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Application of slow-release NPK fertilizer on the growth of sweet corn plants (*Zea Mays* L.)

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Abstract. Inefficiency and asymmetry in applying fertilizer in agricultural cultivation activities cause various problems, including environmental issues, imbalance in soil nutrition, and food production, which could be more optimal and impact human health. The development of slow-release NPK fertilizer products (NPK-SR) is a solution to overcome the problem of inefficiency, providing and improving fertilizer performance through optimal nutrient absorption. This research aims to determine the effect of NPK concentration of slow-release fertilizer on the growth of sweet corn plants. This study was carried out with a wholly randomized non-factorial plan with six treatment levels (0, 10, 20, 30, 40, and 50 grams of NPK-SR Fertilizer); observations were made on days 0, 14, 28, 42, 56, 70, and 84 DAP. The study showed that application of slow-release NPK fertilizer significantly affected plant height, number of leaves, leaf area, ear length, and ear diameter. The best NPK-SR fertilizer concentrate was given in the 30g treatment, which gave the best results for the growth of sweet corn plants.

1. Introduction

Over the past few decades, the massive use of fertilizers has resulted in a significant increase in global food production capacity, with approximately 200 million tons of NPK fertilizers being worldwide used to meet global supply and demand. Farmers' dependence on NPK fertilizers has led to high fertilizer prices and increased input prices. However, in recent years, several studies have highlighted the inefficiency and asymmetry in fertilizer application in agricultural cultivation activities, which have caused various problems, including environmental issues, soil nutrient imbalance, suboptimal food production, and impacts on human health (1). However, in reality, large amounts of inefficiency occur during the fertilization process, with losses of 40-70% nitrogen, 80-90% phosphorus, and 50-70% potassium lost to the environment due to surface runoff and percolation, and evaporation (2). Thus, conventional fertilization practices have raised global concerns with various environmental and economic losses (3). The development of slow-release NPK fertilizer products (NPK-SR) is a solution to overcome the problem of inefficiency in fertilizer delivery and improving performance through optimal nutrient absorption.

NPK fertilizer packed into a biocomposite matrix is one of the technological innovations that has slowed down and limited the release rate of nutrients into the environment. Renewable and sustainable natural polymer composites are a trend in developing the latest materials generation. Various polymers can be used as biocomposite matrix materials by formulating the materials' composition. Some polymers that have the potential to be used as matrices include starch, alginate, chitosan, carrageenan, and also agricultural biomass such as corn cobs, which are waste from agro-industrial activities. As an illustration, corn production in Indonesia in 2022 reached 16.53 million tons, so 30% of the total production, around 4.96 million tons, is produced as corn cob waste (4). Corn cobs as biomass waste that is available in large quantities can be appropriately managed to reduce environmental impacts by utilizing its potential as an alternative biomaterial that can increase economic value and utility value through the application of nanomaterial technology in the form of nanocrystalline cellulose which acts as a matrix strengthener and as an inhibitor of the rate of release of NPK fertilizer. Isolation of cellulose nanocrystals from corn cobs has been carried out in previous research (5). In this research, there will be potential directions for material development towards designing slow-release fertilizer products.

A series of studies on developing slow-release biocomposite matrices has been conducted; among them, the isolation of cellulose nanocrystals from corn cob waste has been carried out (6), and previous research on developing active packaging technology using cellulose nanocrystals to reinforce the bead matrix for slow-release eugenol active compounds (7). Given the working principle of the slow-release matrix that can be applied widely, previous research is the basis for exploring the expansion of applications to slow-release NPK fertilizer development by utilizing cellulose nanocrystals to reinforce the biocomposite matrix. The coating and entrapment mechanism of nutrient fertilizers with a cellulose nanocrystal-reinforced biocomposite matrix is designed to be able to slow down the rate of fertilizer release and ensure that plants utilize the nutrients Nitrogen, Phosphorus, and Kalium efficiently to increase agricultural productivity sustainably. This study aimed to test the performance of a nanocrystalline cellulose-reinforced biocomposite matrix in slowly releasing NPK fertilizer on the growth of sweet corn plants. Various concentrations were tested to recommend the right concentration of NPK fertilizer for sweet corn plants.

2. Methodology

2.1 Making a Demonstration Plot

Trial Demonstration Plot Prepared by Partners, in this case, the Food Crops and Horticulture Service of Gowa Regency. Green House and 18 polybags measuring 18 Liters were prepared to apply slow-release NPK fertilizer on sweet corn plants. The planting medium used a mixture of soil, burnt rice husks, and sand with a ratio of 1:1:1; the corn seeds used were Super Sweet Corn hybrid corn from PT. Bisi International. Fertilization was only done once using slow-release NPK fertilizer with different concentration levels, namely 0, 10, 20, 30, 40, and 50 g, with 3 repetitions.

2.2 Synthesis Slow-Release NPK Fertilizer

The first stage of this study was to synthesize slow-release NPK fertilizer. The type of fertilizer used was liquid NPK (Verti Grow), which was encapsulated with a biocomposite alginate matrix and reinforced with cellulose nanocrystals. The fertilizer used was liquid NPK fertilizer, so the method used the principle of mixing/blending with biopolymers. Alginate was added gradually to the cellulose nanocrystal suspension and heated (90°C) while stirring (600 rpm 60 minutes) to avoid clumping until a homogeneous and transparent suspension was obtained. The dissolved NPK fertilizer was added when the temperature decreased (around 35-40°C). Furthermore, the suspension was dropped into a 10% $CaCl_2$ solution accompanied by magnetic stirring (200 rpm) to produce hydrogel beads, then dried at room temperature.

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2.3 Fertilizer Application to Sweet Corn Plants

Two corn seeds were inserted into the planting hole 5-10 cm deep in each polybag. Watering is done daily with 1 liter of water/polybag. Corn growth is measured and observed every 2 weeks (0, 14, 28, 42, 56, 70, and 84 DAP), with 3 repetitions.

3. Result and discussion

Several factors affect the growth of sweet corn plants. Internal factors include genes and hormones. External factors include sunlight, nutrients, air and humidity, temperature, and soil type (8). All aspects are controlled except for the provision of nutrients through fertilization so that slow-release NPK fertilizer at various levels can be observed in the growth of sweet corn plants. Several parameters were observed in the effectiveness test activities of slow-release NPK fertilizer developed and applied to sweet corn plants, including plant height, number of leaves, leaf area, length and diameter of corn cobs, and the age of male and female flowers.

3.1 Corn Plant Height Measurement

Plant height is an important factor in plant growth because it is crucial in determining a plant's ability to compete for light, essential for photosynthesis and overall plant fertility (9). Additionally, it directly contributes to increasing crop productivity (10).

The results of the ANOVA analysis showed that the treatment of slow-release NPK fertilizer concentration and Days after planting (DAP) each significantly affected plant height. Likewise, the interaction between fertilizer concentration and DAP together had a significant effect on corn plant height. Based on observation data, the study's results showed that the average growth of plant height increased with increasing plant age. Table 1 shows that the best concentration of fertilizer application for sweet corn plant height is treatment P3, with a fertilizer application level of 30 g. This treatment has the highest plant height compared to other treatments, with an average height of 183.75 during the planting period. The results showed a height decrease and no significant difference from the control treatment (P0). The results of the ANOVA test show that the P3 and P0 treatments are significantly different at the 5% level, with a P value of 0.00 < 0.05.

Nitrogen (N), Phosphorus (P), and Potassium (K) are all classified as macronutrients, which means crops require relatively more of these nutrients than other nutrients. NPK is The nutrients essential for plants to grow and survive. Some research showed the same result from the treatment using NPK fertilizer doses had a very significant effect on the observation of plant height during the growth of purple eggplant (11), potato (12), and okra (13).

Table 1. Average Plant Height to The Concentration of Slow-Release NPK Fertilizer.

Treatment	Height Plants (cm)					
	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP	84 DAP
P0	36.33_{l}	69_{ijkl}	114_{ghijk}	142.25_{fg}	165_{de}	184_{ef}
P1	32.33_{kl}	55.33_{ijk}	122.33_{ghi}	155.13_{bcde}	196.38_{abcd}	209.33_{bcde}
P2	49.50_{ijkl}	71_{ghij}	136.25_{fgh}	189.38	214.13_{ab}	228.13_{bcd}
P3	55.67_{ijk}	87.33_{ghi}	149.88_{fg}	240.5_{ab}	278.13_{a}	291_{ab}
P4	51.00_{jkl}	81.67_{hijk}	142.38_{fgh}	197_{bcde}	241_{abc}	264.33_{bcde}
P5	34.01_{kl}	86_{ijk}	138_{ghijk}	152.25_{cde}	181.25_{bcde}	197.5_{de}

Information: Means that do not share a letter significantly differ in level α 5%.

3.2 The number of leaves in corn plants measurement

The function of the leaves is to produce photosynthate, which plants need as a source of energy in growth and development (13). The greater number of leaves may be due to increased growth of morphological characteristics such as plant height and number of branches, which cause more leaves (14). Table 2 presents the results of the data analysis using ANOVA to determine the relationship between fertilizer concentration and the number of leaves in sweet corn plants. The results showed that the P3 treatment with slow-release NPK fertilizer showed a higher average number of leaves, which was 10.97 leaves during the planting period. These results were significantly different from the control treatment (P0), with an average number of leaves of 7.56. The results of the ANOVA test showed that the P3 and P0 treatments were significantly different at the 5% level, with a P value of 0.047 < 0.05.

Table 2. Average Number of Leaves to The Concentration of Slow-Release NPK Fertilizer.

Treatment	Number of Leaves					
	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP	84 DAP
P0	3.33_{l}	5.33_{ijkl}	6.67_{ghijk}	8.67_{fg}	11.00_{de}	10.33_{ef}
P1	4.67_{kl}	6.00_{ijk}	7.33_{ghi}	12.00_{bcde}	13.00	12.33_{bcde}
P2	5.33_{ijkl}	7.00_{ghi}	8.33_{fgh}	12.67_{bcd}	13.67_{ab}	12.67_{bcd}
P3	7.50_{ijk}	7.33_{ghi}	8.67_{fg}	13.67_{ab}	15.00_{a}	13.67_{ab}
P4	5.00_{jkl}	6.33_{hijk}	8.33_{fgh}	12.33_{bcde}	13.33	12.33_{bcde}
P5	4.67_{kl}	6.00_{ijk}	6.67_{ghijk}	11.33_{cde}	12.33_{bcde}	11.00_{de}

Information: Means that do not share a letter significantly differ in level α 5%.

Nitrogen absorption is important, so it must be available throughout the growing season. Continuous provision of nitrogen in limited amounts through the application of slow-release NPK fertilizer can supply the nitrogen needs of sweet corn plants throughout the growing season. Nitrogen elements in fertilizers can increase the vegetative growth of corn plants, as measured by the number of leaves (15). This is supported by several researchers, including those who have found that plants that grow with low nitrogen availability have lower photosynthesis rates, resulting in lower yields and fruit sizes (16) because photosynthesis is a function of leaf surface, not mass (17).

3.3 The leaf area in corn plants measurement

Leaf area, a commonly used measure for assessing the fertility and productivity of biogeochemical cycles, represents the potential leaf area available for gas exchange with the atmosphere and biosphere. A plant's number of vertical leaves directly affects its leaf area, and a higher leaf area index indicates a higher light saturation level. Leaf area relates to the amount of light a plant can capture and the amount of water and nutrients it can absorb.

Leaf area is a parameter of plant growth. It results from cell division and elongation activities, which are influenced by the availability of nutrients N, P, and K (18). The addition of NPK nutrients to corn plants encourages increased leaf area growth. NPK fertilizer is a compound fertilizer containing nitrogen, phosphorus, and potassium, which are important for plant growth (19). The results of the ANOVA analysis presented in Table 3 show that the concentration of slow-release NPK fertilizer and DAP partially and simultaneously significantly affect leaf area in sweet corn plants, with a P-value of 0.00 < 0.005. The highest average leaf area was shown in treatment P3

(30g NPK-SR) with a value of 462546 cm^2. In comparison, the lowest leaf area was shown in treatment P5 (50 g NPK-SR) with an average value of 2429.58 cm^2; based on the results of the Tuckey further test, it is known that treatments P3 and P5 are significantly different at the 5% level. Fertilization with a higher P5 concentration (50 g NPK-SR) did not show the best results for leaf area. Balanced fertilization ensures the provision of the right amount and proportion of nitrogen (N), phosphorus (P), potassium (K), and nutrients based on plant needs and soil fertility performance (20). This is in line with the research of Nemadodzi et al. (2017), which showed that giving too high K+ decreases leaf area, which results in small leaf size (21).

Table 3. Average Leaf Area to The Concentration of Slow-Release NPK Fertilizer.

Treatment	Leaf Area (cm^2)					
	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP	84 DAP
P0	137.4_{w}	578.7_{v}	1303.2_{r}	3816.7_{l}	4619.5_{i}	4613.2_{i}
P1	148.9_{w}	784.5_{u}	1398.7_{q}	4089.2_{k}	4702.0_{h}	4720.9_{h}
P2	155.2_{w}	797.4_{u}	1397.8_{q}	5985.3_{f}	6107.7_{e}	6285_{d}
P3	182.7_{w}	1275.0_{r}	2692.3_{n}	7416.2_{c}	7874.6_{a}	7717.9_{b}
P4	162.5_{w}	1192.3_{s}	1680.9_{o}	5808.4_{g}	5951.5_{f}	5816.8_{g}
P5	140.9_{w}	899.6_{t}	1596.4_{p}	3611.6_{m}	4193.3_{j}	4135.9_{jk}

Information: Means that do not share a letter significantly differ in level α 5%.

3.4 Length and Diameter of Corn Cob

Anova's results show that fertilizer administration at various concentrations significantly affects the corn cob length in sweet corn plants; this can be seen from the P-value of P 0.00, which is smaller than 0.05 (P-value 0.00 <0.05). The same thing is shown in the results of measuring the diameter of the cob, showing a significant interaction with a P value of 0.043 <0.05. Table 4 shows the data length measurement results for the length and diameter of corn cobs produced from the P3 treatment (30 g NPK-SR), with an average cob length of 25.20 cm and a diameter of 26.67 cm. The measurement data showed significantly different results from the PO treatment (control), which produced a corn cob length of 13.23 cm and a diameter of 24.20 cm.

Table 4. Length and Diameter of Corn Cob to The Concentration of Slow-Release NPK Fertilizer

Treatment	Length of Corn Cob (cm)	Diameter of Corn Cob (mm)
P0	13.23_{d}	24.20_{b}
P1	18.73_{bc}	25.73_{ab}
P2	21.27_{b}	25.07_{ab}
P3	25.20_{a}	26.67_{a}
P4	21.20_{b}	24.80_{ab}
P5	17.30_{c}	24.73_{ab}

Information: Means that do not share a letter significantly differ in level α 5%.

Slow-release NPK fertilizer can provide N, P, and K content during the sweet corn planting period to increase the sweet corn crop yield. The nutrient Nitrogen can influence the formation of corn cobs because the Nitrogen element is the main component in the protein synthesis

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process. A good protein synthesis process will be positively correlated with increased cob size in length and cob diameter (22). In addition, the role of P nutrients in flower formation is no less important. The role of P in flower formation affects the size of the corn cob because the cob is a development of the female flower (23).

3.5 Age of Appearance of Male and Female Flowers in Corn Plants Measurement
The results of the ANOVA test showed that the treatment of slow-release NPK fertilizer concentration did not significantly affect the age of male and female flowers in sweet corn plants. This is indicated by the P-value produced at the age of male flowers of 0.791 and the P-value for the age of female flowers of 0.116, where the resulting P-value is greater than 0.05 (0.791> 0.116> 0.05). The fastest emergence of male flowers in the P3 treatment (30 g NPK-SR) was, on average, 44.67 DAP 3 days earlier than the emergence of male flowers in the P0 treatment (control). For the fastest emergence of female flowers in the P4 treatment (40 g NPK-SR), female flowers appeared on average 52.33 DAP 4 days earlier than female flowers in the P0 treatment (control). However, there was no significant difference between all treatments. Data is presented in Table 5**.**

Table 5. Average Age of Flower Emergence to The Concentration of Slow-Release NPK Fertilizer

Treatment	Appearance of Male Flowers (DAP)	Appearance of Female Flowers (DAP)
P0	47.67_a	57.00_a
P1	46.00_a	55.00_a
P2	46.00_a	55.33_a
P3	44.67_a	54.33_a
P4	45.67_a	52.33_a
P5	48.33_a	58.00_a

Information: Means that do not share a letter significantly differ in level α 5%.

The study results indicate that slow-release NPK fertilizer can meet corn plants' nutritional needs during planting. NPK fertilizers trapped in the composite matrix limit the release of NPK and slow it but still meet the nutritional needs of sweet corn plants. The study also shows the efficiency of providing slow-release fertilizers (24–27).

4. Conclusion

The development of slow-release NPK fertilizer products (NPK-SR) is a solution to overcome the problem of inefficiency. These products provide and improve fertilizer performance through optimal nutrient absorption. The study's results showed that the concentration of NPK-SR fertilizer significantly affected several observation parameters, including plant height, number and area of leaves, and length and diameter of corn cobs. The age of male and female flowers appearing on sweet corn plants showed a relationship that was not significantly different. The best NPK-SR fertilizer concentration was given in the 30 g treatment, which gave the best results for the growth of sweet corn plants. NPK fertilizers trapped in the composite matrix limit the release of NPK and slow it but still meet the nutritional needs of sweet corn plants.

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