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Innovative hydrogels use in the germination and growth of tree species *Paulownia tomentosa* and *Cupressus sempervirens*

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Abstract

Research goal: This article presents the results of a research project aimed at demonstrating the effects and benefits of using an organic ingredient, hydrogel (Hydro Start), to improve the germination and growth of *Paulownia tomentosa* and *Cupressus sempervirens* seedlings.

Materials and Methods: The experiments started in May 2022 and were conducted in the CREA-OF greenhouses in Pescia (PT) on seeded plants of Paulownia tomentosa and Cupressus sempervirens. The seeds were placed in pots with various hydrogel capsules to determine whether there were any effects on germination and plant growth. Agronomic analyses of the seeds and plants, microbiological analyses and substrate evaluation were also conducted.

Results and Discussion: The experiment showed that the use of hydrogel can improve the quality and resistance of sown plants of Paulownia tomentosa and Cupressus sempervirens. In general, the improvement in average germination time and plant growth was proportional to the number of hydrogel capsules inserted into the substrate at the time of sowing; this also influenced the microbial colonisation of the soil. Studies show that the water retained by the hydrogel forms a water reserve in the soil that can increase the water uptake efficiency of plants. Mixing superabsorbent materials (hydrogels) with soils or growing media can significantly increase the water-holding capacity of the soil. Water is available to plants for a longer period of time, making them more resistant, especially during transplanting. Furthermore, the incorporation of hydrogels into the soil or growing media allows for improved germination, plant growth and nutrient and water uptake.

Conclusions: Research shows that hydrogels can be used in a variety of ways due to their ability to retain water. These innovations can also ensure and promote plant survival in drought conditions. The results show that new hydrogels need to be evaluated not only for their physical properties, but also for their biological attributes related to the positive and negative aspects that bind microorganisms to plants.

Keywords: Forestry plants; Climate change; Sustainable agriculture; Hydrogel; Rhizosphere

1. Introduction

Agriculture is increasingly subject to abiotic stress (water, heat, salt) due to climate change, soil degradation, and urbanization. Despite the increase in food demand, the need for water to irrigate crops is decreasing. In order to maintain soil moisture and increase crop resistance to drought, new techniques and technologies must be developed. Hydrogels, crosslinked materials that can absorb water without dissolving and provide plant nutrients, could be a

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solution to these environmental problems [1]. Proteins such as collagen and polysaccharides such as alginate are typically found in hydrogels. Hydrogels are usually formed from synthetic polymers that are produced through chemical polymerization [2,3]. When exposed to certain external stimuli, such as temperature, pH, or solvents, a hydrogel can undergo drastic changes in volume as a result of a single polymer molecule sandwiched between a liquid and a solid. In agriculture, petroleum products are usually used to improve the water retention of soils in dry environments. They can also absorb water many times their weight. In water-scarce conditions, hydrogels have been shown to be very useful for meeting the water needs of plants [4]. The water retention capacity of the sand was increased from 171% to 402% by using these polymers at a dose of 2 g/kg in these studies. By improving the soil's water retention capacity, increasing plant resistance, and reducing wilting, hydrogels reduce irrigation turnover [5]. Water can be absorbed by hydrogels because of their particular swelling capacity, which depends on the polymer's structure and the external environment. In order to study the swelling process, geometric dimensions were measured and the volume of liquid remaining in the structure was recorded [6]. These water-absorbent polymers were developed exclusively for agricultural use in the late 1980s. The use of hydrogels can reduce synthetic fertilizers significantly, improving crop yields and nutritional value. Especially in arid and semi-arid regions, sustainable practices would be beneficial. Furthermore, hydrogels are non-toxic and can be used safely in agricultural environments [7].

1.1. Applications and structure of hydrogels

According to a number of studies, hydrogels can increase soils' capacity to hold water and, as a consequence, can prolong their usefulness as a source of water for plants [8,9,10]. Due to the presence of hydrophilic groups, hydrogels are capable of absorbing and retaining large volumes of liquids [11,12]. A common form of hydrogel in agriculture is a hybrid of acrylate-based and cellulose-based [13]. An acrylate-based hydrogel is composed of synthetic polymers, such as acrylamide, while cellulose-based hydrogels are naturally derived polysaccharides such as cellulose, chitin, and chitosan. In comparison with acrylate or hybrid hydrogels, cellulose-based hydrogels are the most biocompatible, biodegradable, and non-toxic [14,15]. The study by Demitri et al. (2013) [9] found that soil amended with a cellulose-based hydrogel increased tomato plant survival by 14 days by increasing soil water retention and sustained water release. In three soils with different textures, Womack et al. (2021) [16] evaluated the effects of a polyacrylate hydrogel and a cellulose-based hydrogel on soil porosity and pore distribution. In contrast to unamended soils, adding hydrogels to soils increased macroporosity (pores > 828 m) by at least 12%. The hydrogel matrix can be mixed with liquid fertilizer to produce slow-release fertilizers [17,18]. In addition to hydrogels' high swelling ability, fertilizers are diffused slowly into the soil, which affects nutrients' release slowly [18]. In addition to improving plant nutrition, these slow release fertilizers can reduce environmental impact, decrease evaporation losses, and decrease irrigation frequency [17,18]. It was found by Cheng et al. (2018) [19] that urea fertilizer could be encapsulated with a superabsorbent HG for 40 days, resulting in slow N release. According to Davidson et al. (2013) [17], fertilization with SRF doubled wheat seeds' mass compared to conventional fertilization. Based on the same study, conventional fertilizer was reduced by 78% to obtain the same plant yield in nutrient-depleted soil with SRF [17]. In these studies, it has been shown that the use of hydrogels in plant production can have many advantages, but very little is known about the effect of hydrogels on the germination and growth of difficult-to-germinate plants such as trees.

Objectives

This article presents the results of a research project aimed at demonstrating the effects and benefits of using a biological ingredient, Hydrogel (Hydro Start), to improve the quality of seedlings of tree species such as *Paulownia tomentosa* and *Cupressus sempervirens*, which often encounter difficulties at germination.

2. Material and methods

The experiments, which started in May 2022, were conducted in the greenhouses of CREA-OF in Pescia (Pt), Tuscany, Italy (43°54'N 10°41'E) with *Paulownia tomentosa* (Figure 1A,1B) and *Cupressus sempervirens*. Seeds were placed in pots with a diameter of 12 cm; 16 seeds per thesis were divided into four replicates of 4 seeds each.

The experimental groups were:

- Group without hydrogel (CTRL) (peat 90% + sand 10%), watered with water and previously fertilized with (1 kg m-3 COMPO Floranid Starter NPK 17-23-8, three months);
- Group with one hydrogel capsule near the seed (CP1) (peat 90% + sand 10%), watered with water;
- Group with two hydrogel capsules near the seed (CP2) (peat 90% + sand 10%), irrigated with water;
- Group with three hydrogel capsules near the seed (CP3) (peat 90% + sand 10%), irrigated with water.

Hydrogel (Hydro Start) had the following characteristics: 78% organic carbon; 5,8% nitrogen; 1% phosphorus; 1,2% potassium; 1% sulfur. Substrate pH was 6.8.

A single irrigation per day was provided for eight months to the plants. Using drip irrigation, plants were watered. It was activated by a timer, whose program was adjusted weekly according to climatic conditions and leaching percentages. Plant height, vegetative weight, root weight, the number of germinated seeds, average germination time, number of microorganisms in the substrate, and pH were measured on 4 December 2022.

2.1. Analysis methods

- pH: For pH measurement, 1 kg of the substrate was taken from each plant, and 50 g of the mixture was placed in a beaker containing 100 ml of distilled water. After 2 hours, the water was filtered and analyzed [20];
- Microbial count: direct determination of total microbial count by microscopy of cells contained in a known sample volume using counting chambers (Thoma chamber). The surface of the slide is etched with a grid of squares, with the area of each square known. Determination of viable microbial load after serial decimal dilutions, spatula seeding (1 ml) and plate counting after incubation [21];
- Analytical instruments: IP67 PHmeter HI99 series - Hanna instruments; combined test kit for soil analysis - HI3896 - Hanna instruments; Microbial diversity of culturable cells [22].

2.2. Statistics

The experiment was carried out in a randomized complete block design. Collected data were analyzed by one-way ANOVA, using GLM univariate procedure, to assess significant ($P \leq 0.05$, 0.01 and 0.001) differences among treatments. Mean values were then separated by the LSD multiple-range tests ($P = 0.05$). Statistics and graphics were supported by the programs Costat (version 6.451) and Excel (Office 2010).

3. Results

According to the experiment, hydrogels improved the quality and resistance of *Paulownia tomentosa* and *Cupressus sempervirens* plants sown (Figure 1). Plant growth in general and germination times were improved by inserting a greater number of hydrogel capsules in soil at sowing; soil microbial colonization was also improved. Microbial colonization in soils was higher with a higher number of hydrogel capsules (3 capsules). There was a significant increase in plant height in *Paulownia tomentosa* among all three experimental types (CP1, CP2, and CP3) (Table 1) (Figure 2). With hydrogel capsules, plants showed a significant decrease in pH, vegetation and root weight, germination time and germination rate, as well as microorganism numbers.

It was also observed that the hydrogel significantly reduced the average germination time and increased plant growth in *Cupressus sempervirens* (Table 2). Again, theses with two or three hydrogel capsules performed better in terms of plant height, vegetative and roots growth (Figure 3) and microbial colonization of the substrate. Unlike *Paulownia tomentosa*, no differences in substrate pH were detected between the different theses.

Table 1 Evaluation of hydrogel use on the agronomic characters of *Paulownia tomentosa*

Groups	Plant height (cm)	Vegetative weight (g)	Roots weight (g)	Germinated seeds (n°)	Germination time (days)	Substrate microbial Count (cfu/g)	Ph substrate
CTRL	13.33 b	6.65 c	5.31 b	1.67 b	19.00 a	1.30×10^2 c	6.76 a
CP1	20.00 a	7.40 b	6.01 a	3.33 a	16.33 b	8.60×10^2 b	6.67 b
CP2	19.67 a	7.59 ab	6.08 a	3.00 a	15.33 b	1.05×10^3 a	6.63 b
CP3	18.33 a	7.71 a	6.10 a	3.67 a	15.67 b	1.08×10^3 a	6.60 b
ANOVA	*	***	***	*	***	***	*

One-way ANOVA; n.s. – non significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05).Legend: (CT) control; (CP1) 1 capsule ;(CP2) 2 capsules; (CP3) 3 capsules

Table 2 Evaluation of hydrogel use on the agronomic characters of *Cupressus sempervirens*

Groups	Plant height (cm)	Vegetative weight (g)	Roots weight (g)	Germinated seeds (n°)	Germination time (days)	Substrate microbial Count (cfu/g)	pH substrate
CTRL	12.30 b	6.38 d	5.25 b	19.63 b	16.80 a	1.40×10^2 d	6.76 a
CP1	12.92 a	6.54 c	5.85 a	20.61 ab	14.40 b	7.77×10^2 c	6.72 a
CP2	12.91 a	6.91 b	5.87 a	24.22 a	14.00 b	9.51×10^2 b	6.78 a
CP3	13.04 a	6.96 a	5.95 a	20.44 b	14.80 b	1.01×10^3 a	6.72 a
ANOVA	***	***	***	ns	***	***	ns

One-way ANOVA; n.s. – non significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05).Legend: (CT) control; (CP1) 1 capsule ;(CP2) 2 capsules; (CP3) 3 capsules

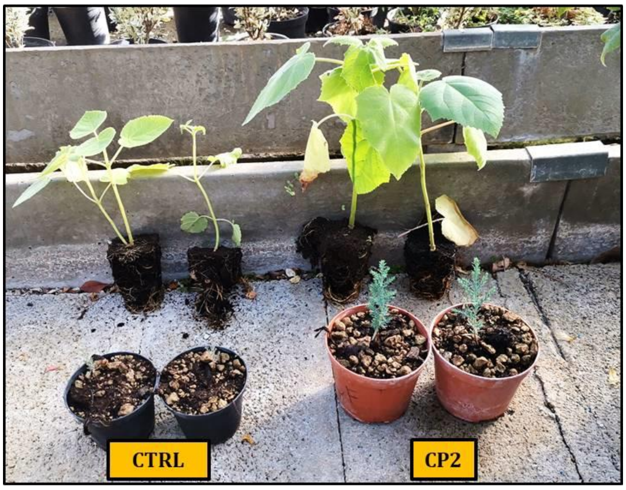

Figure 1 Effect of Hydrogel on the vegetative growth of *Paulownia tomentosa and Cupressus sempervirens* plants, control (CTRL) vs two hydrogel capsules (CP2)

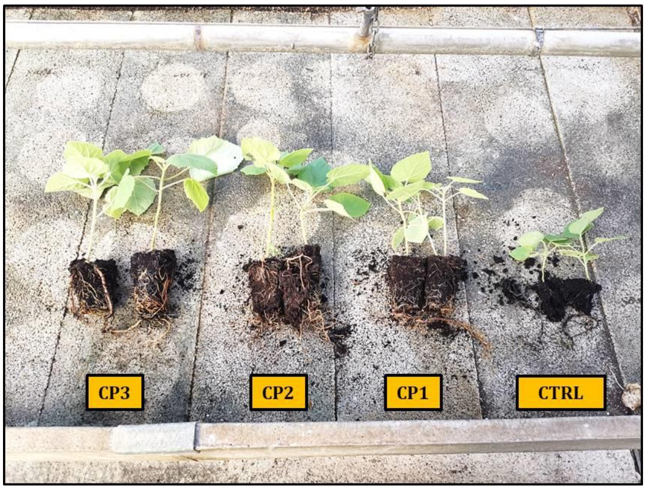

Figure 2 Effect of Hydrogel on the vegetative and radical growth of *Paulownia tomentosa* plants, control (CTRL), one hydrogel capsule (CP1), two hydrogel capsules (CP2), three hydrogel capsules (CP3)

Figure 3 Effect of Hydrogel on radical growth of *Cupressus sempervirens* plants, control (CTRL) vs two hydrogel capsules (CP2)

4. Discussion

Hydrogels have been applied to agriculture to enhance soil water retention capacity and to promote plant germination and growth in soils with extreme conditions, especially when there is no water available [23,24,25,26]. Also, hydrophilic polymers have been used to facilitate plant survival and transplantation of trees and shrubs in arid regions on the African and Australian continents. Anionic polymers have shown the best results for seed emergence and soil water retention [27,28,29,30].

In order for hydrogels to have a beneficial effect on plant growth, they need to be used and applied to the soil, growing medium, or directly to the plants. Spraying hydrogels over the roots isn't enough, for example [31]. The hydrogel capsules were found to work better if they were layered a few centimeters above the soil surface [32,33]. This was also observed in this experiment, where the capsules were placed alongside the seeds in the substrate. As a result, the properties of these products were fully used, which resulted in *Paulownia tomentosa* and *Cupressus sempervirens* plants growing and being of excellent quality. Several factors must be considered when using hydrogels, including the quality and type of hydrogel, the size of the granules, the application, and the type of plant.

Hydrogels can create a water reserve in the soil, which can increase the efficiency of plant water uptake [34,35]. It is possible to significantly increase the water-holding capacity of cultivation soils or substrates by mixing superabsorbent materials (hydrogels) with them. Especially during transplantation, plants are more resilient because water is available for longer periods of time [36,37,38]. In addition, incorporating hydrogels into the soil or growing medium improves germination, plant growth, and nutrient and water absorption [39,40,41].

In addition to ultraviolet radiation, fertiliser salts, and freezing and thawing processes, the hydrogel can be degraded by environmental factors [42,43,44,45]. Microorganisms such as *Acinetobacter sphaericus* and *Bacillus sphaericus* are capable of degrading polyacrylamide gels, while fungi such as *Phaenorochaete chrysosporium* and *Pleurotus ostreatus* can degrade them. The soil microbes dissolve the polymer and make it more susceptible to further degradation [46]. The microorganism populations in the hydrogel-treated theses were significantly higher than those in control theses, likely because the polymers provide more water reserves for the substrate, and they can maintain favourable conditions for microorganisms in the rhizosphere for longer periods, which is beneficial to plant growth [47,48]. Abo-Sedera (2006) [49] examined the effects of hydrogels on microbial activities, concluding that they contributed to a 127% increase in bugs and 23% increase in fungi. Hydrogels have also been found to increase bacterial aggressiveness and the number of bacteria (16%) and fungi (18%) [50]. For a better understanding of polyacrylate hydrogel degradation, longer studies may be required. Incorporating biofertilizing microorganisms into hydrogels could represent an important future research prospect for controlling fungi and bacteria that degrade polyacrylamide gel, as well as improving plant growth.

5. Conclusion

Research shows that hydrogels have many uses due to their ability to bind water. The polymers can absorb up to 600 times their weight in water and alter the water capacity of the growing medium to promote the growth of plant species under water-stressed conditions. In addition, these innovations can help ensure and promote plant survival under drought conditions. Further experiments are currently underway to evaluate hydrogels for germination, transplantation, and acclimatization of various plant species. The results show that new hydrogels need to be evaluated not only for their physical properties, but also for their biological attributes related to the positive and negative aspects that bind microorganisms to plants.

Compliance with ethical standards

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Disclosure of conflict of interest

The author declares no conflict of interest.

Statement of ethical approval

The present research work does not contain any studies performed on animal/human subjects.

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