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UTILIZATION OF SODIUM ALGINATE HYDROGEL AS A SUSTAINABLE PLANTING MEDIUM

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Abstract

Soil quality degradation can be attributed to both individual and industrial human activities, directly or indirectly. The depletion of soil nutrients, specifically nitrogen (N), phosphorus (P), and potassium (K), contributes to a decline in soil fertility. Sodium alginate, when employed as a planting medium, exhibits notable efficacy in the absorption and subsequent release of nutrients and water due to its inherent stability. The robust capacity for absorption and resilience to SA is attributed to covalent crosslinking with elemental hydrogen or essential plant nutrients. The ionotropic gelation process was used to make alginate hydrogel, and a solution of $CaCl_2$ was used as the crosslinking agent. The results of this study suggest that augmenting the potassium concentration can enhance plant growth rate, hence aiding the attainment of optimal plant height. Sodium alginate-based hydrogels exhibit potential as a feasible alternative for utilization as planting substrates.

Key words: *sodium alginate, hydrogels, planting medium, green bean.*

INTRODUCTION

Soil resources are often the focus of attention because their quality is deteriorating or degrading. Human activities, agriculture, households, and industry have contributed to this decline. Some unfavorable natural conditions, such as rainfall and population movement, can also reduce the soil quality as a cultivation medium. N, P, and K are soil components that are often lost, resulting in decreased soil fertility. These problems will reduce soil resistance and porosity. Soil water resistance as a planting medium and plant growth rate is influenced by soil texture and nutrient content. In the dry season, groundwater resistance tends to decrease due to the tendency of the soil to harden and agglomerate. It would be difficult to cultivate and develop plants in hardened soil.

The soil's capacity to absorb water as a planting medium is also greatly influenced by its porosity. The reduced porosity of the compacted soil texture reduces the amount of water the soil can absorb. Increased salinity levels caused by climate change can also diminish crop yields. High sodium concentrations typically inhibit plant growth. Polymer hydrogels have been extensively employed to ameliorate soil structure to address these challenges and enhance the efficacy of water utilization in agricultural settings, mitigate water evaporation, and enhance soil quality (Thakur & Thakur, 2015; Song et al., 2020). Currently, most hydrogels available in the market are synthetic, derived from acrylic acid monomers or polymers, and polyacrylamide. The monomers and polymers discussed here are chemical compounds derived from petroleum products.

Consequently, their decomposition in the soil environment is challenging. If they degrade over an extended period, the resulting degradation byproducts can contaminate the surrounding environment and adversely affect the resident fauna (Song et al., 2020). In addition, the overutilization of synthetic hydrogels in soil has adverse implications for plant life, impeding their growth and development.

Using natural polymers as a planting medium is also a significant focus, as it can absorb and release the macro components and water plants require (Durpekova et al., 2022; Xiong et al., 2022; Palanivelu et al., 2023; Abdel-Raouf et al., 2018; Djidonou & Leskovar, 2019; Ma et al., 2023; Ahmed et al., 2015; Montesano et al., 2015). Sodium alginate (SA) has the potential to be used as a planting medium due to its moderate water resistance. SA can store significant quantities of plant nutrients (Song et al., 2020). Because it is stable and non-toxic, sodium alginate can easily absorb and release nutrients and water as a planting media mixture. SA's high absorption capacity and resistance result from covalent crosslinking with elemental hydrogen or plant-required nutrients.

MATERIALS AND METHODS

The chemicals used in this study were Sodium Alginate (SA) CAS-No 9005-38-3, Potassium chloride (KCl) CAS-No 7783-90-6, phosphoric acid (H_3PO_4) CAS-No 7664-38-2, urea CAS-No 57-13-6, monopotassium phosphate (KH_2PO_4) CAS-No 7778-77-0, and water. The plant used was green beans (*Vigna radiata*).

The ionotropic gelation technique was employed to create alginate hydrogel, with the crosslinking agent being a solution of $CaCl_2$. The process of producing hydrogel can be briefly described as follows: Initially, a sodium alginate solution was prepared by dissolving it in water at a concentration of 2.5% (w/w). The solution was stirred for 2 hours at a rotational speed of 100 revolutions per minute (rpm) until achieving a state of homogeneity. Subsequently, the alginate solution was gradually introduced into a 100 cc $CaCl_2$ solution. The $CaCl_2$ solution was gently agitated after adding the alginate solution. After adding the alginate solution to the $CaCl_2$ solution, the resultant mixture was left undisturbed for 60 minutes to facilitate crosslinking. The obtained hydrogel was subjected to a washing process to eliminate any surplus unbound calcium ions. The hydrogel was subjected to a 24-hour soaking period and subsequent drying before its utilization for NPK loading and as a planting medium.

The dry hydrogel specimen was assessed in terms of its mass and afterward submerged in deionized water at room temperature for 1 hour, leading to its expansion. Subsequently, the swollen gel was subjected to filtration and subsequently re-weighed. Water absorption (WA (g/g)) is calculated using Equation 1.

$$WA = \frac{W_2 - W_1}{W_1} \quad (1)$$

The variable W_1 represents the weight of the sample before swelling in water, while W_2 represents the weight of the sample after swelling in water.

The process for loading macronutrients into the hydrogel was conducted as follows: Initially, a certain quantity of the dry hydrogel was introduced into a 50 ml solution containing a concentration of 1 M for each constituent. The mixture was allowed to stand for the hydrogel to expand and facilitate complete liquid absorption into the hydrogel. Subsequently, the hydrogel was employed as a substrate for planting purposes.

This investigation includes three variations: adding a single component, two, and three components. Research was conducted to determine the optimal composition formulation for the production of sowing media. Consideration must be given to the texture of the resultant planting medium at the time of preparation. The successful formulation of planting media involves the formation of solid gel planting media. In the production of developing media, sodium alginate (SA) is used as a primary component to form hydrogels, which are then combined with nutrients and macro components. Nitrogen from urea, phosphorus from phosphoric acid, and potassium from potassium chloride are incorporated as nutrients and macrocomponents. The nutrition is provided as a 1M solution for each component. The provision of P and K components is also altered by substituting the original compound, monopotassium phosphate (KH_2PO_4), which is typically used to stabilize and modify the pH of the planting medium.

By measuring plant height, plant weight, leaf width, and the pH of the planting medium, quantitative tests were conducted to determine the optimal composition for manufacturing planting media. The pH of the planting medium was determined at the start of the germination/planting process and after the experiment. The weight of the plant was measured using a balance both before and after the seeding process. The daily plant height measurement was conducted using a ruler, starting from the emergence of sprouts in a green bean (*Vigna radiata*) plant.

RESULTS AND DISCUSSIONS

The primary objective of this study is to investigate the formulation of a planting medium utilizing sodium alginate (SA), water, and plant macronutrients to produce a hydrogel. The maximum water absorption capacity of the hydrogel after soaking for 1 hour is 2.25 g water/g hydrogel. The macronutrients of the plant investigated in this study consisted of nitrogen derived from urea, phosphorous obtained from phosphoric acid, and potassium sourced from potassium chloride. The present study examines the impact of micronutrient supplementation on the germination rate of tiny plants, specifically green bean seeds.

The experimental study involved the incorporation of individual elements, namely nitrogen (N), phosphorous (P), and potassium (K), into the planting substrate, with specific modifications, during the germination phase of green bean plants. Figure 1 displays the experimental findings on the impact of individual components on the germination rate. During the green bean germination process, a single nutrient, specifically N, produces a more rapid germination rate than the absence of NPK (sodium alginate alone) (Djidonou & Leskovar, 2019). In the first figure, labeled as Figure 1(a), The inclusion of the N component resulted in a noticeable rise in the germination rate throughout the period spanning from days 10 to 14. The inclusion of the N component exhibited a reduced germination rate during the initial nine days, followed by a notable increase from day 10 to day 14. The gradient of the rate demonstrated this. The rate of germination during the first period, spanning from days 1 to 9, was observed to be 0.13 cm per day. Subsequently, between days 10 to 14, the germination rate increased to 0.46 cm per day. At the end of the observation period on day 14, the plant height was measured to be 4.9 cm for composition 1 and 6.7 cm for composition 2.

The presence of nitrogen is attributed to its facilitation of the photosynthetic process through its role in promoting chlorophyll synthesis in leaves and augmenting leaf production. A positive correlation exists between the chlorophyll concentration in leaves and the rate of photosynthesis, resulting in the adequate fulfillment of essential nutrients and oxygen (O) plants require. The efficacy of nitrogen is demonstrated by a bigger increase in the width of the leaf with the inclusion of the nitrogen component compared to other variants, specifically measuring 1.5 cm (composition 1) and 1.4 cm (composition 2). Nitrogen in the planting media leads to an initial acidic pH range of 4.86-5.71, impeding germination due to suboptimal absorption of essential ions and minerals. Nevertheless, compared to NPK 1:1:1, incorporating the N component exhibited a reduced germination rate. Including NPK 1:1:1 resulted in a growth rate of 0.48 cm per day during the first nine days and a growth rate of 0.55 cm per day between days 10 and 14. The final height of the plants was 7.5 cm for Composition 1 and 5.9 cm for Composition 2. This finding indicates that the germination rate can also be influenced by additional nutrients, namely phosphorus (P) and potassium (K).

The concentration of the phosphorus (P) component was manipulated to two different levels, specifically 0.1 M and 1 M. Figure 1(b) demonstrates that the inclusion of the P component in the experimental setup accelerates the initial germination process, specifically the seed opening in comparison to the control group which solely consists of sodium alginate without the addition of NPK. The P component, at a concentration of 1 M, exhibited early germination on day 4, while at a concentration of 0.1 M, germination occurred on day 1. However, when the concentration of P component was non-NPK, germination did not occur until day 6. From the initial period spanning days 1 to 7, the germination rate at a concentration of 0.1 M exhibited a growth rate of 0.17 cm/day. Subsequently, the growth rate increased from days 8 to 14 to 0.24 cm/day. The final plant heights recorded were 3.3 cm (1) and 3.2 cm (2). The enhancement of the germination rate of the P component demonstrates accelerated outcomes during the initial stages of germination and exhibits efficacy between days 7 and 14.

This phenomenon occurs due to the role of phosphorus in promoting root growth and development. However, excessive phosphorus concentrations can decrease pH levels within the planting medium, resulting in acidity. An excessively acidic pH level can impede phosphorus's solubility, hindering plants' mobility and nutrient uptake capacity. The pH discrepancy occurred initially, specifically ranging from 1.99 to 2.26 for a concentration of 1 M and from 4.03 to 4.12 for a concentration of 0.1 M. In contrast to other variations, such as Non-NPK and NPK 1:1:1, including P components in the fertilizer mixture generally results in reduced yields. Based on the observed germination rates over the first seven days, it can be determined that the non-NPK variation exhibits a rate of 0.13 cm per day, while the NPK variation demonstrates a rate of 1:1:1 of 0.47 cm per day. Furthermore, the final heights of the non-NPK and NPK 1:1:1 variations were recorded as 5.2 cm and 7.5 cm, respectively.

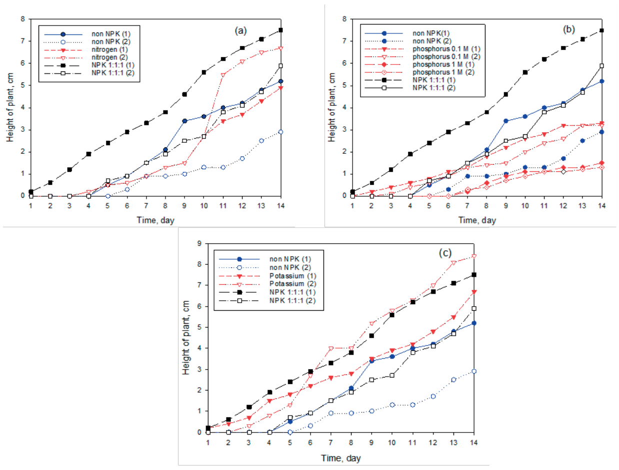

Figure 1. The effect of the addition of (a) nitrogen, (b) phosphorus, and (c) potassium on the growth of green beans

Potassium (K) is known to influence germination rate enhancement significantly. The germination rate exhibited a similar trend when potassium was introduced, comparable to the germination rate observed with NPK 1:1:1. The experiment commenced by initiating germination with the addition of potassium (K) on the first day. The observed germination rate was determined to be 0.5594 cm per day, resulting in a final height of 8.4 cm. In a separate trial, the germination rate was recorded as 0.5308 cm per day using a nitrogen-phosphorus-potassium (NPK) ratio 1:1:1, leading to a final height of 7.5 cm. This phenomenon is attributed to the high solubility of potassium in water, which facilitates its efficient distribution throughout various plant tissues, optimizing overall mobility. During the initial stages of germination (Figure 1c), including potassium (K) demonstrated accelerated outcomes compared to using sodium alginate alone, specifically within the time frame spanning from day 4 to day 1. The observed greater growth rate resulting from the addition of potassium, as compared to the addition of NPK 1:1:1, highlights the significant role of potassium in promoting plant development throughout all plant organs. The functions encompass enhancing tissue growth rate in the stem, augmenting insect resistance, fortifying various plant components (with particular emphasis on leaf retention), and promoting root development. The influence of potassium on leaf characteristics was indicated by a leaf width range of 1.3-1.4 cm. The leaf width is nearly equivalent to nitrogen application, suggesting that potassium benefits plants across various species.

The combination of two individual components in the formulation of planting media yields enhanced performance in terms of germination and plant growth rates. Each particular component serves a distinct role in the process of plant growth. Nevertheless, it is crucial to note that every individual component possesses a vital supportive role that is indispensable to the functioning of other components. This phenomenon is observable in Figure 2.

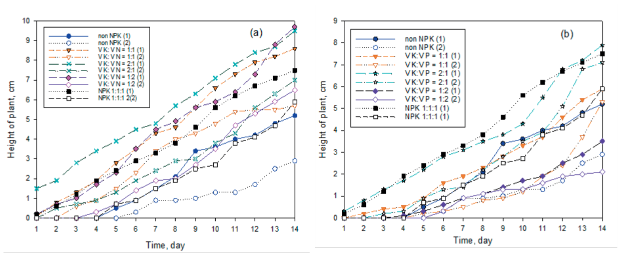

Figure 2. The effect of the addition of (a) nitrogen and potassium and (b) phosphorus and potassium on the growth of green beans

The synergistic effect of combining N and K components has been found to enhance germination rates and promote robust plant growth significantly. The

two components mentioned above fulfill distinct functions: Nitrogen (N) primarily facilitates leaf growth via photosynthesis, while potassium promotes root development and enhances overall plant vigor. Figure 2(a) demonstrates that the development rate of variations in the application of potassium and nitrogen exhibits superior outcomes compared to the application of three components: nitrogen, phosphorus, and potassium. The most favorable growth rate was observed when nitrogen (N) and potassium (K) were added in a ratio of 1:2 and 2:1, resulting in growth rates of 0.70 and 0.62 cm/day, respectively. The plants' ultimate height was 9.5 cm and 9.7 cm, respectively, with a notable surge in growth rate evident in the 2:1 variation. On the twelfth day, the height of the plants in the N: K = 2:1 variation reached 7.3 cm and surpassed the height of the plants in the 1:2 variation on the thirteenth and fourteenth days.

The presence of nitrogen in plant tissues facilitates the process of photosynthesis in mature cells and facilitates the transport of essential nutrients and food resources for developing cells. The effective distribution of nutrients throughout young tissue enables and further enhances the optimal growth rate of plants. The plant height and leaf width measurements for the 1:2 and 2:1 variations exhibit nearly the same range, specifically from 1.2 to 1.5 cm. In the experimental conditions where the ratio of nitrogen to potassium (N:K) is 1:1, and the ratio of nitrogen to phosphorus to potassium (NPK) is 1:1:1, there is a tendency for the leaf width to be lower in comparison to the two preceding variants. Specifically, the leaf width measures approximately 0.6-0.8 cm. The disruption of nutrient distribution required by plants occurs due to the contrasting effects of phosphorus, which primarily acts on young tissue, in contrast to nitrogen. This disruption will result in a reduction in the diameter of the plant stems, thereby leading to a drop in the overall weight of the plant.

In Figure 2(b), the inclusion of P and K constituents in a 2:1 proportion demonstrates a comparable magnitude to the incorporation of NPK constituents in a 1:1:1 ratio. A notable rise was observed over days 12 to 14, characterized by a growth rate of 0.45 cm per day for days 1 to 11 and an increased rate of 0.56 cm per day for days 12 to 14. Ultimately, the total height reached was 7.9 cm. This phenomenon can be attributed to a positive correlation between the quantity of potassium introduced and both the rate of plant development and the overall strength of the plant. In alternative scenarios, the growth rate experiences a decline due to the increased quantity of phosphorus introduced, which poses challenges to the process of nutrient absorption. Phosphorus is a constituent that exhibits limited solubility; an increase in phosphorus concentration within the planting substrate results in reduced mobility of ions and essential nutrients required by plants. The acidity level and the composition of the planting media are other factors that determine leaf width. In addition to the P:K = 1:2 ratio, other variances can affect leaf widths, ranging from 0.6-0.8 cm. These variations suggest a deficiency of potassium components in the planting media, resulting in smaller leaves with a yellowish tint and the appearance of spots (Figure 3).

Figure 3. Leaf color in variation P:K = 2:1

Nitrogen (N), phosphorus (P), and potassium (K) have distinct functional characteristics, although they operate synergistically to support plant growth and development. The composition of planting media is adjusted by altering the ratio of the three components throughout the manufacturing process to optimize plant growth rates. The outcomes acquired are visible in Figure 4.

Nitrogen (N), phosphorus (P), and potassium (K) have distinct functional characteristics, but they operate synergistically to complement one another. The most effective composition for adding NPK was a ratio of 1:1:2 and 2:1:2, resulting in growth rates of 0.70 and 0.69 cm per day, respectively. This ultimately led to final heights of 10.7 and 9.8 cm. The findings of this study demonstrate that an elevated concentration of potassium has the potential to enhance the rate of plant development, hence facilitating the attainment of optimal plant height. In other iterations, the plant's ultimate height exhibited diminished outcomes, spanning from 4.8 to 7.7 cm. The growth performance did not exhibit an increase when administering increased amounts of two individual components. The incorporation of phosphorus necessitates a commensurate augmentation in the inclusion of other constituents. The observed phenomenon of plant height growth is evident in applying NPK fertilizers with ratios of 1:2:2 and 2:2:1, resulting in final plant heights of 7.7 cm and 6.5 cm, respectively. In contrast, using NPK fertilizer with a ratio of 1:2:1 only yields a final height of 4.8 cm. The enhanced mobility of potassium relative to phosphorus promotes healthy root and stem growth.

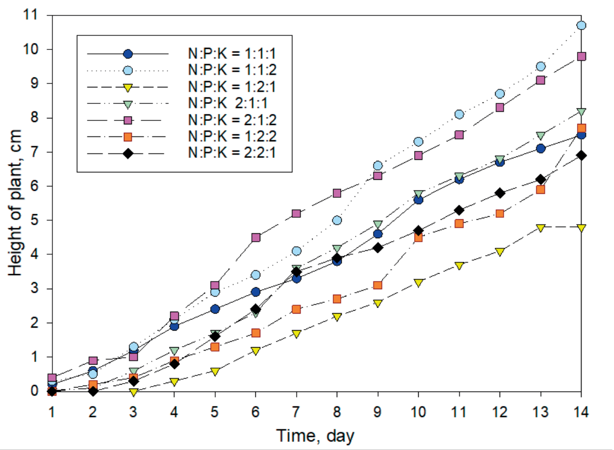

Figure 4. Effect of addition of nitrogen, phosphorus, and potassium on plant growth

The provision of increased quantities of nitrogen and phosphorus has been observed to produce more favorable outcomes. This is attributed to the role of phosphorus in facilitating the nitrogen process, which aids in the efficient distribution of nutrients throughout all plant components during photosynthesis. As a result, plant growth is enhanced, even in acidic soil conditions. Applying NPK fertilizer with different ratios, specifically 1:2:2 and 2:2:1, resulted in notable plant weight and leaf breadth improvements. Concerning leaf width, the ratios of 1:2:2 and 2:2:1 result in measurements of 1.3 cm and 1.8 cm, respectively, compared to an initial width of 0.9 cm. In a similar vein, the weight of the plant exhibits a transition from 0.7519 grams to 0.98 centimeters and then to 0.95 centimeters. In the optimal formulation of NPK 1:1:2, the width of the plant leaves attains a measurement of 1.2 cm. However, when NPK 2:1:1 is introduced, the width increases to 1.5 cm. An increase in nitrogen concentration has resulted in a larger water content in the stem, thereby increasing plant weight. The presence of a watery stem can be attributed to the restricted movement of nutrients inside the plant's anatomical structure. The observed augmentation of leaf width within this particular variation can be attributed to the optimal functioning of the photosynthesis process within the leaves, resulting in a progressive widening of the plant's width.

Including monopotassium sulfate (KH_2PO_4) is a common practice for supplying the P and K components in agricultural applications, particularly for root crops. The KH_2PO_4 solution is an acid buffer to reestablish the plant's optimal pH level. In Figure 5, the observed plant growth rate when NPK 1:1:1 and KH_2PO_4:urea were added in a ratio of 2:1 exhibited similar outcomes, specifically measuring 7.5 cm and 7.3 cm, respectively. The findings suggest that including salts with a greater volume composition did not produce statistically significant outcomes. The utilization of KH_2PO_4 is attributed to its ability to increase pH levels, thereby facilitating the efficient functioning of essential nutrients and components for plant growth. In addition, this component serves the sole purpose of enhancing the growth of flowers and fruits through optimization. An elevated presence of nitrogen (in the form of urea) also indicates a diminished growth pace. Excessive nitrogen without adequate supporting components tends to impede the growth rate.

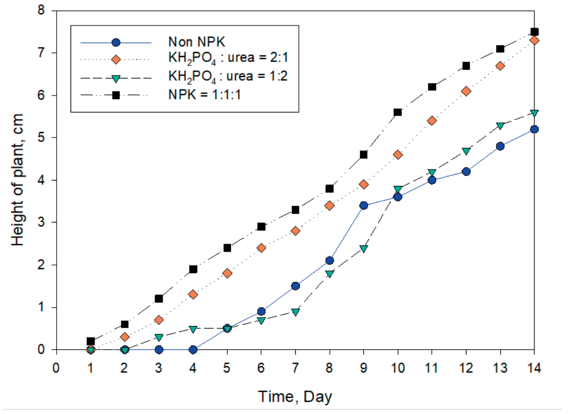

Figure 5. Effect of addition of potassium and phosphorus from KH_2PO_4 on plant growth

In order to assess the impact of planting efficacy on hydrogel planting media, further experiments were conducted with soil planting media. The N:P:K mixture was applied in the same manner as the hydrogel planting medium, and the growth trend of the green bean plants is depicted in Figure 6. Upon comparing Figures 4 and 6, it is evident that the growth of green beans on the hydrogel planting media exhibited better outcomes than the growth observed on the soil growing medium.

The porosity and content of the soil planting medium exhibit non-uniformity, resulting in uneven nutrient absorption by the soil. As a result, the nitrogen uptake of plants is similarly impacted. In the context of hydrogels, it is possible to manipulate the composition and porosity of the hydrogel to effectively manage the diffusion of nutrients to plants, hence facilitating optimal nutrient supply to plants. This finding suggests that sodium alginate-based hydrogel holds promise as a viable option for use as a planting substrate.

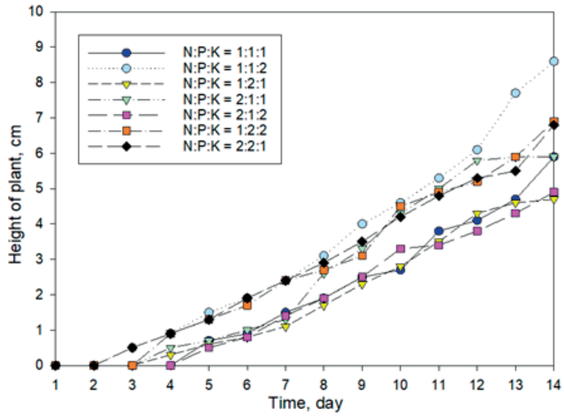

Figure 6. Effect of addition of nitrogen, phosphorus, and potassium on plant growth in soil media

CONCLUSIONS

Sodium alginate (SA) exhibits promising characteristics that render it a viable candidate for utilization as a planting medium, owing to its notable water resistance properties. Sodium alginate (SA) can accumulate substantial quantities of essential nutrients plants require. The ionotropic gelation process was utilized to produce alginate hydrogel, whereby a solution of $CaCl_2$ served as the crosslinking agent. Nitrogen (N), phosphorus (P), and potassium (K) possess unique functional attributes, although they perform synergistically to facilitate the growth and development of plants. The findings of this study indicate that increasing the concentration of potassium has the potential to increase the rate of plant development, thereby facilitating the achievement of optimal plant height. Porosity and soil content in the planting medium show non-uniformity, resulting in uneven absorption of nutrients by the soil. As a result, nutrient absorption by plants is also similarly impacted. In the context of hydrogels, the composition and porosity of hydrogels can be manipulated to effectively regulate the diffusion of nutrients to plants, thereby facilitating optimal nutrient supply to plants. These findings indicate that sodium alginate-based hydrogels show promise as a viable option for use as planting substrates.

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