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Right dose of NPK hydrogel concentration improves the growth of spinach (*Amaranthus hybridus* L.)

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ABSTRACT

The productivity of horticultural crops is highly dependent on the availability of balanced nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K). However, conventional fertilization is often inefficient due to nutrient leaching. One innovation to improve fertilization efficiency is the use of hydrogel as a slow-release nutrient medium. This study aims to investigate the effect of varying concentrations of sodium alginate-based NPK (16:16:16) hydrogel fertilizer on the growth parameters of spinach (*Amaranthus hybridus* L.). The study was conducted in the greenhouse of the Biology Education Program at the Faculty of Education and Teacher Training, Pasundan University, over 21 days using a Completely Randomized Design (CRD) with seven treatments: negative control, hydrogel NPK concentrations of 3.4%, 4.4%, 5.4%, 6.4%, 7.4%, and positive control (fertilizer without hydrogel). The observed parameters included the number of leaves, plant height, and stem diameter. Data were analyzed using normality tests, homogeneity tests, one-way ANOVA, and DMRT post-hoc tests with the assistance of SPSS version 29. The results showed that the treatment with a 5.4% concentration yielded the best results significantly for all three parameters: number of leaves (5.25 leaves), plant height (11.525 cm), and stem diameter (0.1748 cm). In conclusion, the 5.4% NPK hydrogel formulation is the most effective in promoting optimal and efficient growth of spinach plants.

Keywords: hydrogel; NPK fertilizer; sodium alginate; spinach growth; slow-release

1. INTRODUCTION

The productivity of horticultural crops, particularly leafy vegetables such as spinach (*Amaranthus hybridus* L.), is greatly influenced by the availability of sufficient and balanced nutrients (Matshona et al., 2018). Nutrients such as nitrogen (N), phosphorus (P), and potassium (K) play a crucial role in plant physiological processes, including chlorophyll formation, root growth, cell division, and regulation of osmotic pressure and water balance in tissues (Sinha & Tandon, 2020). Imbalances or deficiencies in nutrients can cause plants to experience deficiencies, stunted growth, and reduced crop quality and quantity.

In agricultural practice, fertilization is one of the primary efforts to meet plant nutrient needs. One of the most widely used fertilizers is NPK fertilizer, which is a compound fertilizer containing the three main macronutrients in balanced proportions. However, the direct application of inorganic fertilizers to the growing medium is often inefficient. Many nutrients are not optimally absorbed by plants because they are washed away by rain or irrigation, evaporate into the air, or become trapped in forms unavailable to plant roots (Estiaty et al., 2005). In addition to causing waste, this also has the potential to cause environmental pollution and gradual soil degradation (Muslimah, 2017).

To address these issues, innovations in fertilization technology are urgently needed. One promising approach is the use of hydrogel as a slow-release nutrient-releasing medium. Hydrogel is a hydrophilic polymer material with a three-dimensional structure capable of absorbing and storing large amounts of water and nutrient solutions, then releasing them slowly according to plant needs (Adi, 2012). The use of hydrogel in fertilizer formulations is believed to enhance fertilization efficiency, maintain soil moisture, and reduce nutrient leaching into deeper soil layers(Erlangga et al., 2015).

However, the effectiveness of hydrogel fertilizer use depends not only on its constituent materials but is also greatly influenced by the concentration or dosage of the formulation used (Tambing et al., 2023). A hydrogel concentration that is too low can result in insufficient nutrient supply, while a concentration that is too high risks causing salt accumulation and increased osmotic pressure in the root zone, which can actually hinder water and

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nutrient absorption by plants (Sahmat et al., 2022). Therefore, determining the appropriate hydrogel concentration is a crucial aspect in the application of this technology in the field.

Spinach (*Amaranthus hybridus* L.) was selected as the subject of this study because it has a short life cycle, adapts quickly to the environment, and is highly responsive to nutrient availability (Taufiqurrohman & Dewi, 2024). Additionally, spinach is a C_4 plant with high photosynthetic efficiency, particularly under high light intensity and warm temperatures, making its growth highly dependent on climatic factors and available nutrients (Kumar et al., 2025). This makes spinach an ideal model for observing plant responses to fertilization treatments and nutrient delivery technologies.

Based on the above, this study aims to investigate the effect of varying concentrations of hydrogel formulated with NPK fertilizer (16:16:16) on spinach plant growth parameters, including the number of leaves, plant height, and stem diameter. It is hoped that the results of this study will contribute to the development of more efficient, environmentally friendly fertilization methods that support sustainable agriculture, particularly in horticultural crop cultivation.

2. MATERIAL AND METHODS

This study was conducted using an experimental approach aimed at determining the effect of varying concentrations of NPK fertilizer hydrogel (16:16:16) on the growth of spinach plants (*Amaranthus hybridus* L.). The study was designed to allow for replication of results, complete with a systematic description of materials, tools, and procedures. All stages were carried out under controlled conditions to ensure that environmental factors did not influence the results, and statistical methods were used to objectively analyze the effects of the treatments.

2.1 Research location

This research was conducted in a greenhouse owned by the Biology Education Study Program, FKIP, Pasundan University, located at Jl. Tamansari No. 6–8, Tamansari, Kec. Bandung Wetan, Kota Bandung, Jawa Barat 40116. This location was chosen to maintain a homogeneous and controlled environment, protected from extreme weather fluctuations. The study lasted for 21 days, from May 7 to May 28, 2025, with regular recordings of temperature and humidity as part of environmental control.

2.2 Tools and materials

The materials used included amaranth seeds (*Amaranthus hybridus* L.), NPK fertilizer (16:16:16), sodium alginate, calcium chloride dihydrate/$CaCl_2$, distilled water, and soil as the planting medium, which was a mixture of burnt husks and humus soil. The equipment used in this study included: digital scale, measuring cup, beaker, stirrer, dropper, sieve, ruler, caliper, soil pH meter, and 25 × 25 cm polybags.

2.3 Research design

The research used an experimental method with a completely randomized design (CRD) consisting of seven treatments and three replicates. The treatments used were shown in Table 1.

2.4 Research procedure

Hydrogel production was carried out by dissolving sodium alginate in distilled water, then mixing it with NPK fertilizer according to the concentration of each treatment. This mixture was dripped into a $CaCl_2 \cdot 2H_2O$ solution to form a gel through an external ionotropic gelation process. The resulting hydrogel was filtered and stored until use. The preparation steps of the hydrogel formulation are shown in Figure 1.

Planting is done by filling soil into polybags, planting three spinach seeds per polybag, then leaving one plant that grows the healthiest. Hydrogel application is done at the beginning of planting according to the treatment dose. During the study, the plants are watered twice a day and no additional fertilizer is given.

Table 1. Treatment Concentrations

CODE	TREATMENT
A	NEGATIVE CONTROL
B	NPK HYDROGEL CONCENTRATION 3,4%
C	NPK HYDROGEL CONCENTRATION 4,4%
D	NPK HYDROGEL CONCENTRATION 5,4%
E	NPK HYDROGEL CONCENTRATION 6,4%
F	NPK HYDROGEL CONCENTRATION 7,4%
G	POSITIVE CONTROL

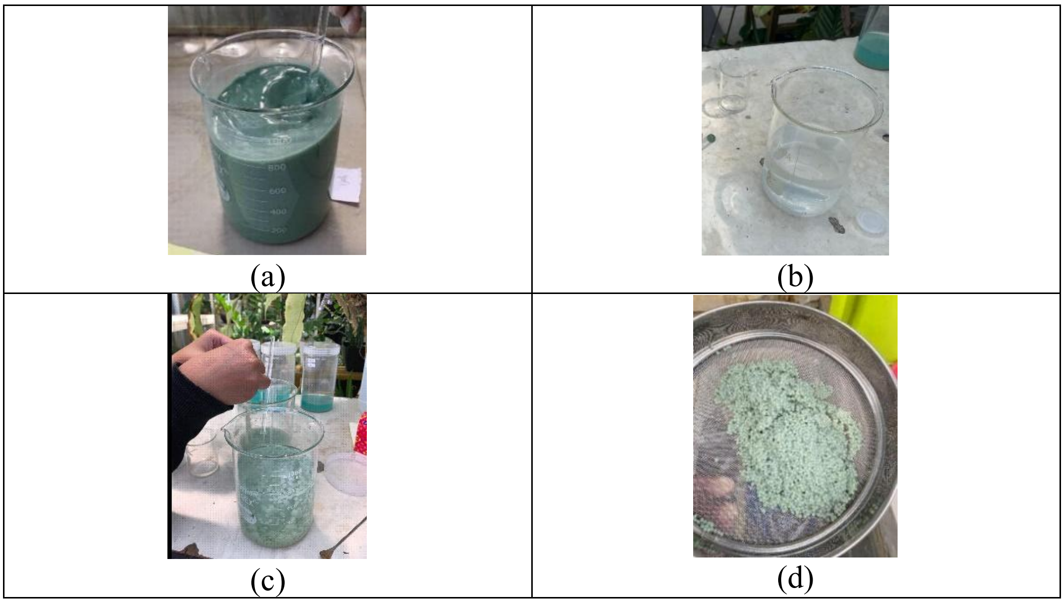

Figure 1. Preparation steps: (a) mixing the NPK solution with sodium alginate, (b) dissolving 2 g of $CaCl_2 \cdot 2H_2O$ in 100 mL of distilled water, (c) dropping the dispersion mixture into the $CaCl_2 \cdot 2H_2O$ solution using a dropper pipette, and (d) filtering the formed capsules.

2.5 Data analysis

Data from observations of the number of leaves, plant height, and stem diameter were analyzed using a statistical approach to test the effect of varying concentrations of NPK (16:16:16) fertilizer hydrogel on spinach plant growth. Before further analysis, the data was tested for normality using the Shapiro-Wilk test to determine whether the data was normally distributed. Additionally, a homogeneity test (Levene's Test) was conducted to ensure that the variance between treatments was uniform. These two tests are important prerequisites for the use of parametric analysis.

If the data met the assumptions of normality and homogeneity, a one-way ANOVA test was conducted to determine whether there were significant differences between treatments. This test was conducted at a significance level of 5% ($\alpha = 0.05$). A significance value < 0.05 indicated that the treatment had a significant effect on plant growth.

Furthermore, to determine which treatments produce significant differences, a Duncan Multiple Range Test (DMRT) is conducted. The DMRT is used to group treatments based on significant differences in the mean values of each observed parameter. All statistical analyses were performed using IBM SPSS Statistics software version 29.

3. RESULTS AND DISCUSSION

This study was conducted to determine the effect of varying concentrations of NPK fertilizer hydrogel (16:16:16) on the growth of spinach (*Amaranthus hybridus* L.). Three parameters were observed over a period of

21 days: number of leaves, plant height, and stem diameter. The average growth results for each treatment are presented in Table 3.

Table 3. Average increase in number of leaves, plant height, and stem diameter of spinach

Treatment	Average increase		
	Leaves	Height	Diameter
A	2,75	7,5	0,05675
B	3,75	8,475	0,0805
C	4	8,6	0,0915
D	5,25	11,525	0,17475
E	4,75	9	0,114
F	4,75	9,375	0,13575
G	4,75	10,25	0,1565

The results of the study indicate that variations in the concentration of NPK fertilizer hydrogel have a significant effect on spinach plant growth. Increasing the concentration of fertilizer encapsulated in sodium alginate hydrogel affects the availability of nutrients such as nitrogen, phosphorus, and potassium, which are essential for supporting plant physiological processes. A concentration of 5.4% resulted in optimal growth in terms of leaf number, plant height, and stem diameter. This indicates that nutrient release is balanced with the physiological needs of the plant, without causing deficiency or excess.

This finding aligns with research Lestari et al., (2022) showing that sodium alginate-based hydrogels can retain and release nutrients slowly and steadily, enhancing nutrient absorption efficiency by plants. Treatments E and F, despite containing more fertilizer, showed reduced growth, likely due to over-fertilization increasing osmotic pressure in the root zone, thereby inhibiting water and nutrient uptake. This aligns with the findings of Hao et al., (2021), who explained that excessive fertilizer can disrupt ionic balance and cause physiological stress in plants.

Meanwhile, treatments B and C with low concentrations were unable to optimally meet the nutritional needs of the plants. The positive control (treatment G) did show better results than the negative control, but its effectiveness was still inferior to that of the hydrogel treatment. This highlights the importance of hydrogel in regulating the sustained release of nutrients, thereby supporting plant growth over a longer period of time. The characteristics of spinach as a C_4 plant that requires stable availability of nutrients and light also reinforce that hydrogel-based nutrient management is highly relevant to supporting its productivity (Badr et al., 2024).

3.1 Increase in the number of leaves

The graph (Fig.2) shows that the highest average number of spinach leaves was obtained in treatment D (NPK hydrogel concentration of 5.4%) with a value of 5.25 leaves. This number is significantly higher than treatment A (negative control), which only produced an average of 2.75 leaves. This indicates that fertilizer application, particularly in the form of a hydrogel formulation that releases nutrients slowly, has a significant impact on leaf growth. Spinach plants are highly responsive to nitrogen, which plays a crucial role in chlorophyll formation and the development of vegetative tissues such as leaves. Meanwhile, treatments B and C (low doses) were unable to promote optimal leaf formation, and treatments E, F, and G, although producing the same number of leaves (4.75), were unable to surpass the effectiveness of treatment D. This indicates that there is a specific concentration point that provides the optimal nutrient balance for leaf organ formation. This success reflects an optimal balance between the amount of nutrients released and the plant's capacity to absorb them, in accordance with the principle that nutrient supply must occur in sufficient and balanced amounts (Inaya et al., 2021).

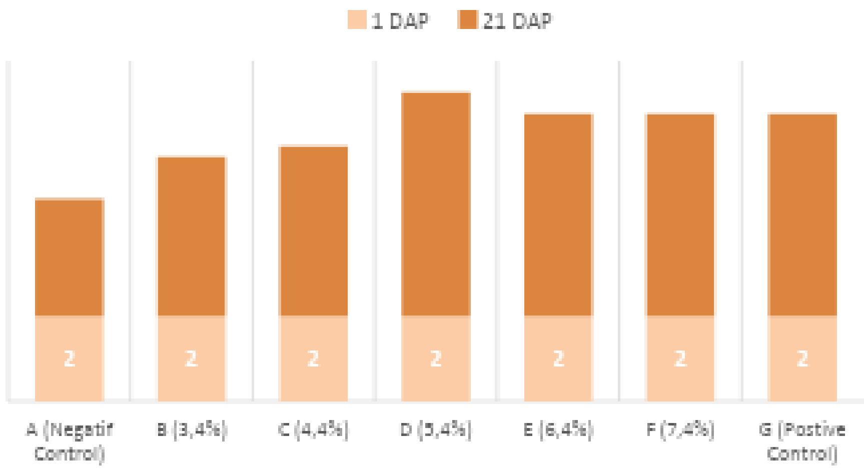

Figure 2. Increase in the number of leaves

3.2 Increase in plant height

Treatment D again recorded the highest value for the plant height parameter, namely 11.525 cm (Fig.3). These results indicate that the release of nutrients from hydrogel at a concentration of 5.4% is able to promote optimal vertical growth (Ali et al., 2021). Plants that receive nutrients in balanced amounts and at the right time will experience better physiological activity, including cell division and elongation. In contrast, the negative control (A) only reached 7.5 cm, confirming that without sufficient nutrient supply, plant growth is inhibited. Meanwhile, treatment G (fertilizer without hydrogel) reached 10.25 cm, which is relatively high but still lower than treatment D, indicating that the efficiency of conventional fertilizer absorption is still not as good as the slow-release system. Treatments E and F (high doses) showed a decrease, likely due to osmotic stress caused by salt accumulation, which disrupts water and nutrient absorption by the roots.

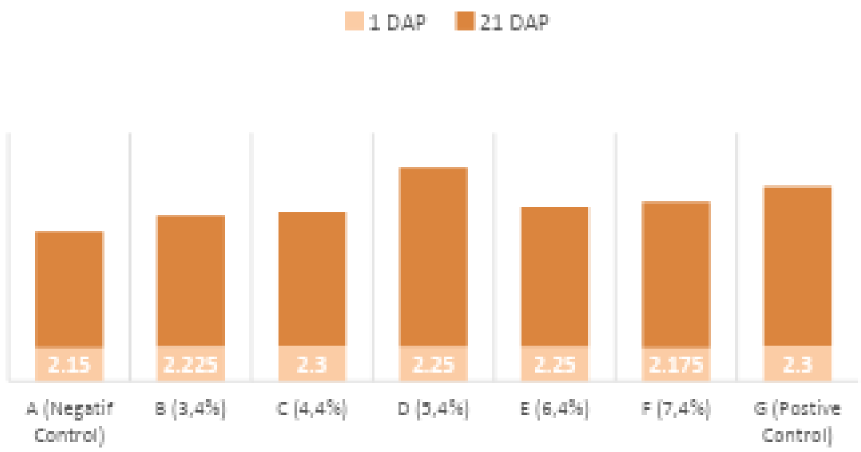

Figure 3. Increase in plant height

3.3 Increase in stem diameter

Stem diameter is an indicator of plant structural strength and water and nutrient transport in the vascular system. Treatment D (5.4%) produced the highest stem diameter of 0.17475 cm (Fig. 4), indicating that stable nutrient uptake strongly supports the formation of plant strengthening tissue. Plants deficient in nutrients typically have small and weak stems, as seen in treatment A with a diameter of only 0.05675 cm. Meanwhile, treatment G (positive control) yielded a diameter of 0.1565 cm, indicating the effectiveness of NPK fertilizer even without hydrogel. However, this result is still lower than treatment D, reinforcing that the hydrogel formulation can prolong nutrient availability and maximize its absorption (Ridlo et al., 2023) Treatments E and F, although higher than the negative control, did not produce a larger stem diameter than D, again indicating that too high a dose can actually inhibit growth effectiveness.

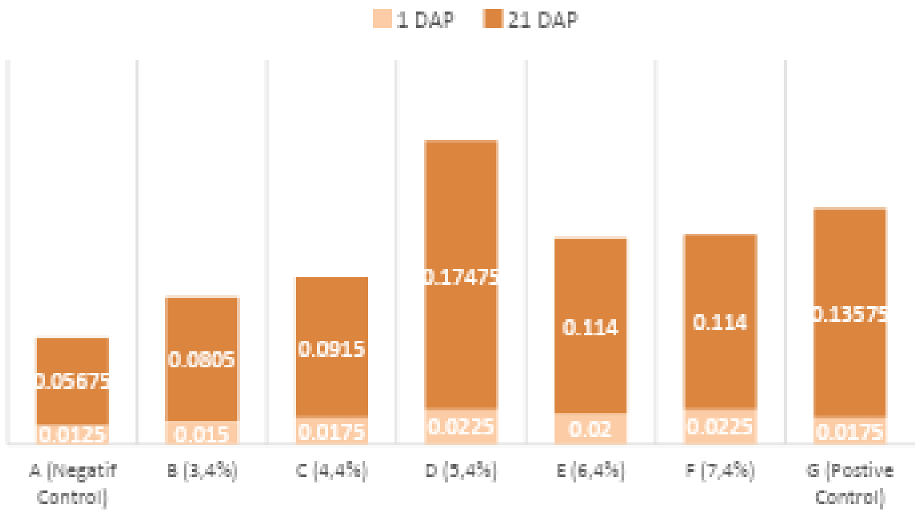

Figure 4. Increase in stem diameter

3.4 Statistical analysis

The Shapiro-Wilk normality test shows that the data from all treatments have a significance value > 0.05, including 0.272 (treatment A), 0.783 (B), 0.677 (C), 0.220 (D), 0.200 (E), 0.628 (F), and 0.271 (G). This indicates that the data are normally distributed. The homogeneity test using Levene's Test also yielded significance values of 0.977 for the number of leaves, 0.216 for plant height, and 0.957 for stem diameter, thus all data were declared homogeneous. The results of the one-way ANOVA test showed that the treatment of NPK fertilizer hydrogel concentration had a significant effect on all growth parameters. The significance values obtained were 0.020 for the number of leaves, <0.001 for plant height, and <0.001 for stem diameter. From Duncan's post-hoc test, treatment D (5.4%) consistently yielded the highest average results: 5.25 leaves for leaf number, 11.525 cm for plant height, and 0.1748 cm for stem diameter. This treatment was in a distinct group compared to the other treatments, indicating that the 5.4% concentration is the most optimal formulation for supporting spinach plant growth.

3.5 Discussion

This study aims to determine the effect of NPK fertilizer based on sodium alginate hydrogel on the growth of amaranth (*Amaranthus hybridus* L.). Based on the observations, the application of hydrogel showed an increase in plant height, number of leaves, and stem diameter compared to the negative control (no fertilizer) and positive control (conventional fertilizer).

This growth improvement is attributed to the hydrogel's ability to maintain moisture around the roots and release nutrients slowly. Sodium alginate, as the hydrogel's base material, forms a stable gel structure through a reaction with $CaCl_2$ as a crosslinker, creating "egg-box" type ionic bonds that enhance nutrient absorption and release control (Ridlo et al., 2023). This makes nutrients such as nitrogen, phosphorus, and potassium from NPK fertilizer more consistently available to plants compared to conventional fertilizer, which is easily lost due to leaching or evaporation (Rugayah et al., 2018).

Under the best treatment conditions, the number of leaves and plant height showed significant differences compared to the control. These results align with studies showing that applying NPK fertilizer with a balanced ratio significantly enhances spinach growth. Safitri et al., (2024) also reported that the combination of AB mix nutrients and $CaCl_2$ enhances leaf and stem growth in lettuce under hydroponic systems. From the observations, the stem diameter of plants was also larger in the hydrogel treatment, indicating stronger and more robust tissue growth. Syahidin, n.d, (2024) in his study stated that the use of NPK combined with soil conditioners such as vermicompost or hydrogel can increase stem diameter due to improved nutrient absorption efficiency.

Overall, the use of sodium alginate hydrogel-based NPK fertilizer with the external ionotropic gelation method using $CaCl_2$ resulted in better growth compared to the control treatments, both negative and positive. The effectiveness of this formulation proves that biopolymer-based fertilizer innovations can be a sustainable fertilizer solution with high efficiency and minimal nutrient loss.

4. Conclusion

This study shows that variations in the concentration of NPK fertilizer hydrogel (16:16:16) based on sodium alginate have a significant effect on the growth of spinach plants (*Amaranthus hybridus* L.). Statistical analysis results prove that all treatments have normal data distribution and homogeneous variance, and show significant differences in the number of leaves, plant height, and stem diameter. The treatment with a concentration of 5.4% proved to be the most optimal in enhancing plant growth, with an average number of leaves of 5.25, plant height of 11.525 cm, and stem diameter of 0.1748 cm. This indicates that the hydrogel formulation at this concentration is capable of providing nutrients gradually and in a balanced manner according to the plant's needs. Therefore, the 5.4% concentration NPK hydrogel fertilizer can be recommended as an efficient and environmentally friendly alternative fertilizer to support optimal spinach plant growth.

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