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ARAŞTIRMA MAKALESİ RESEARCH PAPER

Restoration Strategies for Drylands: Impact of Hydrogel and Watering Frequency on Oak, Hawthorn and Pine Seedlings Survival

Emre AKAYDIN[1,2]*
[1]*Department of Landscape Architecture, Faculty of Agriculture, Ankara University, Turkey*
[2]*Ministry of Environment, Urbanization and Climate Change, Directorate General for Combating Desertification and Erosion, Ankara, Turkey*

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*: https://orcid.org/0009-0008-3086-2863

***Corresponding author's:**
Emre AKAYDIN
Department of Landscape Architecture, Faculty of Agriculture, Ankara University, Turkey
: emreakaydin25@gmail.com

Abstract: This study investigates the effects of irrigation frequency and soil hydrogel addition on the drought response and survival of seedlings from three tree species-oak (*Quercus robur L.*), hawthorn (*Crataegus monogyna Jacq.* and pine (*Pinus sylvestris L.*)-in a greenhouse experiment. The objective is to assess these factors' implications for ecological restoration in arid and semi-arid regions. A total of 240 seedlings (80 per species) were subjected to four experimental treatments, varying in watering regimes and soil amendments. Experiments 1 and 3 featured daily irrigation for the first 20 days, while Experiments 2 and 4 involved irrigation five times over the same period, followed by 30 days of drought stress. Hydrogel was incorporated into the soil in Experiments 3 and 4 at a rate of 8-10 grams per 8-10 litters of soil. Seedlings were tracked using unique codes and monitored for wilting and survival. Results showed hawthorn seedlings exhibited the highest survival rates and lowest wilting scores, followed by oak and pine. Seedlings grown in hydrogel-amended soil with daily watering demonstrated reduced wilting. The findings suggest that hydrogel addition and increased irrigation frequency enhance drought resilience, indicating potential benefits for using these methods in ecological restoration efforts in water-limited environments.

Keywords: Drought stress, dryland, ecosystem restoration, hydrogel.

Restorasyon Stratejileri: Hidrojel ve Sulamanın Meşe, Alıç ve Çam Fidanlarının Sağkalımı Üzerindeki Etkileri

***Sorumlu yazar:**
Emre AKAYDIN
Ankara Üniversitesi Ziraat Fakültesi Peyzaj Mimarlığı Bölümü, Türkiye
: emreakaydin25@gmail.com

Öz: Bu çalışmada, sulama sıklığı ve toprak hidrojel ilavesinin, bir sera deneyinde üç ağaç türünden- meşe (*Quercus robur L*), alıç (*Crataegus monogyna Jacq.*) ve çam (*Pinus sylvestris L.*) fidanlarının kuraklığa tepkisi ve hayatta kalması üzerindeki etkileri araştırılmaktadır. Amaç, kurak ve yarı kurak bölgelerde ekolojik restorasyon için bu faktörlerin etkilerini değerlendirmektir. Toplam 240 fide (tür başına 80), sulama rejimleri ve toprak değişiklikleri bakımından farklılık gösteren dört deneysel uygulamaya tabi tutulmuştur. Deney 1 ve 3'te ilk 20 gün boyunca günlük sulama yapılırken, Deney 2 ve 4'te aynı süre boyunca beş kez sulama yapılmış ve ardından 30 günlük kuraklık stresi uygulanmıştır. Hidrojel, Deney 3 ve 4'te 8-10 litre toprak başına 8-10 gram oranında toprağa dahil edilmiştir. Fidanlar benzersiz kodlar kullanılarak izlenmiştir ve solma indekslerine bakılarak hayatta kalmaları takip edilmiştir. Sonuçlar, alıç fidanlarının en yüksek hayatta kalma oranlarını ve en düşük solma skorlarını sergilediğini, ardından meşe ve çamın geldiğini göstermiştir. Günlük sulama ile hidrojel katkılı toprakta yetiştirilen fidanlar daha az solma göstermiştir. Bulgular, hidrojel ilavesinin ve artan sulama sıklığının kuraklığa dayanıklılığı artırdığını ve bu yöntemlerin su kısıtlı ortamlarda ekolojik restorasyon çabalarında kullanılmasının potansiyel faydalarına işaret ettiğini göstermektedir.

Anahtar kelimeler: Ekosistem restorasyonu, hidrojel, kurak alan, kuraklık stresi.

INTRODUCTION

Drought and desertification have emerged as pressing global challenges, driven by climate change, land degradation, urbanization, and various human activities (ÇEM, 2013). These processes are particularly concerning in arid and semi-arid regions, where their environmental and socio-economic impacts are profound. Dryland ecosystems are especially vulnerable due to their fragile nutrient cycles and limited resilience to fragmentation (Acosta et al., 2018). Drought, a widespread issue, threatens ecosystems by exacerbating desertification and soil erosion, particularly in regions characterized by high temperatures and irregular rainfall (Anderegg et al., 2016; ÇEM, 2013; Çorbacı & Ekren, 2022). In Mediterranean climates, for instance, summer droughts represent a critical period for plant survival, significantly influencing vegetation dynamics (Çorbacı & Özyavuz, 2024; Sanchez et al., 2014). Given these challenges, ecological restoration has become a pivotal approach to mitigate the adverse effects of drought and land degradation. Restoration efforts aim to rebuild ecosystems to resemble their historical conditions, restoring biodiversity and ecological functions (Öner & Sıvacıoğlu, 2010). Effective restoration requires the identification and management of biological factors that limit recovery, along with strategies that enhance natural ecological processes. Approaches that focus on accelerating natural restoration processes, rather than merely controlling degradation factors, can lead to more successful and cost-effective outcomes (Bongers & Tennigkeit, 2010; Çorbacı & Bayramoğlu, 2021). The selection of appropriate plant species is crucial in restoration efforts, particularly those capable of improving soil moisture retention and reducing salinity and pH levels (Thomas et al., 2014; Yüksek et al., 2018). Native and well-adapted species are often preferred for their ability to thrive under local environmental conditions. Pedunculate Oak (*Quercus robur L*), Hawthorn (*Crataegus monogyna Jacq.*), and Scots Pine (*Pinus sylvestris L.*) are widely used in restoration projects due to their resilience and ecological contributions (Öner et al., 2016). Scots Pine, a common conifer, is valued for its adaptability to diverse environmental conditions, its role in reducing soil erosion, and its economic importance for timber production (Turna & Güney, 2009). Pedunculate Oak, a key broadleaved species in European forests, is notable for its extensive range and ecological significance, thriving in various soil conditions and contributing to erosion control with its extensive root system (Bektaş et al., 2016). Hawthorn, a small, drought-resistant tree, is also commonly used in restoration projects for its hardiness and ability to grow in infertile soils (Balta et al., 2015). This study focuses on assessing the effects of irrigation frequency and soil hydrogel addition on the drought response and survival of these three species. Conducted in a greenhouse setting, the research aims to identify effective techniques for enhancing plant survival and growth under drought conditions. By monitoring growth rates, survival, and wilting responses over a controlled experimental period, this study seeks to provide insights into optimizing restoration strategies for arid and semi-arid regions, contributing to the broader goal of ecological resilience and sustainability.

MATERIAL AND METHOD

Materials

This desiccation experiment, conducted over 50 days (22 June to 10 August) in Greenhouse 1 at Bangor University, involved 80 seedlings each of Pedunculate Oak (*Quercus robur*), Hawthorn (*Crataegus monogyna Jacq.*), and Scots Pine (*Pinus sylvestris L.*). The study aimed to compare plant responses to drought under two soil conditions (with and without hydrogel) and varying irrigation regimes. Scots Pine seedlings were planted in 4.5 x 4 x 19 cm plastic trays, while the others were bare-rooted. Soil was sourced from the Henfaes Research Centre, and the hydrogel used, STOCKOSORB, was incorporated into the soil at a rate of 8-10 grams per 8-10 liters to create a homogeneous mix (Arbona et. Al, 2005; Bowman et al., 1990). Each seedling was planted in individual cells containing 350 grams of soil, either with or without hydrogel (Angelina, 2006). Experiments 1 and 3 included hydrogel, while Experiments 2 and 4 did not. Watering was performed using a graduated injector, with 100 ml of clean drinking water per cell (Bayen et al., 2015; Chirino et al., 2011;). During the initial 20 days, seedlings in Experiments 1 and 3 were watered daily, whereas those in Experiments 2 and 4 received water five times throughout the same period. This setup allowed for the assessment of species' drought resistance and water stress response under controlled conditions.

Table 1: Experiment explanations.

Experiment	Irrigation frequency	Soil type	Irrigation period
Experiment 1	Daily	Hydrogel added	20 days
Experiment 2	5 times	Normal	20 days
Experiment 3	Daily	Hydrogel added	20 days
Experiment 4	5 times	Normal	20 days

Methods

Study Area: This study was conducted in Greenhouse 1, located on the roof of the Memorial Building at Bangor University, adjacent to the Thoday Building and opposite the Deniol Library.

Preparation of Soil: Soil for the experiment was sourced from the Henfaes Research Centre in Abergwyngregyn, North Wales, characterized by a temperate climate with an average annual rainfall of 1060 mm and sandy clay soil (Sanchez-Rodriguez et al., 2018). The soil was excavated, sieved to remove large stones, and stored in buckets. After a day in cold storage to mitigate high temperature effects, 8-10 grams of hydrogel granules were mixed with 8-10 liters of sieved soil for Experiments 1 and 3, while standard soil was used for Experiments 2 and 4.

Soil pH analysis was conducted on five samples, revealing a slightly acidic nature with pH values around 5.90. The process involved crushing the soil, air-drying, and mixing it with water in a 1:2.5 ratio. After shaking and settling, pH readings were taken, confirming consistent slightly acidic values across the samples (Ayan et al., 2007; ÇEM, 2013).

Seedling Cell Preparation: Seedling cells were arranged in book-like trays, each measuring 4.5 x 4 x 19 cm, designed to open easily for root-safe seedling removal. These plastic trays, with narrow holes at the bottom for root aeration, were grouped into sets of 10 book-type cells (Marshall, 2014).

Planting Seedlings: The study utilized 80 seedlings each of oak (*Quercus robur L*), hawthorn (*Crataegus monogyna Jacq.*), and pine (*Pinus sylvestris L.*), sourced from Maelor Nursery in Whitchurch, Wales. The seedlings were delivered bare-rooted and varied in height: Scots pine (10-34 cm), oak (10.5-45.8 cm), and hawthorn (18.8-45 cm). Each cell was filled with approximately 350 grams of soil, and seedlings were randomly planted in the Thoday Building laboratory to avoid interference (Angelina, 2006; Kozlowski et al., 1997). Each seedling was assigned a unique three-digit code to facilitate tracking across the four treatment groups (Experiments 1, 2, 3, and 4). As seen in Table 2, the codes used a combination of letters and numbers, with each digit representing specific details of the treatment setup (Rosenfield & Müller, 2017). Each experimental group contained 60 seedlings (20 of each species), and individuals were numbered from 1 to 20.

Table 2: Unique codes and numbers to track and separate all experiments and species.

Codes	Meaning
A	Daily watering for the first 20 days before dry-down
B	5 times watering in the first 20 days of the experiment
X	Soil without hydrogel
Y	Soil with hydrogel
1	Scots Pine (*Pinus sylvestris*) species
2	Pedunculate Oak (*Quercus robur*) species
3	Hawthorn (*Crataegus monogyna*) species
-1 to 20	The number of each individual in the experiments

The first two codes made it easy to understand the watering frequency and soil type according to the experiments (AX: experiment 1; BX: experiment 2; AY: experiment 3; BY: experiment 4). For example, AX1-13 means the 13th individual of Scots pine in trial 1.

Control of Greenhouse and Bangor Temperatures: The study, conducted from June 22 to August 10, monitored temperature differences between Bangor and the greenhouse daily between 5-6 pm using a thermometer. Water loss was measured by weighing a 10 kg water-filled bucket. The highest greenhouse temperatures (above 30°C) were recorded from June 24 to July 8, promoting seedling growth and flowering during the initial 20-day irrigation period. Water loss increased with higher temperatures.

Watering: Two watering schedules were employed during the first 20 days. Experiments 1 and 3 (120 seedlings total) were watered daily, while Experiments 2 and 4 were watered on days 1, 5, 10, 15, and 20. Careful watering ensured optimal growth without overwatering, which could harm roots. Approximately 100 ml of water was used per seedling, measured to account for soil water retention after drainage. Watering was done at 5 pm to mimic natural evaporation patterns (Marshall, 2014).

Drought Exposure: Irrigation ceased after the first 20 days to induce drought stress, with seedlings monitored for wilting over 30 days (Huangh et al., 2015; Kalefetoğlu & Ekmekçi, 2005). Greenhouse temperatures remained above 27°C. Weeds were manually removed to prevent interference with water uptake and soil quality.

Statistical Analyses: Flowering seedlings were analysed in SPSS, as wilting index assessments relied on leaf changes. Non-flowering oaks and hawthorns were excluded. Variance in trial, soil type, wilting index, and watering frequency was analysed using repeated measures ANOVA. Temperature and water loss differences between Bangor and the greenhouse were evaluated using T-tests. Wilting scores ranged from 0 (normal) to 5 (dead), with statistical significance assessed at $p < 0.05$. Wilting scores were recorded on days 20, 40, and 50.

Wilting Index: The Engelbrecht and Kursar (2003) wilting index was used for daily visual assessments, focusing on changes in leaf angle and surface structure. The most wilted leaves were evaluated to ensure accurate scoring, allowing performance comparison across soil types and watering schedules.

RESULTS

Some species showed no growth or leaf development over the 50-day period, making it impossible to assess wilting and drought resistance. As a result, 37 pedunculate oaks and 13 hawthorns were excluded from the analysis. The specific seedlings excluded were AX2-4, AX2-6, AX2-8, AX2-9, AX2-11, AX2-16, AX2-18, BX2-1, BX2-2, BX2-4, BX2-5, BX2-6, BX2-8, BX2-9, BX2-10, BX2-12, BX2-13, BX2-14, BX2-19, BX2-20, BX3-1, BX3-12, BX3-20, AY2-2, AY2-3, AY2-11, AY2-13, AY2-14, AY2-16, AY2-18, AY2-20, AY3-13, AY3-14, AY3-15, AY3-16, AY3-19, AY3-20, BY2-1, BY2-6, BY2-8, BY2-10, BY2-12, BY2-14, BY2-15, BY2-19, BY2-20, BY3-10, BY3-12, BY3-15, and BY3-16. The mean temperature during the study period was 21°C in Bangor and 27°C in the greenhouse, with these values calculated using a T-test in SPSS. Figure 1 shows that Experiment 2 (five times waterings, no hydrogel) exhibited the highest wilting severity, followed by Experiment 1 (daily watering, hydrogel), Experiment 4 (five times watering, no hydrogel), and Experiment 3 (daily watering, hydrogel). Daily watering and hydrogel use positively influenced wilting stages, while limited watering and no hydrogel accelerated wilting and seedling mortality. Figure 1 indicates that daily watering consistently resulted in lower wilting scores compared to five waterings, especially after day 40, where wilting scores increased steadily in all experiments. Scots pines showed the poorest growth and survival, with many nearing death. In contrast, hawthorns had the lowest wilting scores and highest growth rates, with wilting patterns for oak and hawthorn being similar. However, hawthorns experienced less wilting and demonstrated superior growth. Figure 1 highlights that hydrogel significantly improved seedling survival and reduced wilting index values, with lower mean wilting scores observed in hydrogel-treated soils. The wilting stages, ranging from 0 (normal) to 2.5 (wilted), reflect the positive impact of hydrogel on plant resilience.

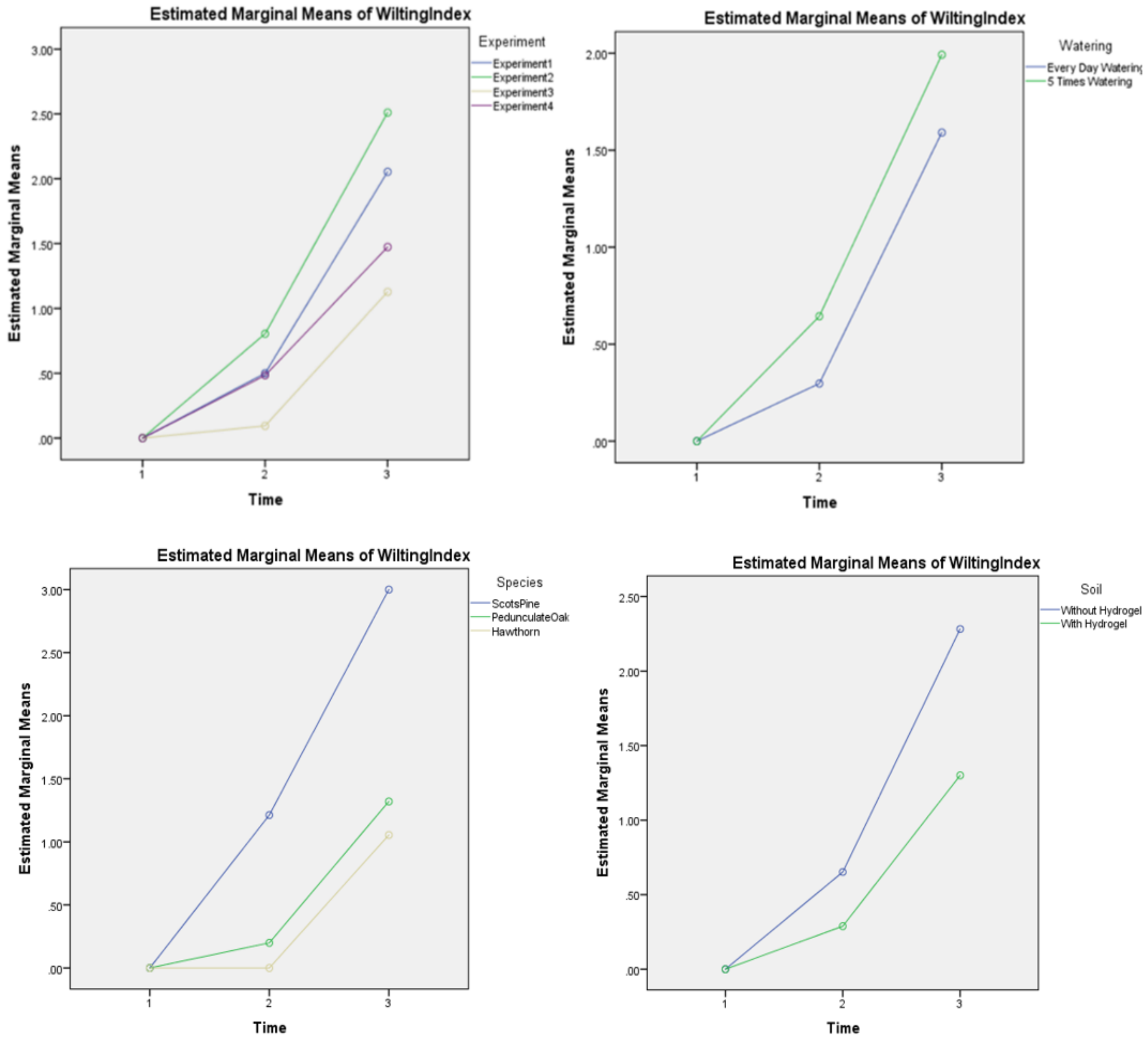

Figure 1. Mean Wilting Index Values Over Time: Variations by Experiment, Species, Watering Frequency, and Soil Type.

Growth rates of seedling species: In this part, mean growth rates were calculated in SPSS according to seedling species. Hawthorn exhibited the highest growth rate across all trials, while Scots Pine consistently showed the lowest (Table 3). Significant differences were observed between Scots Pine and Pedunculate Oak, as well as between Hawthorn and Pedunculate Oak, but not between Pedunculate Oak and Hawthorn (Table 4).

Mean seedling growth rates according to hydrogel use in soil: These analyses examined the effects of hydrogel use in soil on seedling growth. As indicated in Table 5, 94 seedlings were planted in hydrogel-amended soil and 96 in soil without hydrogel. By day 50, seedlings in hydrogel-amended soil exhibited a higher average growth rate. Table 6 confirms a significant difference between the two groups, indicating a positive impact of hydrogel on seedling growth.

Table 3. Mean growth rates of species from the beginning to the end of the study.

	Species	Mean	Std. Deviation	N
Beginning	Scots Pine	238.850	644.354	80
	Pedunculate Oak	287.860	762.157	43
	Hawthorn	281.060	699.339	67
	Total	264.826	723.460	190
Growth on the 50th day	Scots Pine	250.000	861.031	80
	Pedunculate Oak	304.605	773.419	43
	Hawthorn	316.731	833.906	67
	Total	285.889	884.230	190

N: The number of individuals used in analysis.

Table 4. Comparisons of species growth performance.

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	Sig.
Scots Pine	Pedunculate Oak	-5.181	1.399	0.001
	Hawthorn	-5.447	1.225	0.000
Pedunculate Oak	Scots Pine	5.181	1.399	0.001
	Hawthorn	-0.266	1.445	1.000
Hawthorn	Scots Pine	5.447	1.225	0.000
	Pedunculate Oak	0.266	1.445	1.000

Table 5. Mean growth rates of species from the beginning to the end of the study according to the use of hydrogel in soil.

	Soil	Mean	Std. Deviation	N
Beginning	Without Hydrogel	251.552	783.357	96
	With Hydrogel	278.383	632.505	94
	Total	264.826	723.460	190
Growth on the 50th day	Without Hydrogel	274.271	1.011.977	96
	With Hydrogel	297.755	717.398	94
	Total	285.889	884.230	190

N: The number of individuals used in analysis.

Table 6. Comparisons of soils with and without hydrogel in terms of their effects on seedling growth.

(I) Soil	(J) Soil	Mean Difference (I-J)	Std. Error	Sig.
Without Hydrogel	With Hydrogel	-2.516	1.123	0.026
With Hydrogel	Without Hydrogel	2.516	1.123	0.026

Mean seedling growth rates as a function of watering frequency: Watering frequency was another factor affecting seedling growth and wilting during the first 20 days of the study. Tables 7 and 8 demonstrate that daily watering was consistently more effective than watering five times, with a significant difference observed irrespective of soil type.

Table 7. Mean growth rates of species from the beginning to the end of the study according to watering frequency.

	Watering	Mean	Std. Deviation	N
Beginning	Daily Watering	276.000	718.528	100
	5 Times Watering	252.411	712.440	90
	Total	264.826	723.460	190
Growth on the 50th day	Daily Watering	302.260	868.938	100
	5 Times Watering	267.700	870.000	90
	Total	285.889	884.230	190

N: The number of individuals used in analysis.

Table 8. Comparisons of soils with and without hydrogel.

(I) Watering	(J) Watering	Mean Difference (I-J)	Std. Error	Sig.
Daily Watering	5 Times Watering	2.907	1.119	0.010
5 Times Watering	Daily Watering	-2.907	1.119	0.010

Wilting index of species: Wilting was not observed during the first 20 days. The analysis focused on days 20, 40, and 50, as wilting changes were noted during this period. Day 20 was selected for initial analysis due to significant leafing and flowering. Table 9 shows Scots Pine experienced the most wilting, followed by Pedunculate Oak, while Hawthorn exhibited the least. Table 10 indicates significant differences in wilting for Scots Pine compared to other species, but no significant difference between Hawthorn and Pedunculate Oak.

Table 9. Wilting index of species according to 3 time points.

	Species	**Mean**	**Std. Deviation**	**N**
20th Day	Scots Pine	0.0000	0.00000	80
	Pedunculate Oak	0.0000	0.00000	43
	Hawthorn	0.0000	0.00000	67
	Total	0.0000	0.00000	190
40th Day	Scots Pine	12.125	161.240	80
	Pedunculate Oak	0.1395	0.77402	43
	Hawthorn	0.0000	0.00000	67
	Total	0.5421	124.544	190
50th Day	Scots Pine	30.000	203.140	80
	Pedunculate Oak	12.791	136.845	43
	Hawthorn	10.597	117.912	67
	Total	19.263	186.441	190

N: The number of individuals used in the analysis.

Table 10. Comparisons of wilting index of species.

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	Sig.
Scots Pine	Pedunculate Oak	0.9313	0.15395	0.000
	Hawthorn	10.509	0.13483	0.000
Pedunculate Oak	Scots Pine	-0.9313	0.15395	0.000
	Hawthorn	0.1196	0.15909	1.000
Hawthorn	Scots Pine	-10.509	0.13483	0.000
	Pedunculate Oak	-0.1196	0.15909	1.000

Effect of watering frequency on wilting index: Watering frequency also affected the wilting of seedling species in all soil types. Table 11 shows that daily watering resulted in lower wilting scores compared to watering five times over 20 days, irrespective of soil type or hydrogel use. Table 12 highlights a significant difference between daily and five-time watering ($p = 0.014$), confirming the effectiveness of daily watering.

Table 11. Species wilting index in accordance with watering frequencies.

	Watering	**Mean**	**Std. Deviation**	**N**
20th Day	Daily Watering	0.0000	0.00000	100
	5 Times Watering	0.0000	0.00000	90
	Total	0.0000	0.00000	190
40th Day	Daily Watering	0.3500	0.93609	100
	5 Times Watering	0.7556	149.389	90
	Total	0.5421	124.544	190
50th Day	Daily Watering	16.400	171.458	100
	5 Times Watering	22.444	197.917	90
	Total	19.263	186.441	190

N: The number of individuals used in analysis.

Table 12. Comparisons of the effect of watering frequencies on wilting index.

(I) Watering	(J) Watering	Mean Difference (I-J)	Std. Error	Sig.
Daily Watering	5 Times Watering	-0.337	0.136	0.014
5 Times Watering	Daily Watering	0.337	0.136	0.014

Comparison of trials and wilting index: In order to know the wilting scores of all the experimental groups and how they related to each other, the experiments and wilting situations were generally compared. Table 13 shows that from day 20 to day 50, Experiment 3 had the lowest wilting value (1.08), indicating minimal wilting, followed by Experiment 4 (1.72), Experiment 1 (2.13), and

Experiment 2 (2.8), the highest. Table 14 reveals no significant differences between Experiments 1 and 2, 1 and 4, 2 and 4, and 3 and 4, but significant differences were observed between Experiments 1 and 3, and 2 and 3.

Table 13. Mean wilting index values of all trials according to 3 time points.

	Experiment	Mean	Std. Deviation	N
20th Day	Experiment 1	0.0000	0.00000	53
	Experiment 2	0.0000	0.00000	43
	Experiment 3	0.0000	0.00000	47
	Experiment 4	0.0000	0.00000	47
	Total	0.0000	0.00000	190
40th Day	Experiment 1	0.5660	121.702	53
	Experiment 2	0.9070	155.554	43
	Experiment 3	0.1064	0.31166	47
	Experiment 4	0.6170	143.789	47
	Total	0.5421	124.544	190
50th Day	Experiment 1	21.321	194.182	53
	Experiment 2	28.140	205.004	43
	Experiment 3	10.851	121.279	47
	Experiment 4	17.234	177.791	47
	Total	19.263	186.441	190

N: The number of individuals used in analysis.

Table 14. Comparisons of experiments mean wilting index.

(I) Experiment	(J) Experiment	Mean Difference (I-J)	Std. Error	Sig.
Experiment 1	Experiment 2	-0.3409	0.18713	0.420
	Experiment 3	0.5022	0.18268	0.039
	Experiment 4	0.1192	0.18268	1.000
Experiment 2	Experiment 1	0.3409	0.18713	0.420
	Experiment 3	0.8431	0.19241	0.000
	Experiment 4	0.4602	0.19241	0.107
Experiment 3	Experiment 1	-0.5022	0.18268	0.039
	Experiment 2	-0.8431	0.19241	0.000
	Experiment 4	-0.3830	0.18808	0.259
Experiment 4	Experiment 1	-0.1192	0.18268	1.000
	Experiment 2	-0.4602	0.19241	0.107
	Experiment 3	0.3830	0.18808	0.259

The Effects of Soil Types on the Wilting Index: The soil impact on seedlings species was quite high since the beginning of this study, so it was necessary to analyse its effects on the wilting of seedling species. Table 15 shows that by day 50, the absence of hydrogel significantly increased wilting, with an average wilting index of 2.44, indicating moderate wilting. Table 16 confirms a significant difference, with hydrogel-amended soil exhibiting better performance than soil without hydrogel.

Table 15. Mean wilting index rates in accordance with soil types.

	Soil	Mean	Std. Deviation	N
20th Day	Without Hydrogel	0.0000	0.00000	96
	With Hydrogel	0.0000	0.00000	94
	Total	0.0000	0.00000	190
40th Day	Without Hydrogel	0.7188	138.186	96
	With Hydrogel	0.3617	106.611	94
	Total	0.5421	124.544	190
50th Day	Without Hydrogel	24.375	200.952	96
	With Hydrogel	14.043	154.724	94
	Total	19.263	186.441	190

N: The number of individuals used in analysis.

Table 16. Comparisons of mean wilting index in accordance with soil types.

(I) Soil	(J) Soil	Mean Difference (I-J)	Std. Error	Sig.
Without Hydrogel	With Hydrogel	0.463	0.134	0.001
With Hydrogel	Without Hydrogel	-0.463	0.134	0.001

DISCUSSION

The ability of plants to resist drought is critical for understanding species' soil moisture association and physiological and morphological adaptations (Engelbrecht & Kursar, 2003). This study evaluated drought responses of 43 pedunculate oaks (*Quercus robur L.*), 67 hawthorns (*Crataegus monogyna Jacq.*), and 80 Scots pines (*Pinus sylvestris L.*) under hydrogel supplementation and two irrigation treatments, using repeated-measures ANOVA. Fifty broadleaved species were excluded due to defoliation. Contrary to expectations, *Crataegus monogyna Jacq.* outperformed *Pinus sylvestris L.* in survival and growth during 20-day irrigation and 30-day drought periods. Survival was assessed using a six-level wilting index. Experimental groups included variations in irrigation density and hydrogel addition (STOCKOSORB). By day 20, seedlings-except for *Pinus sylvestris L.*-exhibited significant flowering under watering conditions. Hydrogel reduced wilting across all groups, with *Pinus sylvestris L.* showing the highest mean wilting score (3, "wilted"). *Quercus robur L.* ranged between "slightly wilted" and "wilted," while *Crataegus monogyna Jacq.* remained "normal" to "slightly wilted." Experiment 3 (daily watering, hydrogel) showed the lowest wilting rates. Annual rainfall impacts biodiversity and species distribution even in tropical forests, where dry seasons lasting over 30 days can reduce survival and growth (Engelbrecht & Kursar, 2003). Engelbrecht and Kursar (2003) and Larcher (1980) define drought resistance as the ability to survive dry periods. Tropical plants like *Beilschmiedia Meisn.* and *Calophyllum L.* wilted early in watering trials, whereas others (e.g., *Tabebuia*) demonstrated high survival. In arid zones, hydrogel-based soil amendments enhance seedling performance by increasing water retention and reducing wilting (Arbona et al., 2005; Chirino et al., 2010). This Bangor greenhouse study confirmed hydrogel's positive impact on drought resistance. Experiment 3 (daily watering, hydrogel) achieved the highest survival. Similar results were noted for *Poncirus trifoliata (L.) Raf.* and *Citrus reshni (Engl.) Yu. Tanaka* in hydrogel-amended soils (Arbona et al., 2005). Chirino et al. (2010) found *Quercus suber L.* seedlings in hydrogel-enriched soils exhibited superior water retention and growth. Conversely, lack of hydrogel increased mortality, particularly for *Pinus sylvestris L.* Further, superabsorbent polymers (SAPs) like hydrogel reduce transpiration and increase water retention (Specht & Harvey, 2000), aiding dryland restoration. However, root collar diameter effects remain underexplored (Chirino et al., 2011). Local species with bare roots, mulching, and hydrogel significantly reduce water stress in arid regions (Ayan et al., 2007; Taeger et al., 2015). Native UK species like *Pinus sylvestris L.* adapted well to greenhouse conditions, although high temperatures during transport may have stressed roots. Despite time constraints (30-day desiccation), findings highlight hydrogel's potential for improving survival in restoration studies. Tested species

(*Pinus sylvestris L.*, *Quercus robur L.*, *Crataegus monogyna Jacq.*) are viable for arid restoration. Future studies should explore hawthorn's performance under diverse environmental conditions and drought intensities.

CONCLUSIONS

All expectations were met except for the performance of Scots pine (*Pinus sylvestris L.*) in this greenhouse experiment. Surprisingly, *Pinus sylvestris L.* showed the poorest growth and highest wilting rates over 50 days, while hawthorn (*Crataegus monogyna Jacq.*) performed best in survival and growth, followed by pedunculate oak (*Quercus robur L.*). Significant differences in wilting rates were observed between *P. sylvestris* and *C. monogyna*. Out of 240 seedlings, 190 were analyzed, with 37 *Quercus robur L.* and *Crataegus monogyna Jacq.* excluded due to defoliation. Experiment 3 (daily watering with hydrogel) yielded the best results, followed by Experiment 4 (five waterings with hydrogel). Hydrogel improved survival and reduced wilting across all conditions, highlighting its effectiveness. Future studies could test alkaline soils, potted seedlings, and extended durations to explore soil traits (e.g., organic matter, root growth). Additional amendments like perlite and peat, and different plant species may enhance restoration success. (De Groot et al., 2013; Escolar et al., 2012). Field experiments in arid areas with sheltered plots would provide more realistic data. Ultimately, selecting drought-adapted species and understanding ecosystems are key to combating drought (Berrahmoni et al., 2015).

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