natural polymers such as guar gum contain abundant functional groups that can be chemically modified to produce water-responsive networks. Reviews have highlighted the potential of polysaccharide-based hydrogels for agricultural water management, while also emphasizing the need to evaluate environmental compatibility and performance under realistic soil conditions.

In the authors' previous work, a guar gum–g-poly(acrylic acid) superabsorbent composite (SAC1) was prepared and characterized. The present study does not repeat the structural characterization of that material; instead, it focuses specifically on its application as a soil-water retention amendment. The objective was to examine the change in soil water content during drying after incorporation of SAC1 at three application rates (0.5, 1.0 and 2.0% w/w) and to compare the observed drying behavior with untreated soil.

II. MATERIALS AND METHODS

2.1. Superabsorbent composite

The material investigated was SAC1, a guar gum–g-poly(acrylic acid) cross-linked superabsorbent composite prepared for the present study. For identification and reproducibility, the preparation conditions used in the original work were guar gum 1.8% (w/v), acrylic acid 6% (v/v), potassium persulfate (KPS) 0.25% (w/v), N,N'-methylene bis(acrylamide) (MBA) 1% (w/v), and a reaction temperature of 60 °C. The reported swelling capacity of the material in distilled water was approximately 4600%. Detailed structural characterization is outside the scope of the present application-focused manuscript.

2.2. Soil

Soil collected from the Jodhpur district of Rajasthan, India, was used for the application study. The soil was classified as black loamy soil. The soil was used as the untreated control and as the matrix for SAC1-amended treatments.

2.3. Preparation of soil–SAC1 mixtures

SAC1 was incorporated into the soil at 0.5, 1.0 and 2.0% (w/w). The amended samples were hydrated and subsequently subjected to drying, while the untreated soil was evaluated as the control. Water content was expressed on the same mass basis used in the original experimental dataset, as grams of water per gram of soil–SAC1 mixture (g g⁻¹).

2.4. Drying experiment and water-content measurement

The soil and soil–SAC1 mixtures were monitored during drying and water content was plotted against drying time. For the 0.5% treatment, measurements were followed over approximately 13 h; the 1.0 and 2.0% treatments were likewise evaluated over a 13-h drying period. The original dataset reports the first-stage evaporation period as approximately 5–6 h for untreated soil and approximately 13 h for the soil–SAC1 mixtures.

Linear regression was used to describe the reported drying relationships, and the corresponding coefficients of determination (R^2) were retained from the original plots. Because replicate-level observations and variance estimates were not available for the reported measurements, no inferential statistical test or significance claim was made in the present manuscript.

III. RESULTS AND DISCUSSION

3.1. Drying behavior of untreated soil

The untreated soil showed a comparatively rapid decline in moisture during drying. The measurements indicate that the first stage of evaporation in the soil alone lasted approximately 5–6 h, after which the soil approached a nearly dry condition. This behavior provides the reference against which the persistence of moisture in SAC1-amended soil can be considered.

3.2. Effect of 0.5% SAC1

Addition of 0.5% SAC1 increased the initial measured water content of the soil mixture to approximately 1.00 g g⁻¹. During drying, the water content decreased progressively to approximately 0.09 g g⁻¹ by about 13 h. The drying relationship showed a strong linear fit with $R^2 = 0.988$ (Figure 1). Compared with the untreated soil, the amended system maintained measurable moisture over a substantially longer experimental period.

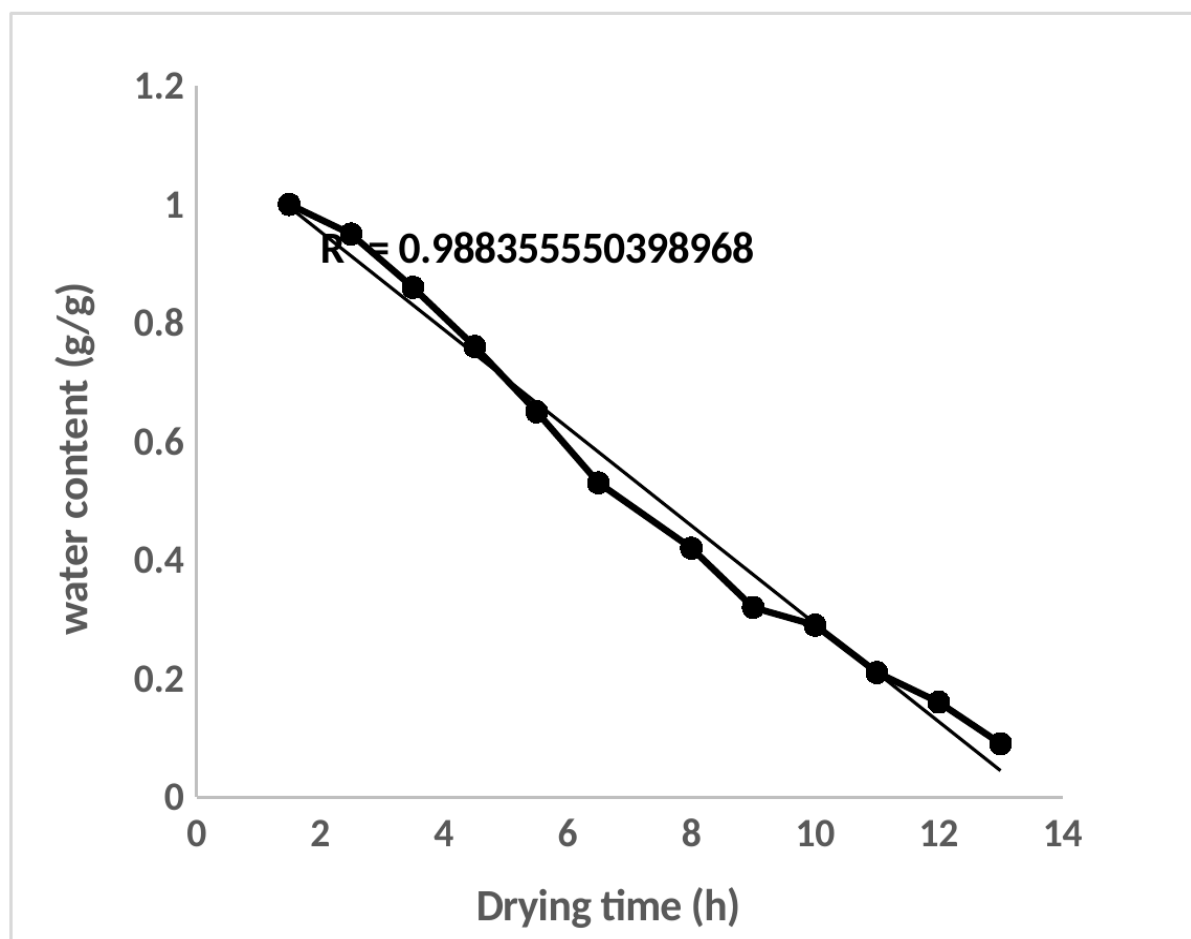


Figure 1. Water content of the soil–SAC1 mixture containing 0.5% SAC1 as a function of drying time ($R^2 = 0.988$).

3.3. Effect of 1.0% SAC1

At 1.0% SAC1, the initial water content increased to approximately 1.40 g g⁻¹. The water content decreased progressively during the 13-h drying period and reached approximately 0.10 g g⁻¹ at the end of the recorded period. The drying curve showed $R^2 = 0.982$ (Figure 2), indicating that a linear model described the observed values well over the measured range.

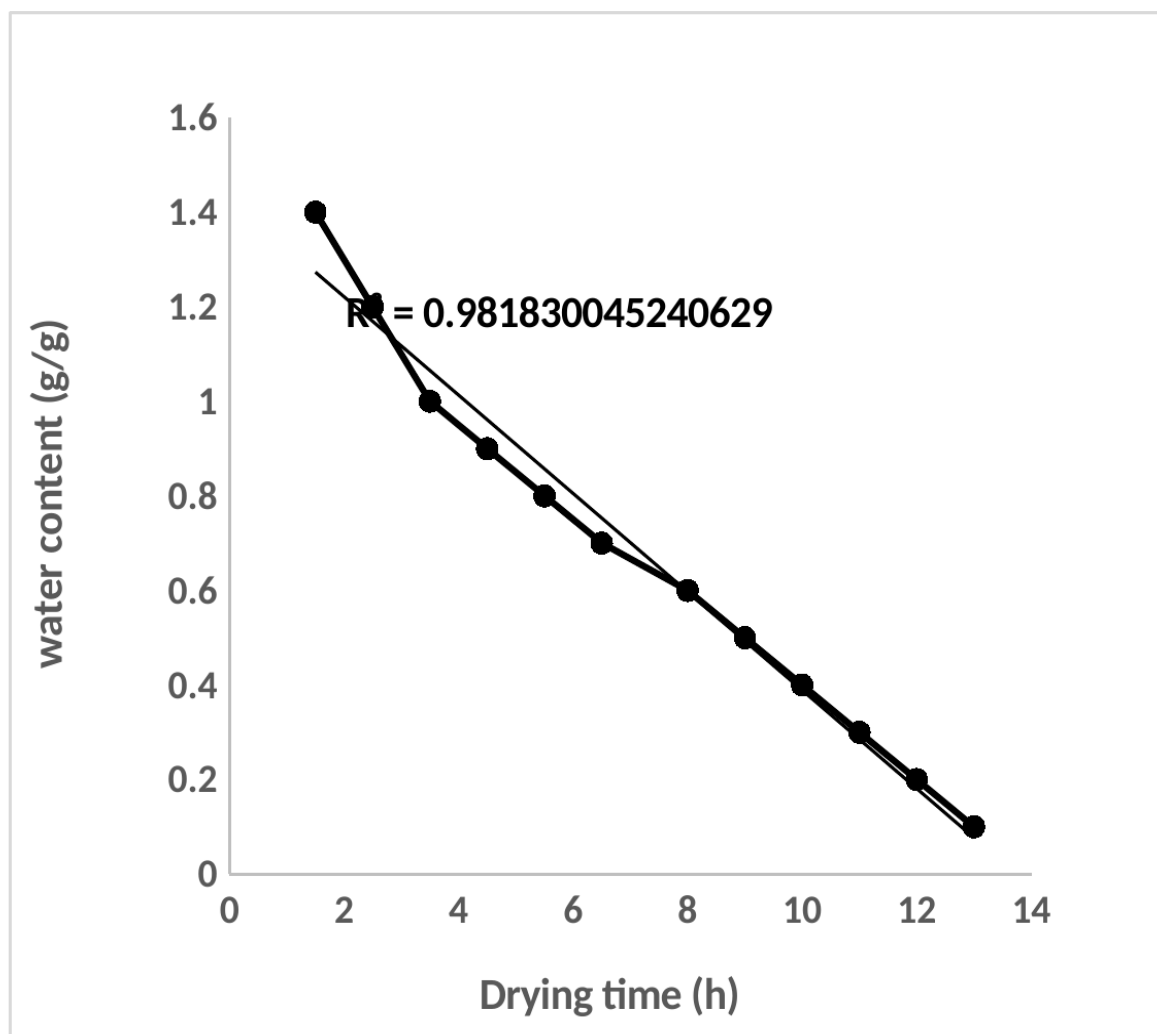


Figure 2. Water content of the soil–SAC1 mixture containing 1.0% SAC1 as a function of drying time ($R^2 = 0.982$).

3.4. Effect of 2.0% SAC1

The 2.0% SAC1 treatment showed the highest initial and residual water contents among the tested application rates. The initial water content was approximately 1.60 g g⁻¹ and decreased to approximately 0.30 g g⁻¹ after about 13 h. The drying relationship exhibited $R^2 = 0.997$ (Figure 3), representing the highest coefficient of determination among the three treatments.

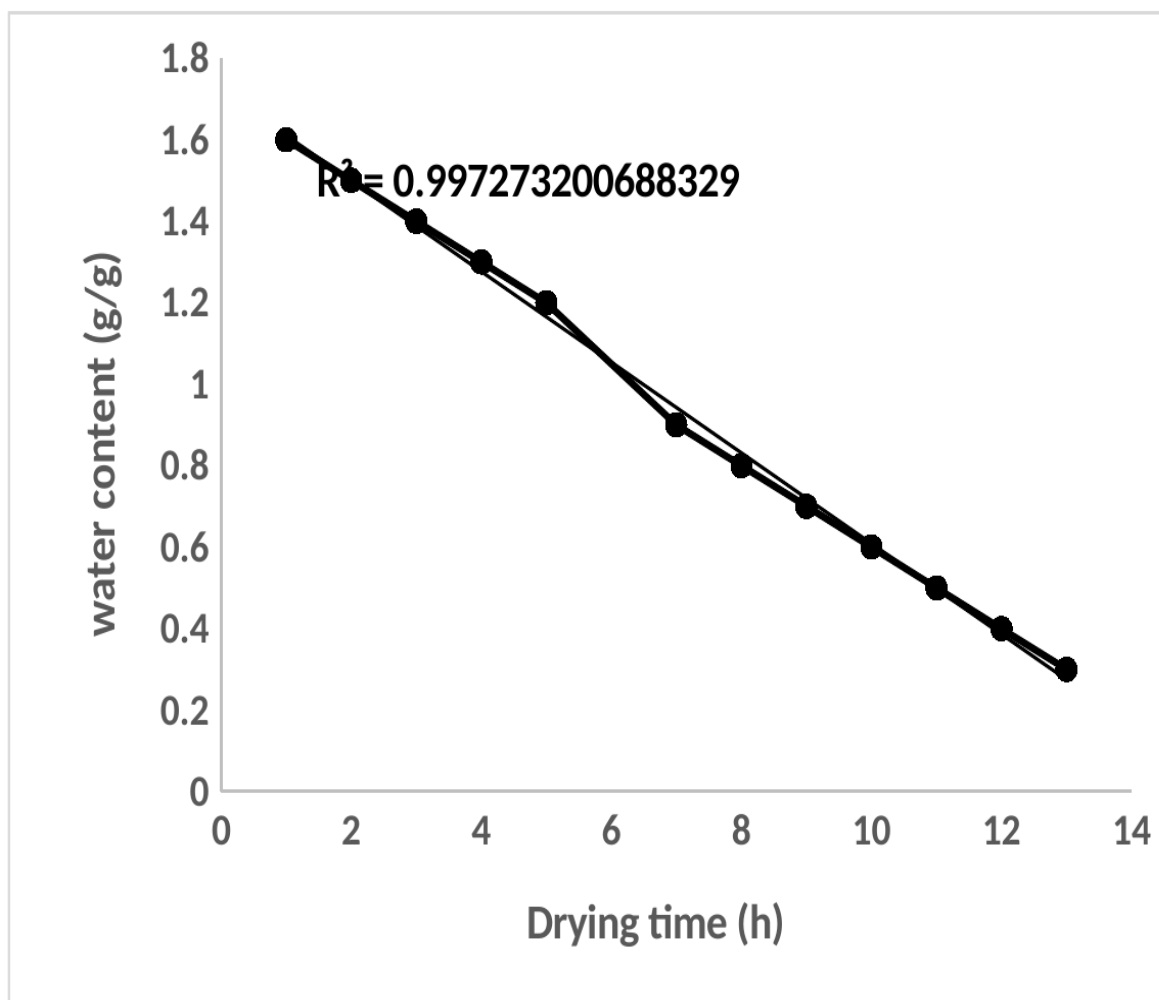


Figure 3. Water content of the soil–SAC1 mixture containing 2.0% SAC1 as a function of drying time ($R^2 = 0.997$).

3.5. Comparative effect of SAC1 concentration

The measured water-storage behavior increased with SAC1 application rate across the tested range. The initial water content increased from approximately 1.00 g g⁻¹ at 0.5% SAC1 to 1.40 and 1.60 g g⁻¹ at 1.0 and 2.0%, respectively. At the end of the approximately 13-h observation period, the corresponding water contents were approximately 0.09, 0.10 and 0.30 g g⁻¹. The results therefore demonstrate a concentration-dependent increase in residual water content under the experimental drying conditions.

SAC1 concentration (% w/w)	Initial water content (g g ⁻¹)	Water content near end (g g ⁻¹)	Drying period	R ²
Control	≈0.50	Nearly dry	≈5–6 h first stage	—
0.5	≈1.00	≈0.09	≈13 h	0.988
1.0	≈1.40	≈0.10	≈13 h	0.982
2.0	≈1.60	≈0.30	≈13 h	0.997

Table 1. Summary of measured soil-water retention behavior under the tested drying conditions.

3.6. Mechanistic interpretation

The observed behavior is consistent with the water-retention function expected from a hydrophilic, cross-linked polymer network. After hydration, the polymer can swell and create localized water-rich domains within the soil matrix. As the surrounding soil dries, water loss from these domains may occur more gradually than direct evaporation or drainage from the untreated soil. The magnitude of this effect depends on polymer concentration, pore structure, soil texture, water composition and the physical confinement of the swollen polymer.

The present data support delayed moisture depletion but do not directly establish the amount of plant-available water. Plant-available water is a soil-water-potential-dependent parameter and should be determined using appropriate matric-potential

measurements rather than inferred solely from total water content. This distinction is important because increasing total retained water does not necessarily mean that all of the additional water is accessible to plant roots.

3.7. Comparison with previous studies

The present observations are consistent with the broader literature showing that SAP amendments can slow moisture loss from soil. Takahashi et al. reported that evaporation from soil–SAP mixtures became slower as soil water content decreased and that SAP application extended the time to complete desiccation. Their work also demonstrated that SAP performance is strongly influenced by soil pore space and solution salinity. Saha et al. similarly concluded that soil texture, salinity and application rate are important determinants of hydrogel performance. These findings support the interpretation that the drying response observed here is a soil–polymer interaction rather than a simple consequence of the polymer’s swelling capacity in distilled water.

Other agricultural studies have shown that SAP effects can vary substantially with material type and application conditions. For example, Situ et al. demonstrated that some SAPs can alter soil exchangeable cations and plant responses, illustrating why soil chemical effects should be evaluated alongside water retention. The present study therefore provides evidence for water-retention behavior only and should not be interpreted as evidence of crop-yield improvement or water-use efficiency.

3.8. Significance and limitations

The main significance of the present experiment is that it demonstrates a measurable extension of moisture persistence in soil amended with a guar gum-based SAP under laboratory drying conditions. The effect was observed at all three tested application rates, with the 2.0% treatment showing the highest residual water content at the end of the measurement period.

Several limitations should be considered. The experiment was conducted under laboratory drying conditions rather than a field environment; plant growth was not evaluated; soil matric potential and plant-available water were not measured; salinity effects were not tested; repeated wetting–drying cycles were not examined; and replicate-level data were not available for statistical inference. In addition, the available source record does not provide all environmental and procedural details required for complete reproducibility. These limitations should be addressed in future experiments.

3.9. Application rate and future research

Within the tested range, 2.0% SAC1 produced the highest observed residual water content. However, this concentration should not be described as an agronomic optimum. An optimum field application rate requires simultaneous consideration of plant response, soil aeration, nutrient dynamics, salinity, polymer persistence, economic cost and repeated irrigation or rainfall cycles.

Future work should include replicated experiments with controlled temperature and humidity, measurement of soil matric potential and plant-available water, repeated wet–dry cycling, saline irrigation water, nutrient interactions, soil-incubation studies and greenhouse or field trials. Crop-specific experiments would be necessary to determine whether the observed increase in soil water persistence translates into improved plant establishment, biomass, yield or water productivity.

IV. CONCLUSION

A guar gum–g-poly(acrylic acid) superabsorbent composite (SAC1) increased measured water retention and delayed moisture depletion in the tested soil during laboratory drying. At 0.5, 1.0 and 2.0% SAC1, the initial water contents were approximately 1.00, 1.40 and 1.60 g g⁻¹, respectively, while the corresponding water contents near the end of the approximately 13-h observation period were approximately 0.09, 0.10 and 0.30 g g⁻¹. The drying relationships showed high R² values of 0.988, 0.982 and 0.997, respectively. The results demonstrate the potential of the guar gum-based composite to delay moisture depletion under the tested conditions. The study does not, however, establish plant-available water, crop response or an optimum agricultural application rate. Further replicated, soil-physical and plant-based studies are required before practical field recommendations can be made.

DECLARATIONS

Author Contributions

Musarrat Khan: Conceptualization, methodology, investigation, data analysis, writing—original draft, and writing—review and editing.

Funding

No specific external funding was reported for this study.

Conflict of Interest

The author declares no conflict of interest.

Data Availability

The data underlying the reported drying curves are derived from the experimental records generated in this study and can be made available by the corresponding author upon reasonable request.

Ethical Approval

Not applicable.

REFERENCES

- Mignon, A., De Belie, N., Dubruel, P., & Van Vlierberghe, S. (2019). Superabsorbent polymers: A review on the characteristics and applications of synthetic, polysaccharide-based, semi-synthetic and “smart” derivatives. *European Polymer Journal*, 117, 165–178. <https://doi.org/10.1016/j.eurpolymj.2019.04.054>
- Saha, A., Sekharan, S., & Manna, U. (2020). Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. *Soil and Tillage Research*, 204, 104736. <https://doi.org/10.1016/j.still.2020.104736>
- Takahashi, M., Kosaka, I., & Ohta, S. (2023). Water retention characteristics of superabsorbent polymers (SAPs) used as soil amendments. *Soil Systems*, 7(2), 58. <https://doi.org/10.3390/soilsystems7020058>
- Malik, S., Chaudhary, K., Malik, A., Punia, H., Sewhag, M., Berkesia, N., Nagora, M., Kalia, S., Malik, K., Kumar, D., Kumar, P., Kamboj, E., Ahlawat, V., Kumar, A., & Boora, K. (2023). Superabsorbent polymers as a soil amendment for increasing agriculture production with reducing water losses under water stress condition. *Polymers*, 15(1), 161. <https://doi.org/10.3390/polym15010161>
- Situ, Y., Yang, Y., Huang, C., Liang, S., Mao, X., & Chen, X. (2023). Effects of several superabsorbent polymers on soil exchangeable cations and crop growth. *Environmental Technology & Innovation*, 30, 103126. <https://doi.org/10.1016/j.eti.2023.103126>
- Masoumi, Z., Bahmanyar, M. A., Emadi, M., Ghajar Sepanlou, M., & Biparva, P. (2023). Improvement of water use efficiency in rice cultivation using bio-based superabsorbent. *Polish Journal of Environmental Studies*, 32(3), 2243–2250. <https://doi.org/10.15244/pjoes/157549>
- El Idrissi, A., Channab, B.-E., Essamlali, Y., & Zahouily, M. (2024). Superabsorbent hydrogels based on natural polysaccharides: Classification, synthesis, physicochemical properties, and agronomic efficacy under abiotic stress conditions: A review. *International Journal of Biological Macromolecules*, 258(Part 2), 128909. <https://doi.org/10.1016/j.ijbiomac.2023.128909>

Copyright & License:

© Authors retain the copyright of this article. This work is published under the Creative Commons Attribution 4.0 International License (CC BY 4.0), permitting unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.