

Research

Effect of hydrogel on survival and growth of *Grevillea robusta* seedlings under semi-arid field condition

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Received: 1 November 2023 / Accepted: 25 April 2024

Published online: 02 May 2024

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Abstract

Water scarcity limits the survival and growth of planted-out seedlings in Ethiopia's semi-arid regions. Hydrogel, recently introduced in Ethiopia, is a super-absorbent polymer to reduce water stress. This study investigated its effect on the early survival and growth of *Grevillea robusta* seedlings in semi-arid areas. Relevant soil characteristics were analyzed. Four hydrogel levels (control, 3, 5, and 7 g/plant) were applied to the bottom of planting holes in a randomized complete block design with three replicates. Survival, Height, and Root Collar Diameter were measured at 6 and 14 months after planting. One-way ANOVA assessed hydrogel effects. No significant positive effects of hydrogel on survival or early growth compared to the control (0 g/plant) were observed in the sandy-loam soil. These findings suggest limited benefit under the study's specific conditions. Further research is crucial to explore the potential of hydrogels, considering broader ranges of application rates and methods, tree species, and environmental conditions. This knowledge may support forest restoration efforts in the face of severe land degradation, climate change, and variability in Ethiopia.

Keywords Ethiopia · Height growth · RCD growth · Hydrogel · Semi-arid · Survival

1 Introduction

Globally, water scarcity is aggravated in semi-arid regions, posing threats to food production and ecosystems [1, 2]. This scarcity is characterized by limited rainfall, high evaporation rates, frequent droughts, and land degradation, deterring forestry and agricultural development [3–5]. Consequently, innovative options have been widely utilized to enhance soil moisture and promote plant survival and growth in water-deficient areas around the globe. Hydrogel emerges as one of the promising technologies for addressing water scarcity challenges [6–9]. Its remarkable ability to retain large quantities of water when added to the soil and gradually release it reduces the risk of drought stress. It creates a favorable microenvironment for planted-out seedlings [10]. Research recommendations have demonstrated hydrogel benefits in water-scarce environments in various countries e.g., [11–15]. Despite the promising potential of hydrogel technology, its adoption and effectiveness vary across different regions (e.g. species, soils) and contexts (methods, hydrogel types, application rates) [16–18].

The Ethiopian landmass covers a 27% semi-arid environment [19] and has been experiencing rapid land degradation and recurrent drought [20–23]. Accordingly, the country is implementing a sustainable land management program and the Green Legacy Initiative, aimed at conserving soil and water resources and rehabilitating degraded communal lands through tree planting and constructing physical structures like soil or stone bunds to address the problems of water scarcity and land degradation [24–28]. Accelerating the land restoration process in the semi-arid region of Ethiopia

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is essential, considering the severity of land degradation [29–31]. In this regard, introducing and using relatively new hydrogel technology is essential for the country [32]. However, a knowledge gap hinders the practical application of hydrogel technology in Ethiopian forestry, where its potential to combat water scarcity and promote forest development still needs to be explored.

Grevillea robusta was chosen as the ideal tree species for this study investigating hydrogel effectiveness in Ethiopia due to its unique characteristics. *G. robusta* is a fast-growing tree species that offers significant economic value due to its valuable timber used in construction, furniture, and fuelwood [33, 34]. Successful establishment of *G. robusta* seedlings through hydrogel application could lead to significant economic benefits for communities in Ethiopia's semi-arid regions. Furthermore, *G. robusta* grows in low-fertility soils and plays a critical role in soil erosion control. Improved seedling establishment using hydrogel may have the potential to accelerate this ecological benefit. Most importantly for this study, *G. robusta*'s rapid growth rate allows the researchers to observe the impact of hydrogel on seedling development within a shorter timeframe compared to slower-growing native species.

Therefore, the objectives of this study were to evaluate the effects of various hydrogel concentrations on the survival and early growth of *G. robusta* seedlings in sandy loam soil and to recommend the most effective hydrogel concentration level for this specific combination of species and soil type.

2 Materials and methods

2.1 Study area description

The study was conducted from 2018 to 2020 in the “Lume” district of the East Shoa Zone in the Oromia Regional State of Ethiopia (Fig. 1). The district is located in the semi-arid agro-ecological zone, which is characterized by erratic rainfall, high evaporation rates, and poor soil quality [35]. The annual rainfall in the district varies between 500 and 1200 mm, and the rainy season is short and unimodal. The average monthly temperature in the district ranges from 22 °C to 34 °C. The primary soil type is Vertisols [36]. The study site was selected with the consultation of the district experts and located on the northwest side of “Koka” Dam between 8° 31' 739" N and 39° 10' 899" E. Its average altitude was 1680 masl [37].

2.2 Design and analysis of the experiment

Core soil samples were collected. A composite soil sample was also collected from three 2 m × 3 m × 0.30 m pits of mixed excavated soils. The Engineering Corporation of Oromia laboratory in Addis Ababa analyzed these samples for bulk density, particle size, texture class, field capacity, permanent wilting point, available water content, pH, electrical conductivity, exchangeable bases, cation exchange capacity (CEC), base saturation, organic carbon (OC), and organic matter (OM) [38].

The hydrogel experiment was conducted using *G. robusta* seedlings (Fig. 2). They were raised at the nursery of the Central Ethiopia Forestry Development Center. The seeds were collected from the center seed store and sown directly in polythene pots, 8 cm in diameter and 15 cm in Height, filled with a mixture of forest soil, farm yard manure, and sand with a ratio of 2:1:1, respectively. Seedlings in the nursery were watered twice daily, in the morning and late afternoon. Weeding and cultivation of seedlings were applied uniformly, and the seedlings' hardening-off was applied 2 weeks before planting by reducing the daily watering frequency to one in the 1 week and altogether ceased in the 2nd. In the nursery, seedlings were matured for planting at 6 months. We favored this particular tree species due to its rapid growth rate, wide range of ecological niches, and elevated environmental and socio-economic benefits [33]. The planting holes were manually dug to a depth of 40 cm before two weeks of planting, aiming to capture adequate moisture.

The research site was fenced for protection, and the plots and blocks were separated by 2 m and 3 m, respectively. The size of each experimental plot was 10 m × 10 m, and the spacing between planted-out seedlings was uniform, 2 m × 2 m. Thirty-six seedlings were planted in a hole with a different rate of hydrogel (four treatments) placed in the bottom of them. Treatments were: 0 g hydrogel/plant (Control), 3 g hydrogel/plant, 5 g hydrogel/plant, and 7 g hydrogel/plant. The optional rates of hydrogel were literature-based. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications. The source of Stockosorb 400 K hydrogel was Evonik East Africa Limited, Kenya. It is a super-absorbent hydrophilic polymer (cross-linked poly-acrylamides) that can absorb and store enormous amounts of water when incorporated into the soil and release it to plants, ensuring their survival and growth when they are under prolonged drought conditions [39, 40].

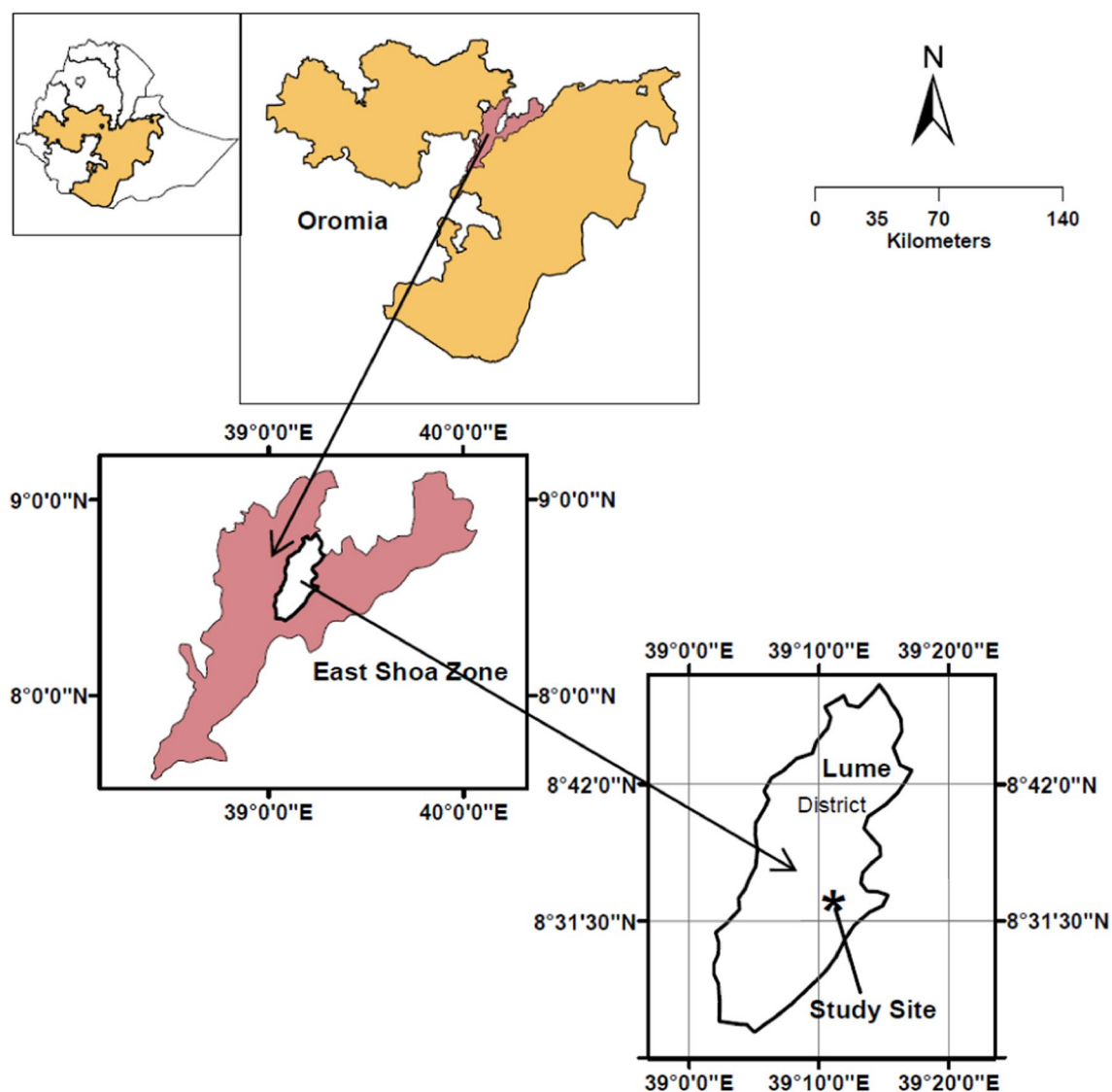


Fig. 1 Study area

Fig. 2 Part of the study site when the experiment was completed. This photograph was taken by one of the researchers during data collection



Data on Survival, RCD, and Height of the seedlings were collected at 6 and 14 months after planting. A total count was applied to determine the survival rates, while seedling growth measurements were made for the inner sixteen seedlings in each plot to avoid border effects. Data were subjected to a one-way analysis of variance (ANOVA), and means were compared by Fisher tests ($P \leq 0.05$) using SPSS software, Version 22.

3 Results

3.1 Soil physico-chemical properties

Soil characteristics of the study site are presented in Table 1. The findings show that the soil textural class was sandy loam. The soil pH was alkaline, with a value of 8.7. The sum of the exchangeable bases (CEC), organic carbon (OC), and bulk density of the soil was 27.8 cmol/kg, 0.5%, and 1.3 g/cm³, respectively. The results also show that the most abundant exchangeable base in the sandy loam soil was calcium, followed by potassium, magnesium, and sodium. The field capacity of the soil was 36.6%, and the permanent wilting point was 14.5%. Thus, the sandy loam soil can hold only 22.1% of its water content for plant uptake.

Interestingly, the mean monthly rainfall distribution in the nearby study site is depicted in Fig. 3. It shows that the rainy season usually commences in June and facilitates the follow-up planting activities in July. However, after August, the amount of rainfall reduces and may not fully support the survival of planted-out seedlings because of the long dry spell where the temperate and evapotranspiration are rising too high.

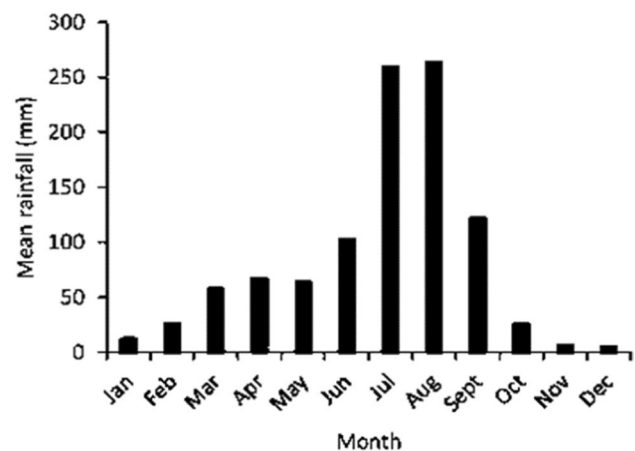
3.2 Effect of hydrogel on the survival rate of planted-out seedlings

The survival rates of the seedlings are presented in Table 2. The results show no evidence of a significant difference in survival rates among the four treatments at 6 months ($F = 1.1$, $p = 0.4$) and 14 months ($F = 0.5$, $p = 0.7$). The slightly highest

Table 1 Soil characteristics

I. Physical parameter	
1. Particle size (%)	
• Sand	54
• Silt	35
• Clay	11
• Textural class (USDA)	Sandy loam
2. Bulk density (g/cm ³)	1.31
3. Field capacity (FC, %)	36.65
4. Permanent wilting point (PWP, %)	14.52
II. Chemical parameter	
1. pH-H ₂ O (1:2.5 ratio)	8.7
2. Electrical conductivity (EC, ds/M)	0.294
3. Exchangeable bases (cmol/kg)	
• Ca ²⁺	21.2
• Mg ²⁺	2.15
• K ⁺	2.71
• Na ⁺	1.7
• Sum	27.76
4. Cation exchange capacity (CEC, cmol (+) kg ⁻¹)	27.5
5. Base saturation (PBS, %)	101
6. Organic carbon (OC, %)	0.49
7. Organic matter (OM, %)	0.84

Fig. 3 Mean monthly rainfall patterns of the nearby Mojo meteorological station (1981–2020) to the study site. Source: [41]



survival rates of *G. robusta* seedlings were revealed for the control ($93.5 \pm 4.2\%$) and the 3 g hydrogel/plant treatment ($81.5 \pm 12.5\%$) at 6 and 14 months, respectively. However, the lowest survival rates were revealed for the 5 g hydrogel/plant treatment in both ages.

3.3 Effect of hydrogel on the growth of root collar diameter (RCD) and height

Table 3 presents the RCD growth of *G. robusta* seedlings. The analysis revealed significant variations in RCD growth among treatments at both 6 ($F_{0.05} = 2.88$, $p = 0.04$) and 14 months ($F_{0.05} = 5.36$, $p = 0.002$) after planting. Seedlings grown in soil amended with the 5 g/plant hydrogel exhibited the highest RCD at both 6 months (0.34 ± 0.15 cm) and 14 months (0.68 ± 0.29 cm) compared to other treatments. However, no significant differences were found between the 5 g hydrogel/plant treatment and the controls on the RCD growth. Furthermore, the 7 g/plant hydrogel treatment resulted in significantly lower RCD than other treatments except 3 g/plant at both 6 months (0.23 ± 0.13 cm) and 14 months (0.53 ± 0.23 cm). Interestingly, both the 3 g and the 7 g hydrogel/plant treatments had a detrimental effect on the RCD growth.

Table 3 also shows the height growth of *G. robusta* seedlings. The analysis revealed significant differences in height among treatments at both 6 ($F_{0.05} = 3.09$, $p = 0.03$) and 14 months ($F_{0.05} = 3.40$, $p = 0.02$) after planting. The control treatment exhibited the greatest height at 6 months (29.8 ± 7.5 cm), while the 5 g/plant treatment achieved the highest height at 14 months (40.5 ± 18.77 cm). Interestingly, there were no significant differences in height between the control and the 5 g/plant treatment at any time point. Conversely, the 7 g/plant and 3 g/plant hydrogel treatments, as well as the 3 g/plant resulted in significantly lower heights compared to the controls at both 6 and 14 months, respectively. Notably, both the 3 g/plant and 7 g/plant hydrogel treatments had a detrimental effect on height growth, particularly at 14 months for the 3 g/plant treatment.

Table 2 Effect of hydrogel on the survival rates of seedlings at 6 and 14 months after planting

Treatments	Survival rate (%) $\pm$ SD	
	6 months after planting	14 months after planting
0 g/plant (Control)	93.5 ± 4.2^a	80.6 ± 10.0^a
3 g/plant	89.8 ± 9.8^a	81.5 ± 12.5^a
5 g/plant	83.3 ± 2.8^a	73.1 ± 5.8^a
7 g/plant	88.0 ± 8.5^a	76.8 ± 7.0^a
ANOVA	NS	NS

NB: Means of survival rate that do not share similar letters are significantly different; $S = p \leq 0.05$, otherwise not significant ($NS = p > 0.05$)

Table 3 Effect of hydrogel on RCD and height growth of seedlings at 6 and 14 months after planting

Treatments	RCD (cm) $\pm$ SD		Height (cm) $\pm$ SD	
	6 months after planting	14 months after planting	6 months after planting	14 months after planting
0 g/plant (Control)	0.32 $\pm$ 0.15 ^{ab}	0.65 $\pm$ 0.27 ^{bc}	29.8 $\pm$ 7.47 ^a	39.5 $\pm$ 13.12 ^{ab}
3 g/plant	0.26 $\pm$ 0.12 ^b	0.57 $\pm$ 0.18 ^{ab}	25.9 $\pm$ 7.83 ^{bc}	32.7 $\pm$ 9.12 ^c
5 g/plant	0.34 $\pm$ 0.15 ^a	0.68 $\pm$ 0.29 ^c	29.1 $\pm$ 9.58 ^{ab}	40.5 $\pm$ 18.77 ^a
7 g/plant	0.23 $\pm$ 0.13 ^c	0.53 $\pm$ 0.23 ^a	25.7 $\pm$ 6.44 ^c	33.06 $\pm$ 10.83 ^{bc}
ANOVA	S	S	S	S

NB: Means of RCD and Height that do not share similar letters are significantly different; S = $p \leq 0.05$, otherwise not significant (NS = $p > 0.05$)

4 Discussions

A soil with 0.5% organic matter (OC) is classified as low fertility, and a CEC of 27.5 cmol(+)kg⁻¹ is considered moderate [42]. The sandy loam soil texture, with its high proportion of sand particles, allows for rapid water drainage. This, coupled with the low organic carbon content (0.5%), limits the soil's ability to retain water, further contributing to the low available water capacity (AWC) of 22.1% for plant growth [43]. The moderate CEC (27.8 cmol/kg) indicates the soil's ability to hold positively charged ions (cations) like calcium, potassium, magnesium, and sodium. However, the high soil pH (8.7) can negatively impact the availability of certain nutrients, particularly micronutrients, by making them less soluble and less readily taken up by plants [44].

The findings showed that amending sandy loam soil with various levels of hydrogel did not improve the survival rates of planted *Grevillea robusta* seedlings. This aligns with other research [6, 45]. This suggests that the hydrogel application rates in this study might not have been compatible with the water requirements of *G. robusta*, despite its broad ecological adaptability. Remarkably, other studies have shown that hydrogels can improve survival rates [46–52], but excessive use can have detrimental effects e.g., [6, 45, 53, 54].

The effect of hydrogel on Root Collar Diameter (RCD) growth is inconclusive. While some studies also confirmed no significant positive effects [6, 18], others suggest potential benefits [6, 12, 13, 54, 55]. Ostrand et al. [53] even found that applying 7 g/L of hydrogel per seedling led to mortality in *Pinus sylvestris*. This inconsistency likely arises from several factors, including different hydrogel types and application rates, varying water needs and responses among plant species, and potential discrepancies in application methods and timing [9, 10, 12, 45].

Furthermore, some studies also support our finding that the amendment of soil with hydrogel does not affect the plants' height growth [6, 18]. Conversely, the negative effect of hydrogel on height growth of plants is also confirmed [53]. The findings also showed a positive effect on the growth of height [6, 13, 54, 55]; this suggests that the effect of hydrogel on plant height growth is not always beneficial and may depend on several factors, as mentioned earlier [9, 10, 12, 45]. Overall, the evidence on the effect of hydrogel on plant height growth is also mixed.

5 Conclusions

This study investigated the effect of varying hydrogel concentrations on the survival and growth of *G. robusta* seedlings in a semi-arid area with sandy loam soil. The effectiveness of hydrogel application in soil is highly dependent on the soil's physical and chemical characteristics. Sandy soils, with their high drainage rates, benefit most from hydrogel's water retention capabilities. Factors like soil pH and nutrient content may influence how hydrogel interacts with the soil environment and impacts plant growth. Unfortunately, neither seedling survival rate nor growth parameters (root collar diameter and height) were positively affected by the tested hydrogel concentrations. These results suggest that the potential benefits of hydrogels in this study are not realized under the conditions of this experiment. Further research is necessary to evaluate the influence of application rates, tree species, and environmental factors on the effectiveness of hydrogels.

Acknowledgements The author would like to thank Vicky Waitthaka, business development manager of Evonik East Africa Limited, who made this study possible by providing hydrogel. Thanks to Dr. Abayneh Derero and Kebede Gizachew for their close follow-up of the study. We are indebted to Wondwossen Gebretsadik and Abebe Abay for facilitating the technical assistance. We thank the anonymous manuscript reviewers for their valuable and constructive comments that helped us upgrade the manuscript. We are also indebted to the Editor of Discover Environment for granting us a waiver to publish this work.

Author contributions Conception and design: EG, ZW, NE, AA, and TT—Data collection: EG, ZW, and NE—Material preparation, data analysis, and writing up the first draft: EG—All authors: EG, ZW, NE, AA, and TT review and edit the final version of the manuscript.

Funding The authors have not received any funding.

Data availability The generated data of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors have no competing interests with anyone or institution.

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