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EFFECT OF SYNTHETIC HYDROGEL ON SOIL PROPERTIES AND SURVIVAL OF *Melia volkensii* SEEDLINGS IN THE ARID AND SEMI-ARID LANDS OF KENYA

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ABSTRACT

Arid and semi-arid lands (ASALs) face challenges related to soil degradation, water scarcity and reduced agricultural productivity; exacerbated by climate change. This study assessed the effect of synthetic superabsorbent polymers (hydrogels) on agronomy related soil properties and survival of *Melia volkensii* seedlings in arid and semi-arid zones of Kenya. Treatments included four hydrogel concentrations (0, 1.0, 3.0 and 6.0 g L^{-1}); and three application modes (Below Roots, whereby hydrogel soil mixture was placed at the bottom of the pit and not in contact with the roots of the seedlings; Within Roots, whereby the hydrogel soil mixture was directly in contact with tips of the roots of the seedlings; and Complete Mix, where the seedlings roots were fully covered in the hydrogel soil mixture) over 26 weeks. The treatments were laid out in randomised complete block design, in four replications and the study repeated three times. Results revealed significant ($P<0.05$) improvements in soil temperature and pH stability, with hydrogel application rates. Survival rates of seedlings peaked at 95% of mean (n=19; out of 20) when the rate of 6.0 g L^{-1} hydrogel was used in the Complete Mix (C) mode. No significant association ($P>0.05$) was found between hydrogels and the soil's electrical conductivity (EC); while a linear trend suggested predictable changes in EC with varying levels of hydrogel application. The findings highlight the potential of hydrogels to enhance soil water retention, mitigate the impacts of water scarcity, and promote sustainable agricultural practices in ASALs, and has the potential to contribute to climate smart agricultural adaptation.

Key Words: ASALs, *Melia volkensii*, synthetic superabsorbent polymers

RÉSUMÉ

Les terres arides et semi-arides (TASA) sont confrontées à des défis liés à la dégradation des sols, à la pénurie d'eau et à la baisse de la productivité agricole, exacerbés par le changement climatique. Cette étude a évalué l'effet des polymères synthétiques superabsorbants (hydrogels) sur les propriétés agronomiques du sol et la survie des semis de *Melia volkensii* dans les zones arides et semi-arides du Kenya. Les traitements comprenaient quatre concentrations d'hydrogel (0, 1,0, 3,0 et 6,0 g L^{-1}) ; et trois modes d'application (Sous les racines, où le mélange de sol hydrogel était placé au fond de la fosse et non en contact avec les racines des semis ; Dans les racines, où le mélange de sol hydrogel était directement en contact avec les extrémités des racines des semis ; et mélange complet, où les racines des semis étaient entièrement recouvertes du mélange de sol hydrogel) en 26 semaines. Les traitements ont été disposés selon un plan en blocs complets randomisés, en quatre répétitions et l'étude a été répétée trois fois. Les résultats ont révélé des améliorations significatives ($P<0,05$) de la température du sol et de la stabilité du pH, avec les taux d'application d'hydrogel. Les taux de survie des semis ont culminé à 95 % de la moyenne (n=19 ; sur 20) lorsque le taux de 6,0 g L^{-1} d'hydrogel a été utilisé dans le mode de mélange complet (C). Aucune association significative ($P>0,05$) n'a été trouvée entre les hydrogels et la conductivité électrique du sol (CE) ; alors qu'une tendance linéaire suggérait des changements prévisibles de La CE avec différents niveaux d'application d'hydrogel. Les résultats ont mis en évidence le potentiel des hydrogels à améliorer la rétention d'eau du sol, à atténuer les impacts de la pénurie d'eau et à promouvoir des pratiques agricoles durables dans les TASA, et ont le potentiel de contribuer à une adaptation d'agriculture intelligente face au Climat.

Mots Clés : TASA, *Melia volkensii*, polymères superabsorbants synthétiques

INTRODUCTION

Arid and semi-arid lands (ASALs) encompass vast areas globally, but especially in sub-Saharan Africa, where climatic conditions are marked by prolonged droughts, erratic rainfall, and inherently poor soil fertility (Ndichu, 2021). According to Kalele *et al.* (2021), these challenges are increasingly exacerbated by the adverse impacts of climate change, which can accelerate soil degradation, reduce vegetation cover, and diminish crop productivity. As droughts become more frequent and severe, water scarcity threatens food security and sustainable livelihoods (Algur *et al.*, 2021; Ahmad *et al.*, 2022; Saleem *et al.*, 2024); particularly in the ASALs where reliance on agriculture is high.

Among the strategies developed to mitigate these challenges, drought-tolerant tree species such as *Melia volkensii,* are of particular interest for afforestation and agroforestry efforts (Njehu *et al.*, 2022; Gupta *et al.*, 2023). However, their growth and survival are often hindered by extreme water scarcity, inadequate soil moisture retention, and practices that exploit land unsustainably. Current adaptation measures, including traditional soil amendments and water conservation approaches, have fallen short of effectively addressing the intricacies of these environmental shortfalls (Altynbay *et al.*, 2024; de Sousa and Grichar, 2024; Ntsomboh-Ntsefong *et al.*, 2024).

In this context, hydrogels, or synthetic superabsorbent polymers, emerge as a potential innovation for improving soil water retention and facilitate plant growth (Ali *et al.*, 2024; Campanile *et al.*, 2024; Dingley *et al.*, 2024). Thakur *et al.* (2023) indicated that, by enhancing the availability of water in the soil, hydrogels can stabilise soil temperature, regulate pH levels, and bolster soil conductivity; thereby creating a more favourable landscape for plant establishment and development.

However, according to Gültekin (2023), despite their successful application in agriculture, literature reveals a notable lack of researched information on the use of hydrogels in forestry contexts, particularly regarding their implications on soil properties in ASALs. Several studies have documented the critical link between soil health and sustainable agricultural practices (Khatoon *et al.*, 2020; Tahat *et al.*, 2020; Yang *et al.*, 2020), yet the specific effects of hydrogel applications on soil properties remains blurred. The objective of this study, therefore, was to assess the effect of hydrogel application on agronomic soil properties and its potential for enhancing the survival of *Melia volkensii* tree seedling in the arid and semi-arid zones in Kenya.

MATERIALS AND METHODS

Study site. This study was conducted in Kitui County, an arid and semi-arid (ASALs) region in Kenya. The region is located at latitude between 0°10 South and 3°0 South and longitude between 37°50 East and 39°0 East, at an altitude of 1,163 meters above sea level. The site has predominantly sandy loam soil, characterised by low organic matter, high porosity, and limited water retention capacity (Mutunga *et al*., 2022).

The area experiences mean annual rainfall ranging from 500 to 1050 mm, concentrated in two short rainy seasons. Temperatures range between 14 and 34 °C, with high evapotranspiration rates exceeding precipitation, thus intensifying water scarcity. The natural vegetation there is a mixture of grasses, shrubs and short trees, interspersed with bare land, which provides the evidence of soil erosion and degradation (Ochungo, 2020).

Treatments and design. Four hydrogel treatment levels (0, 1.0, 3.0, and 6.0 g L^{-1}) were tested; using three distinct application modes, including (i) Below Roots (B), (ii) Within Roots (W), and (iii) Complete Mix (C). The Below Roots (B) model involved applying the hydrogel at the bottom of the planting pit; while ensuring it did not come into direct contact with the seedling roots. The Within Roots (W) involved placement of the hydrogel in direct contact with the roots; while the Complete Mix (C) involved mixing the hydrogel completely with soil surrounding the seedling roots.

The study was laid out in a randomised complete block design (RCBD), in four replicates and was repeated three times. The research field consisted of 20 whole plots, which were further subdivided into 60 subplots. Each subplot represented unique combinations of hydrogel treatment levels and application modes. Within each plot, 10 seedlings of *Melia volkensii* were planted, culminating in a total of 600 seedlings for the whole study.

To assess the effect of the various treatments, soil samples were collected at two depths; namely 0-15 and 15-60 cm, at germination; and early seedling (0 to 8 weeks after one week), vegetative growth (8 to 20 weeks after one week), and at establishment and hardening (20 to 26 weeks and beyond) growth stages of *M. volkensii* tree seedlings.

The samples were analysed for temperature, pH, EC effects, and seedling survival rates; using routine methods (Yüksek and Yüksek, 2011).

Data collection. Weekly measurements of soil temperature, pH and EC were done for 26 weeks, using standardised laboratory methods (Brach *et al*., 2016). Seedling survival rates were assessed through regular visual observations and comprehensive health monitoring, noting any visible signs of stress, disease and pest infestation symptoms.

Data analysis. The effect of hydrogel on *M. volkensii* seedling survival was assessed using seedling survival rate, visual health assessment, and stress indicators (Almeida *et al*., 2016). Data were collected weekly for 26 weeks, over the cropping cycle, through visual observations of wilting, discoloration, and mortality. Survival rates were determined by counting live seedlings per plot.

Data collected were analysed using the Two-Way Analysis of Variance (ANOVA), using the Statistical Package for the Social Sciences (SPSS) version 27. Chi-Square tests were used to assess associations between hydrogel application and soil properties, to evaluate treatment effects on seedling survival, and Spearman's correlation for trends in electrical conductivity. The parameters traced in soil analysis included temperature, pH and electrical conductivity (EC) across 26 weeks. Significant treatment means were separated at $P < 0.05$ using the post-hoc tests (Nanda *et al*., 2021).

RESULTS AND DISCUSSION

Soil properties

Temperature. Results from Chi-Square test done for the effect hydrogel on soil temperature are presented in Table 1. The Pearson Chi-Square P-value of 0.047 indicates a statistically marginal significant association between hydrogel application and soil temperature; corroborating with the Likelihood Ratio P-value (0.036) (Table 1). At the same time, the Linear-by-Linear Association P-value (0.017) suggests a significant linear trend in the relationship. This finding aligns with previous studies, which demonstrated that hydrogels buffer temperature fluctuations, which helps to improve seedling root-zone conditions, thus reducing heat stress.

Optimising hydrogel application could therefore enhance *Melia volkensii* survival in arid regions to better quality of soil for agriculture sustainability. Maraveas *et al.* (2023) also confirmed that hydrogels mitigate drought stress, increase soil moisture retention, and stabilise microclimates for sustainable reforestation.

Our findings (Table 1, Fig. 1) suggest that hydrogels significantly regulates soil temperature, as evidenced by the strong statistical association. This observation is important, especially in ASALs where high temperatures exacerbate water loss and nutrient uptake.

The Chi-Square test results in this study provide strong evidence of the association between hydrogel application and soil temperature effect. Thus, hydrogels regulate soil temperature fluctuations, to prevent extreme heat stress on plant tubers (compared to control that reveal higher temperatures). This suggests that hydrogels retain moisture to buffer temperature spikes and enhance root-zone stability. Similar results were found by Ashraf and Ragavan (2019) and Ngamau *et al.* (2004) that hydrogels improve seedling resilience in arid climates, by maintaining favourable soil microclimates and supporting *Melia volkensii* survival.

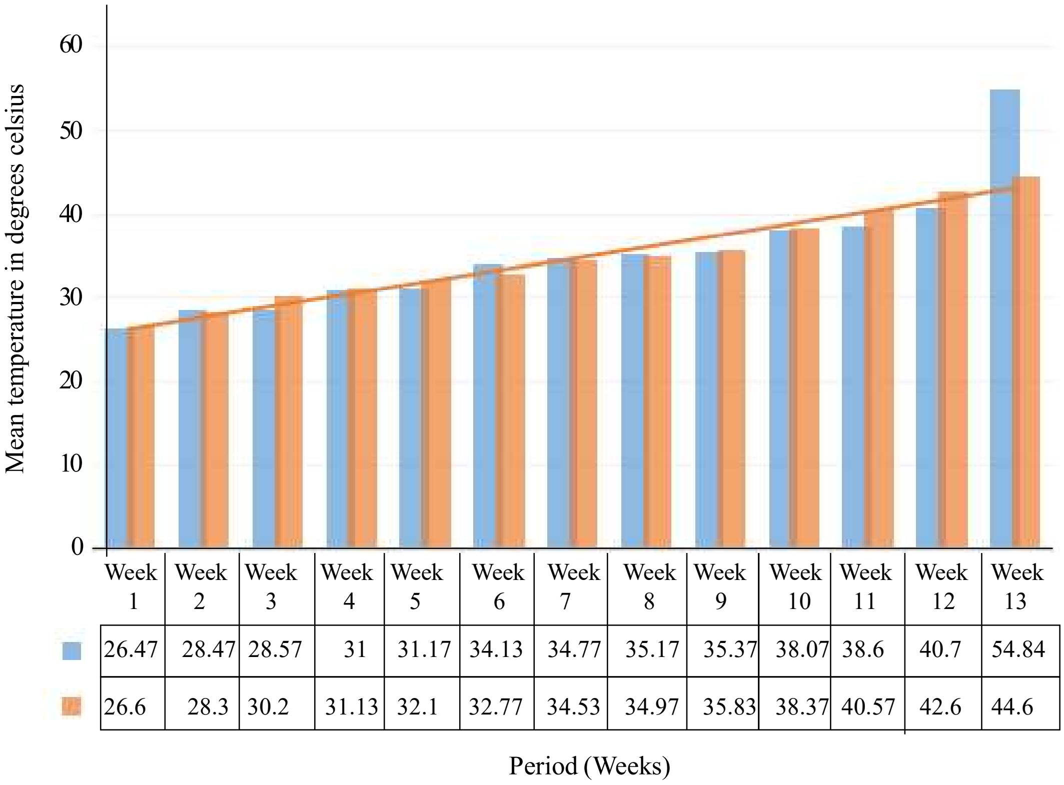
The Pearson Chi-Square P-value (0.047) (Table 1), Likelihood Ratio P-value (0.036) (Table 1), and Linear-by-Linear Association P-value (0.017) (Table 1) all indicate statistically significant and positive associations. These results support the notion that hydrogels can serve as a scalable solution to mitigate climate change impacts in diverse agro-ecological zones (Roy *et al.*, 2023); but with cautious optimisation. This is because hydrogels can mitigate moisture loss and stabilise soil temperatures rather than lowering them outright. Their effectiveness, therefore, depends on proper dosage and application, ensuring benefits in arid and semiarid agro-ecological zones.

Literature has confirmed that hydrogels have undeniable impacts in soil temperature, and mostly, this is attributed to moisture retention effect (Abdallah, 2019; Saha *et al.*, 2020; Rizwan *et al.* (2021). Through the water retention effect, the association between optimal hydrogel application and soil temperature is significant, which suggests that hydrogels can be of great importance in

TABLE 1. Chi-Square test results for the soil temperature

Chi-Square tests	Value	df	Asymptotic significance (2-sided)
Pearson Chi-Square	24.000[a]	22	0.047
Likelihood ratio	26.367	22	0.036
Linear-by-linear association	1.003	1	0.017
Number of valid cases	12		

[a] 36 cells (100.0%) have expected count < 5. The minimum expected count is 0.33



	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
🟦	26.47	28.47	28.57	31	31.17	34.13	34.77	35.17	35.37	38.07	38.6	40.7	54.84
🟧	26.6	28.3	30.2	31.13	32.1	32.77	34.53	34.97	35.83	38.37	40.57	42.6	44.6

Figure 1. Chi-Square test for data on the effect of application of hydrogel on soil temperature in the ASALs in Kenya.

facilitating sustainable soil factors (for example, temperature) in diverse agro-ecological zones (Abdallah *et al.*, 2021; Hussain *et al.*, 2023). de Oliveira *et al.* (2024) found that hydrogel application increased soil moisture content and temperature uniformity in a sandy loam soil. Similarly, Saha *et al.* (2020) discovered that hydrogels improved soil temperature and water retention in a drought-prone region.

Soil pH. There was a gradual increase in soil pH over time for both treatments, when the 6.0 g L^{-1} hydrogel was applied (Table 2), exhibiting a stronger upward trend. In the first week, the 1.0 g L^{-1} treatment had a higher pH (6.68) compared to 6.0 g L (5.94). However, by week 9, the 6.0 g L^{-1} treatment surpassed the 1.0 g L^{-1} treatment, reaching a pH of 8.23, compared to 7.57. This suggests that higher hydrogel concentrations contribute to long-term alkalinisation and stability of soil pH. The descriptive statistics for the 6.0 g L^{-1} treatment suggests a statistically significant increasing trend in pH values, with the positive slope implying that higher hydrogel application promotes a steady rise in soil pH over time. The water retention mechanism buffers against extreme temperature fluctuations by maintaining a more consistent soil moisture level to reduce heat stress on plant roots. Furthermore, hydrogels influence pH by modulating ion exchange and moisture availability to promote alkalinity stabilisation over time, as observed in the increasing pH trend with higher hydrogel application (Table 2). Compared to plant mulches, which provide surface-level moisture conservation and temperature regulation, hydrogels act at the root zone to offer sustained hydration in ASALs of Kenya.

TABLE 2. Weekly changes in pH values after application of hydrogel in different modes to an arid or semi-arid soil in Kenya

Week	pH_Rep 1_0 g L^{-1}	pH_Rep 1_1.0 g L^{-1}	pH_Rep 1_3.0 g L^{-1}	pH_Rep 1_6.0 g L^{-1}	pH_Rep 2_0 g L^{-1}	pH_Rep 2_1.0 g L^{-1}	pH_Rep 2_3.0 g L^{-1}	pH_Rep 2_6.0 g L^{-1}	pH_Rep 3_0.0 g L^{-1}	pH_Rep 3_1.0 g L^{-1}	pH_Rep 3_3.0 g L^{-1}
1	7	6.91	7	7	7	7	7	7	7	7	7
2	7.28	7.67	8.22	8.08	8.12	7.98	8.05	7.54	7.94	7.57	7.23
3	8.31	7.3	7.45	8.26	7.22	7.45	8.12	6.87	6.66	7.42	7.16
4	6.91	7	7.11	6.88	6.87	6.8	7.18	6.67	6.87	6.68	6.75
5	7.07	7.26	6.95	7.67	8.16	7.35	7.32	7.33	7.78	7.31	7
6	7.35	7.67	7.43	7	7.59	7.35	7.17	6.89	6.94	7.36	7.38
7	6.82	6.5	6.72	6.7	6.79	6.8	7	6.93	7	6.7	6.89
8	6.85	6.93	6.88	6.63	6.92	7	6.78	7	6.82	6.92	6.8
9	7	6.68	7	6.75	6.74	6.84	6.87	7	7	6.84	6.84
10	6.77	6.93	6.81	6.92	6.91	6.92	6.82	7	7	6.92	7
11	7	6.88	6.89	7	7	7	7	7	7	7	7
12	7	6.93	7	7	7	7	7	7	7	7	7
13	7	7	7	7	7	7	7	7	7	7	7
14	7	7	7	7	7	7	7	7	7	7	7

pH_Rep 1_0 g L^{-1} = pH Effect for the mode of application "Below Roots" at a hydrogel treatment of 0 g L^{-1}
pH_Rep 1_1.0 g L^{-1} = PH Effect for the mode of application "Below Roots" at a hydrogel treatment of 1.0 g L^{-1}
pH_Rep 1_3.0 g L^{-1} = PH Effect for the mode of application "Below Roots" at a hydrogel treatment of 3.0 g L^{-1}
pH_Rep 1_6.0 g L^{-1} = PH Effect for the mode of application "Below Roots" at a hydrogel treatment of 6.0 g L^{-1}
pH_Rep 2_0 g L^{-1} = PH Effect for the mode of application "Within Roots" at a hydrogel treatment of 0 g L^{-1}
pH_Rep 2_1.0 g L^{-1} = PH Effect for the mode of application "Within Roots" at a hydrogel treatment of 1.0 g L^{-1}
pH_Rep 2_3.0 g L^{-1} = PH Effect for the mode of application "Within Roots" at a hydrogel treatment of 3.0 g L^{-1}
pH_Rep 2_6.0 g L^{-1} = PH Effect for the mode of application "Within Roots" at a hydrogel treatment of 6.0 g L^{-1}
pH_Rep 3_0 g L^{-1} = PH Effect for the mode of application "Complete Roots" at a hydrogel treatment of 0 g L^{-1}
pH_Rep 3_1.0 g L^{-1} = PH Effect for the mode of application "Complete Roots" at a hydrogel treatment of 1.0 g L^{-1}
pH_Rep 3_3.0 g L^{-1} = PH Effect for the mode of application "Complete Roots" at a hydrogel treatment of 3.0 g L^{-1}
pH_Rep 3_6.0 g L^{-1} = PH Effect for the mode of application "Complete Roots" at a hydrogel treatment of 6.0 g L^{-1}

The observed gradual increase in soil pH over time with both hydrogel treatments, and the more pronounced effect at the 6.0 g L^{-1} application rate, aligns with Senna *et al.* (2015) study on synthesis, characterisation and application of hydrogel derived from cellulose acetate as a substrate for slow-release NPK fertiliser and water retention in soil. Hydrogels, as water-retaining polymers, moderates moisture availability and ion exchange capacity, which may influence pH levels; thus could significantly aid in *M. vokensii* plant growth. The initial pH disparity, where the 1.0 g L^{-1} treatment exhibited a slightly higher pH (6.68) compared to 6.0 g L^{-1} (5.94), suggests that lower hydrogel concentrations may temporarily enhance soil buffering capacity; while higher concentrations initially dilute soil acidity before stabilising and gradually increasing alkalinity over time. However, by week 9, the pH increase in the 6.0 g L^{-1} treatment (8.23) exceeded that of the 1.0 g L^{-1} treatment (7.57), indicating a more sustained impact of higher hydrogel concentrations on soil alkalinity stabilisation, which is consistent with the findings of Zhang *et al.* (2021), that higher polymer doses facilitate prolonged shifts in soil pH due to water retention and ion dynamics.

Electrical conductivity (EC). The effect of hydrogel application on the EC of the soil was significant ($P<0.05$) (Table 3). The Pearson Chi-Square P-value of 0.338 suggests that there is no significant association ($P>0.05$) between hydrogel application and the EC effect on the soil. Furthermore, the Likelihood Ratio P-value (0.263) underscores the same conclusion. However, the Linear-by-Linear Association P-value (0.032) indicates a significant linear relationship between hydrogel application and the EC effect. Nevertheless, there is no overall significant association ($P>0.05$) between hydrogel application and the EC effect of the soil, as indicated by the Pearson Chi-Square and Likelihood Ratio tests.

However, there is a statistically significant linear trend between hydrogel application and EC values, suggesting that EC changes predictably with hydrogel application. As limitations in this case for the expected counts issue, all 24 cells had expected counts less than 5, which violated a key assumption of the Chi-Square test and reduce the reliability of the results; yet the sample size was small (N = 12). The dismal number of observations limits the robustness and generalisability of the findings.

The results of the Chi-Square test for the electrical conductivity (EC) effects in soil are presented in Table 3, indicate a complex relationship with hydrogel application. While the Pearson Chi-Square P-value (0.338) and the Likelihood Ratio P-value (0.263) suggested no statistically significant overall association ($P>0.05$), the Linear-by-Linear Association P-value (0.032) highlights a significant linear trend. This suggests that although a clear association existed, there may be predictable changes in EC with varying levels of hydrogel application.

The implications of this finding on soil salinity management and agricultural productivity in arid and semi-arid regions are noteworthy. Hydrogels, being known for their

TABLE 3. Effect of hydrogel application on the EC of arid and semiarid soils

Chi-Square tests	Value	df	Asymptotic significance (2-sided)
Pearson Chi-Square	15.600[a]	14	.338
Likelihood ratio	16.864	14	.263
Linear-by-linear association	4.593	1	.032
Number of valid cases	12		

[a] 24 cells (100.0%) have expected count < 5. The minimum expected count is 0.33

water-retention capabilities, could enhance ion mobility within the soil, potentially improving nutrient availability and absorption by plants (Wu *et al.*, 2024b).

Previous studies corroborated this idea; for instance, research by Hu *et al.* (2024) found that the inclusion of hydrogels improved nutrient dynamics and ion exchange in arid soils, resulting in better plant growth. Similarly, Wu *et al.* (2024a) demonstrated an increase in plant biomass due to enhanced nutrient uptake of essential ions such as nitrogen, potassium, and phosphorus, facilitated by hydrogel application, suggesting that even subtle changes in electrical conductivity because of hydrogels could influence agricultural outcomes.

Seedling survival. The response of survival of *M. volkensii* seedlings to the effect of application of hydrogel in the soils of arid and semiarid lands (ASALs*)* is represented by the data in Table 3.

The descriptive statistics from Table 4 suggest a positive relationship between hydrogel application and improved survival rates of *M. volkensii* seedlings in arid and semiarid lands (ASALs). Higher hydrogel concentrations (3.0 and 6.0 g L^{-1}) consistently resulted in greater mean survival values and lower standard deviations, indicating more stable outcomes. In contrast, lower or no hydrogel application (0 and 1.0 g L^{-1}) was associated with lower survival means and higher variance, suggesting increased variability in seedling response.

Scientifically, this positive trend can be attributed to hydrogels' ability to retain moisture and enhance soil water availability, which is critical in ASALs. Hydrogels improve soil structure, reduce water loss, and enhance nutrient retention, leading to better root development and plant resilience under water-deficient conditions. Hu *et al.* (2024) found that hydrogel application in arid soils significantly improved soil moisture retention and root water uptake efficiency, leading to increased plant survival rates. Similarly, Wu *et al.* (2024a) demonstrated that hydrogels enhanced the availability of essential nutrients, particularly nitrogen and phosphorus, which positively impacted plant biomass and overall growth. These findings are consistent with the present

TABLE 4. Effect of application of hydrogel in the soils of arid and semiarid lands (ASALs) in Kenya

Descriptive statistics	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Applied hydrogel						
Surv_Rep 1_0 g L^{-1}	26	2	20	9.15	5.266	27.735
Surv_Rep 1_1.0 g L^{-1}	26	1	20	10.23	6.377	40.665
Surv_Rep 1_3.0 g L^{-1}	26	10	20	17.15	2.395	5.735
Surv_Rep 1_6.0 g L^{-1}	26	14	20	17.31	2.187	4.782
Surv_Rep 2_0 g L^{-1}	26	0	20	9.04	6.422	41.238
Surv_Rep 2_1.0 g L^{-1}	26	3	20	9.12	5.567	30.986
Surv_Rep 2_3.0 g L^{-1}	26	9	20	16.15	2.894	8.375
Surv_Rep 2_6.0 g L^{-1}	26	12	20	17.19	2.227	4.962
Surv_Rep 3_0 g L^{-1}	26	0	20	7.96	6.797	46.198
Surv_Rep 3_1.0 g L^{-1}	26	6	20	14.12	3.479	12.106
Surv_Rep 3_3.0 g L^{-1}	26	11	20	18.23	2.338	5.465
Surv_Rep 3_6.0 g L^{-1}	26	17	20	19.00	1.095	1.200
Valid N (listwise)	26					

study, which also revealed improved seedling survival with higher hydrogel concentrations.

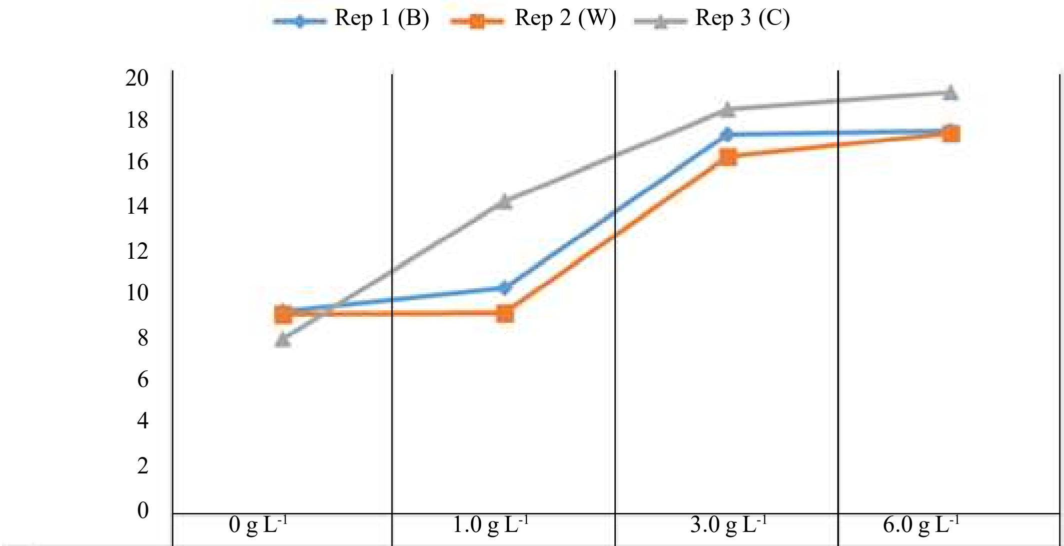
Zhang *et al.* (2021) also showed that hydrogels facilitated microbial activity in the rhizosphere, promoting soil health and enhancing nutrient uptake efficiency in drought-prone environments. Another study by Li *et al.* (2024) highlighted that hydrogel incorporation reduced soil temperature fluctuations, creating a more stable microenvironment for seedling establishment.

These results suggest that incorporating hydrogels into reforestation and afforestation strategies could significantly enhance the survival rates of *M. volkensii* seedlings in ASALs. Through optimisation of hydrogel concentration, particularly at 3.0 and 6.0 g L^{-1}, stakeholders can improve seedling establishment to contribute to ecosystem restoration and sustainable land management in arid environments.

Figure 2 provides a summary of the trend observed in the survival of the seedlings with different treatments and modes of applications. The modes of applications (i.e. Below Roots, Within Roots, and Complete Roots) tended to have different effects onto the survival rates of the tree seedlings (Table 4). Using the maximum quantity application of hydrogel (6.0 g l^{-1}), Complete Roots reflects the highest effect on the survival rates of the seedlings across time at a mean of 19.00. Out of 20 seedlings, a mean of 19 indicates an almost generally effective strategy to improve the survival rates of plants in ASALs regions by improving some aspects of the soil.

Thus, the most effective mode of hydrogel application increasing the survival rates of the tree seedlings was the Complete Roots application, which is the distribution of the hydrogel both below and within the roots. Overall, the higher the quantity of hydrogel application within the complete roots (C), the better the rate of plants' survival in the ASAL region soil and environment.

The results indicate a complex relationship with hydrogel application (Table 3). Although the Pearson Chi-Square P-value (0.338) and



	0 g L^{-1}	1.0 g L^{-1}	3.0 g L^{-1}	6.0 g L^{-1}
Rep 1 (B)	9.15	10.23	17.15	17.31
Rep 2 (W)	9.04	9.12	16.15	17.19
Rep 3 (C)	7.96	14.12	18.23	19

Figure 2. Effect of quantity (in g L^{-1}) and mode of applications (B, W, and C) of hydrogel on the survival rate of seedlings.

the Likelihood Ratio P-value (0.263) suggested no statistically significant overall association (P>0.05), the Linear-by-Linear Association p-value (0.032) highlighted a significant linear trend. This suggests that, although a clear association was not found, there may be predictable changes in EC with varying levels of hydrogel application. The implications of this finding are noteworthy, given that hydrogels known for their water-retention capabilities (Wu *et al.*, 2024b). They could enhance ion mobility within the soil, potentially improving nutrient availability and absorption by plants.

Previous studies corroborate this idea; for instance, research found that the inclusion of hydrogels improved nutrient dynamics and ion exchange in arid soils, resulting in better plant growth (Hu *et al.*, 2024). Wu *et al.* (2024a) similarly, demonstrated grater plant biomass due to enhanced nutrient uptake facilitated by hydrogel application, suggesting that even subtle changes in electrical conductivity because of hydrogels could influence agricultural outcomes.

Policy implications. The findings of this study provide practical insights for policy makers in Kenya and the other ASAL regions. First, the demonstrated effectiveness of hydrogels in enhancing soil moisture retention and seedling survival point out their potential as a climate adaptation tool for afforestation and sustainable agriculture. Policy makers should integrate hydrogel-based soil management practices into national reforestation and dryland restoration programmes.

Secondly, incentives such as subsidies or public-private partnerships should be explored to lower the cost of hydrogel adoption for smallholder farmers. This will enhance uptake and ensure equitable access to the technology. Third, in implementing hydrogel interventions, policy makers must consider soil-specific responses and optimal application rates to avoid unintended consequences such as excessive pH shifts. Rigorous monitoring frameworks should be established to guide sustainable use. Finally, existing policies on land degradation, water conservation, and afforestation, such as Kenya's Climate Change Act and ASAL Development Strategy, may require amendments to explicitly incorporate soil moisture management innovations like hydrogels.

CONCLUSION

Hydrogels, also referred to as synthetic superabsorbent polymers, to the greatest extent, enhance soil temperature regulation and pH stabilisation, leading to improved survival of *Melia volkensii* seedlings in ASALs. The Complete Mix application of 6.0 g L^{-1} hydrogel emerged as the most effective strategy, achieving nearly 95% seedling survival rates. Despite no significant association with soil EC, the linear trend suggests potential nutrient mobility benefits. Hydrogels, therefore, offer a promising solution for mitigating water scarcity and enhancing agricultural productivity that align with global sustainability goals.

Future studies should look into long-term effects of hydrogels on soil properties and their scalability across diverse agro-ecological zones. Policymakers also should prioritise incentives for hydrogel adoption in reforestation and agriculture to bolster climate resilience. Consequently, integrating hydrogels into land management practices can transform ASALs to promote food security and ecosystem sustainability globally.

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