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Down-streaming Small-Scale Green Ammonia to Nitrogen-Phosphorus Fertilizer Tablets for Rural Communities

Raldi H. Koestoer [1*], Tri Ligayanti [1], Sutrasno Kartohardjono [2], Harris Susanto [3]

[1] *School of Environmental Science, Indonesia University, Jakarta, Indonesia.*

[2] *Faculty of Engineering, Indonesia University, Jakarta, Indonesia.*

[3] *Luas Birus Utama, Jawa Barat 17530, Indonesia.*

Abstract

This study aims to evaluate the growth and production of sweet corn plants in response to the application of commercial NPK fertilizer and various doses of nitrogen-phosphorus fertilizer tablets. From early October 2022 to late January 2023, research was conducted at Research and Development Luas Birus Utama to produce nitrogen-phosphorus fertilizer tablets and at Research and Development Syngenta Indonesia Cikampek Station, Karawang, to perform a semi-field analysis. A factorial randomized block design with two treatment factors was employed in this study. The first factor was five types of nitrogen-phosphorus fertilizer tablets, namely, A (0% nitrogen and 6.3% phosphorus), B (0.81% nitrogen and 6.3% phosphorus), C (1.57% nitrogen and 6.1% phosphorus), D (2.33% nitrogen and 6.2% phosphorus), and E (3.06% nitrogen and 6.2% phosphorus). The second factor was F (standard nitrogen, phosphorus, and potassium). The results revealed that applying different dosages of nitrogen-phosphorus fertilizer tablets in combination with potassium chloride fertilizer yielded no different effect on the growth, biomass, and yield components of sweet corn plants when compared to applying NPK fertilizer. A comparison between the soil test results before and after application revealed that the formulation of fertilizers in tablet form helps plants to effectively absorb the required nutrients. It is currently possible to develop small-scale or microscale green ammonia production technology to fulfill the fertilizer requirements of rural communities because of its low cost, low carbon emissions, and low renewable energy consumption. The scarcity of fertilizer supplies endangers Indonesia's food sustainability. Nitrogen-phosphorus fertilizer tablet production technology can be used in areas with a scarcity of inorganic fertilizers but with the potential for low-grade phosphate mines using commercial ammonia solutions. Thus, understanding how to produce nitrogen-phosphorus fertilizer tablets from ammonia solution will aid in the acceptance of microscale green ammonia production technology.

Keywords:

Down-Streaming;

Small-Scale Green Ammonia;

Nitrogen–phosphorus (NP) Fertilizer Tablet;

Semi-Field Study;

Sweet Corn.

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1- Introduction

Social, economic, and environmental factors must be considered in natural resource use planning for sustainable development in order to break free from the curse of natural resources. The paradox of plenty theory, commonly known as the curse of natural resources [1], was proposed based on the observation that many societies with abundant natural resources tend to have lower economic outcomes than those with scarce resources. This paradox is usually related to abundant resources that support initiatives aimed at improving economic outcomes. A recent study [2] found a link between the paradox of plenty, or the resource curse event, and the abundance of renewable energy in lower-middle-income countries. The abundance of renewable energy causes policy and investment strategies to shift from developing human resources to exporting energy to high-income nations that want to diversify their energy sources for long-term, sustainable growth.

* **CONTACT**: raldy.hk@ui.ac.id; ralkoest@gmail.com

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Down-streaming green hydrogen is expected to increase domestic business opportunities by creating new jobs [3]. The implementation and acceleration of downstream activities in natural resource utilization will enable Indonesia to escape the paradox of plenty, which is a condition in which a country is rich in natural resources but its people are poor [1]. Schumacher, an economist, introduced the concept of "appropriate technology" as an ideology movement (and its expressions) and an intermediate technology in his landmark essay, Small is Beautiful. Appropriate technology is often defined as a set of technologies with applications that are decentralized, small-scale, labor-intensive, energy-efficient, and closely tied to local conditions [4].

Osorio-Tejada et al. [5] studies have highlighted that the small-scale distribution of ammonia near farmers can result in co-benefits such as local employment, resource utilization, technology transfer, and knowledge transfer; crop intensification through customized fertilizer production; environmental benefits due to the use of clean energy sources; and minimized global and supply chain issues. Since the goal is to decarbonize the entire fertilizer industry, there must be alternative strategies for reducing the environmental impact of fertilizer use [6]. According to Lynch et al. [7], the agricultural sector significantly mitigates climate change because of its close association with mitigation strategies and capacity. Although using ammonia directly as a fertilizer is technically feasible, adequate precautions must be taken to avoid potential hazards. Contractors/experts must take strict safety precautions and not perform peasant operations [8].

Downstream technology based on small-scale and low-cost production factors can promote the adoption of rural low-carbon technology. To increase the use of renewable resources, small-scale production technologies must be implemented quickly and adaptably [9]. Green ammonia production technology for small-scale and distributed fertilization has the potential to revolutionize the field of low-carbon fertilization; however, due to its complementary nature, it still faces challenges such as high costs, scarce human resources, and technology unavailability. According to some previous studies, the benefits of small-scale energy production are comparable to those of renewable power generation [10, 11]. There are three economic prerequisites for sustainable rural development: 1) the development of new economic ventures that can satisfy future urban demands; 2) local entrepreneurship that can establish and expand new ventures; and 3) social capital that can provide new venture entrepreneurship with resources such as capital, labor, human capital, markets, and outside expertise for learning and creativity [12].

The main goal of the moral economic system is to ensure that the welfare and prosperity of the community come before the prosperity of individuals and a few groups that control the factors of production [13]. The coronavirus disease 2019 (COVID-19) pandemic highlights the urgent need for the global community to have a moral economy [14]. Neoliberalism must be rebuilt to curb the structural inequalities that have rendered society unsustainable [14]. Failure to protect the health and safety of the global poor population has endangered the entire world [14]. The moral economy independently manages whatever economic resources it can cultivate and control, i.e., small and medium-sized enterprises [15]. Renewable energy technology is still deemed impractical and insufficient to support the operation of green ammonia production for rural fertilization in Indonesia because of various obstacles and constraints, including high production costs and inadequate infrastructure, as well as the need for skilled labor, suitable technology, and supportive policies.

The above finding is consistent with that of a previous report [5], which stated that decentralized and renewable energy-based fertilizer production generates fewer pollutants than traditional production lines. Although these fertilizers are environmentally friendly and beneficial, their commercial viability continues to impede the adoption of alternative technologies. One strategy for facilitating the transition to a more sustainable fertilizer supply chain is to internalize the environmental effects of ammonia production and account for the implications of transportation, storage, and by-product use. Owing to the high cost of natural gas and carbon, green ammonia adoption has become the most cost-effective choice [16]. Green ammonia could play an important role in future decarbonization scenarios [16–18].

Sweet corn (*Zea mays saccharate L.*) is also known as sugar corn or polar corn. It is a milky and sweet maize variety with a sugar content of more than 25% during the milking stage [19]. Sweet corn can be harvested 70–75 days after planting, and the corn husk and stover have a moisture content of 70%–80%, making them suitable for ruminant feed [20]. Sweet corn is in high demand, both domestically and internationally. However, this demand is not directly proportional to Indonesia's sweet corn productivity. Since maize is the second-most important source of carbohydrates, it is an essential food [21]. Maize plants adapt better than other plants [22]. One of the causes of low sweet corn productivity is a lack of soil fertility. Inorganic fertilizer application is the quickest and easiest way to meet the nutritional needs of plants because inorganic fertilizers decompose easily and can be directly absorbed by plants.

Most crop-producing soils in Indonesia are deficient in phosphorus and nitrogen, but they can be improved by applying inorganic fertilizers such as triple superphosphate and ammonium sulfate (ZA) [23]. Many studies on green ammonia production indicate that small-scale and distributed green ammonia production can reduce carbon emissions during production and distribution [10, 11, 24]. One of the most sustainable methods of producing ammonia is through decentralized small-scale ammonia plants, which can be realized using many stranded energy sources, including wind or solar electricity, flaring gases, and biogas. In such a case, ammonia can be produced using sustainable or low-cost stranded power/gas or hydrogen at a very low operational cost, substantially lower than that of traditionally manufactured ammonia [25]. Although the use of ammonia as a fertilizer is technically feasible, adequate precautions must be implemented to avoid potential hazards [26, 27]. Contractors and experts must implement strict safety precautions, not farmer operations [8]. In Indonesia, ammonia fertilization has never been used directly. The United States uses ammonia directly as a fertilizer, hence the widespread presence of ammonia storage tanks [28]. Ammonia-based fertilizers, such as urea, monoammonium phosphate, diammonium phosphate, ZA, and nitrogen-phosphorus-potassium (NPK) compound fertilizers, are used following a complex and energy-intensive production process.

Therefore, the primary objective of this study is to examine the appropriate technology for down-streaming small-scale and distributed green ammonia to fertilizer. Thus, this research can bridge the research gap between the development of small-scale and distributed ammonia production technology and the relevant technology used in farmer-produced local fertilizers. A simple manufacturing method, such as tablet formulation, can be used to locally produce green ammonia by mixing it with natural phosphate rock, which is frequently found in small quantities and scattered throughout Indonesia. NP fertilizer tablets are an alternative to standard NPK fertilizers made from fossil-based ammonia, which have carbon-intensive production and distribution processes. The goal of this study is to compare the performance of NP fertilizer tablets to that of standard NPK fertilizer in terms of sweet corn growth, biomass, and yield components.

2- Material and Methods

This study aims to determine the effects of NP fertilizer tablets on the growth, biomass, and yield components of sweet corn plants. The research was conducted in two stages. The first involved the production of NP fertilizer tablets at Research and Development (R and D) Luas Birus Utama in October 2022. The second involved a semi-field test of the NP fertilizer tablets at the R and D Syngenta Indonesia Cikampek Station in Karawang, Indonesia, from November 2022 to January 2023.

The semi-field test was conducted on the NP fertilizer tablets during a sweet corn Talenta variety planting period at Syngenta Indonesia's R and D Cikampek Station research site in Cikampek from November 2022 to January 2023. The experiment was conducted in a plastic house to eliminate any limiting factors that could have interfered with the experiment and caused bias. A randomized block design (RBD) with six treatments and four replications was employed in this study; there were six groups comprising 20 polybags each, making a total of 480 polybags. The polybags used in the experiments were 20 cm × 35 cm in size, with the primary factor being the application of the NP fertilizer tablets in five dose variations.

The performance of commercial NPK fertilizers was compared to that of the NP fertilizer tablets. Meanwhile, each group received the same amount of potassium chloride (KCl) inorganic fertilizer for three times the age of the corn in accordance with the recommended fertilization dosage for corn plants of 100 kg/ha. The NP fertilizer tablets were applied at a depth of 5 cm near the rhizosphere. Soil nutrient measurements were collected before and after planting. The plant height, stem diameter, and chlorophyll content were measured 14, 28, 42, and 56 days after plantation (DAP).

Since the same maize variant was used in this study, the number of leaves was expected to be the same under normal conditions; thus, the leaf number was not measured. The plant biomass, which included root fresh weight, crown fresh weight, root dry weight, crown dry weight, root length, and leaf area index, was measured at 14, 28, and 49 DAP. Yield components, such as corn cob length, corn cob diameter, corn weight (with and without husk), and sweetness level, were measured upon harvest. The obtained data were variance-analyzed before being subjected to the honest differential test at a 5% level. Figure 1 presents the graphic study flowchart for the research methodology.

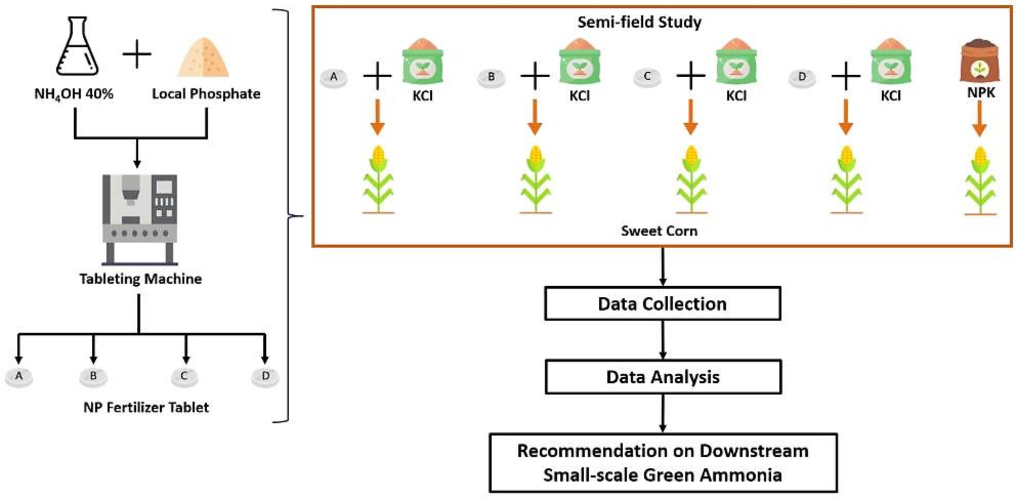

Figure 1. Graphic study flowchart of the research methodology

2-1- NP Fertilizer Tablet Material and Synthesis

In October 2022, NP fertilizer tablets were manufactured at the chemical industry Luas Birus Utama (Cikarang) using *BioPhospate* base material obtained from Javamas Agrophos (a local natural phosphate producer) with a P_2O_5 content of 14%, or 6.1% (P), and an ammonium hydroxide (NH_4OH) solution of 40%, or 16% (N). The synthesis steps are as follows: a) Five *BioPhosphate* samples weighing 5 kg each were collected and placed in a plastic container; b) NH_4OH (40%) was added in amounts of 1,000 mL, 750 mL, 500 mL, and 250 mL; c) the samples were sun-dried; d) each sample was reweighed, ground, and sieved; e) each sample was dried again to create a well-shaped tablet form; and f) the tablet was formed using a tablet press machine (Table 1).

Table 1. Variation in the content of the different NP fertilizer tablets

Description	A	B	C	D	E
P content (kg)	0.31	0.31	0.31	0.31	0.31
N content (kg)	0	0.04	0.08	0.12	0.16
End weight (dry, gram (g))	4.91	4.95	5.11	5.16	5.23
P content (%)	6.3	6.3	6.1	6.2	6.2
N content (%)	0	0.81	1.57	2.33	3.06
N to P Ratio	0	0.1	0.3	0.4	0.5

Figure 2 shows manufacturing process for the NP fertilizer tablets.

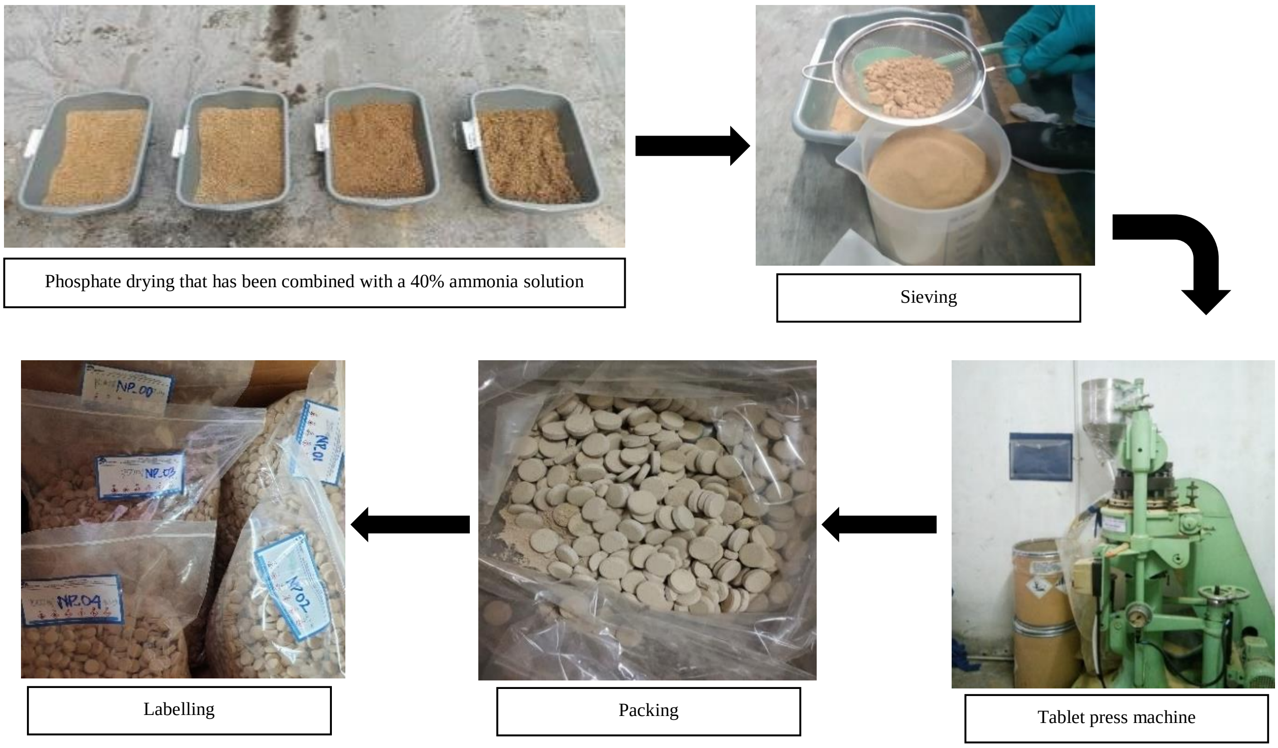

Figure 2. NP fertilizer tablet synthesis process

2-2- Planting Media

An RBD, six treatments with four replications, and six experimental polybag groups comprising 20 polybags each (a total of 480 polybags) were employed in the experiment (Table 2). The polybags employed in the experiments were 20 cm × 35 cm in size, with the major determinant being the delivery of the NP fertilizer tablets in five dosages. To evaluate the performance of the NP fertilizer tablets, one group was treated with only commercial NPK fertilizer. Meanwhile, each group received the same amount of K element (i.e., KCl inorganic fertilizer) for three times the age of the corn in accordance with the fertilization prescription for corn plants, which is 100 kg/ha. Plastic insulation was added to the base, roof, and fence margins to protect the semi-field study space from rain and elements.

Table 2. Treatment and application schedule for the fertilizers

Group Treatment	7 DAP		21 DAP		42 DAP	
	NP Tablet	KCl	NP Tablet	KCl	NP Tablet	KCl
A (kg)	0.80	0.51	0.96	0.51	0.88	0.51
B (kg)	0.80	0.51	0.96	0.51	0.88	0.51
C (kg)	0.80	0.51	0.96	0.51	0.88	0.51
D (kg)	0.80	0.51	0.96	0.51	0.88	0.51
E (kg)	0.80	0.51	0.96	0.51	0.88	0.51
F (kg)	0.121	0.00	0.121	0.00	0.121	0.00

Note:

- 0.80 kg is the amount of fertilizer required for one treatment (80 polybags), which is equivalent to 10 tablets per polybag;
- 0.96 kg is the fertilizer requirement for one treatment (80 polybags), which is equivalent to 12 tablets per polybag;
- 0.88 kg is similar to the fertilizer requirement for one treatment (80 polybags) or 11 tablets per polybag.

2-3- Design

An RBD, six treatments with four replications, and six experimental polybag groups comprising 20 polybags each (a total of 480 polybags) were employed in the experiment (Table 2). The polybags employed in the experiments were 20 cm × 35 cm in size, with the major determinant being the delivery of the NP fertilizer tablets in five dosages. To evaluate the performance of the NP fertilizer tablets, one group was treated with only commercial NPK fertilizer. Meanwhile, each group received the same amount of K element (i.e., KCl inorganic fertilizer) for three times the age of the corn in accordance with the fertilization prescription for corn plants, which is 100 kg/ha. Plastic insulation was added to the base, roof, and fence margins to protect the semi-field study space from rain and elements.

The NP fertilizer tablets and KCl or NPK granules were buried 5 cm beside the plants for fertilization. The fertilizer hole was ~5 cm away from the plant. The NP and KCl or NPK fertilizer tablets were provided at 7 DAP, 21 DAP, and 42 DAP, depending on the dose of each treatment, whereas the organic fertilizers were only administered at the beginning of planting. The urea and NPK fertilizer dosages were in accordance with the fertilization guidelines for sweet corn plants: urea (200 kg/ha), NPK (300 kg/ha), and KCl (100 kg/ha).

Plant maintenance for sweet corn includes replanting, watering, and pest and disease control. Replanting was performed one week after planting using sweet corn plants that had been seeded to achieve a consistent plant age. Watering was performed often and thoroughly during the early growth phase. The plants were watered with 600 mL of water twice a day, in the morning (300 mL) and afternoon (300 mL). Intensive pest management was performed 3–5 weeks after planting using Antracol pesticide (2 mL/L).

(a) (b) (c) (d)

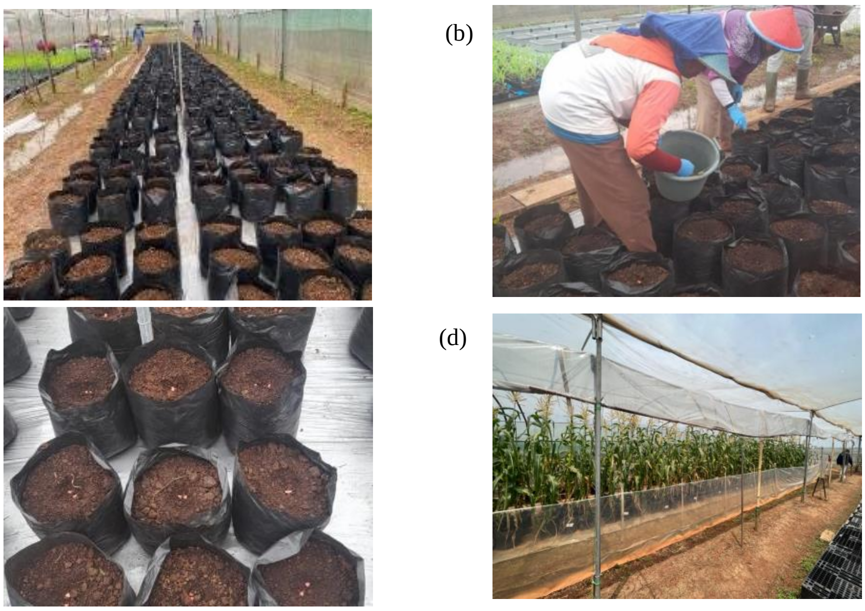

Figure 3. Planting design: (a) Planting preparation process; (b) Seed planting; (c) Planting of two corn seeds per hole; (d) Semi-field study space isolation with plastic to protect it from rain and elements

2-4- Soil Nutrient Analysis

The fraction, acidity, and various compounds of the soil were examined at the Service Laboratory Indonesian Oil Palm Research Institute at Bogor (accreditation No. LP-759-IDN) using generally accepted testing techniques. In this research, we use the unit (g/kg) of dry matter to express the soil fraction, acidity, and various compounds of the samples being analyzed. Before and after planting, soil nutrient observations were taken. Before planting, the soil sample was obtained from a farming field at RnD Syngenta Indonesia Cikampek Station. After planting, the soil samples were obtained from the polybags of each group after three months of planting. The collected samples were tested for fraction, acidity, and compound content (as shown in Table 3) using the method described above.

Table 3. Soil test method

Analysis	Unit	Method
Fraction, and sand	%	Hydrometer
Dust	%	Hydrometer
Clay	%	Hydrometer
C-organic	%	Spectrophotometry
N	%	Kjeldahl
CEC[1]	Cmol(+)/kg[5]	Percolation–Titration
CEV[2]-sodium	Cmol(+)/kg	AAS[3]
CEV-potassium	Cmol(+)/kg	AAS
CEV-calcium	Cmol(+)/kg	AAS
CEV-magnesium	Cmol(+)/kg	AAS
Zinc	ppm[6]	AAS
Al-dd[4]	Cmol(+)/kg	Titration
P_2O_5-available	%	Spectrophotometry
Potassium oxide	%	AAS
Boron	Ppm	Spectrophotometry
pH		pH meter

Note: [1] Cation exchange capacity; [2] Cation exchange value; [3] Atomic absorption spectroscopy; [4] Aluminum content in the soil; [5] Centimoles per kilogram; [6] Part per million.

2-5- Plant Growth

The effects of all treatments applied to the maize plants are equivalent in terms of water availability and nutritional requirements. Adequate nutrient content in the soil will result in the healthy vegetative growth of corn plants [29]. Nitrogen, which is readily available to plants, is the most important nutrient and is required by plants as it promotes the growth of vegetative plant parts such as leaves, stems, and roots. Nitrogen is a component of several substances, including amino acids, that are required for the creation or growth of vegetative parts, including stems, leaves, and roots [30]. At 14 DAP, 28 DAP, 42 DAP, and 56 DAP, the plant growth components were observed, including plant height, stem diameter, and chlorophyll content.

2-5-1- Plant Height Analysis

Plant growth is characterized by plant height. As a result, plant height is an important characteristic to monitor since it can be linked to nutrient uptake activities in maize plants as an indicator of plant growth. Plant height is the primary point of reference for determining the success of plant growth activities [31]. Using a ruler/meter, the plant height was determined by measuring 5 cm from the base of the corn stalk to the highest point of the plant.

2-5-2- Stem Diameter Analysis

The diameter of the stem is the easiest plant dimension to measure, especially at the base. A digital caliper was used to measure the diameter of the stem at the base of the plant.

2-5-3- Chlorophyll Content Analysis

The soil plant analysis development (SPAD) chlorophyll meter is a commonly used diagnostic technique for determining crop nitrogen status. The SPAD chlorophyll meter allows users to check chlorophyll levels in the field quickly and non-destructively [31]. The SPAD chlorophyll meter was used to measure the corn leaf chlorophyll level for various treatments (Figure 4).

Figure 4. Plant growth data collection: (a) Plant height measurement; (b) Measurement of stem diameter using a digital caliper; (c) SPAD measurements of leaf chlorophyll

2-6- Plant Biomass

Plant biomass, including root fresh weight, crown fresh weight, root dry weight, crown dry weight, root length, root volume, and leaf area index, was observed at 14 DAP, 28 DAP, and 49 DAP. Meanwhile, upon harvest, yield components such as cob length, cob diameter, cob weight (with and without husk), sweetness level, and root length were calculated.

2-6-1- Root Fresh Weight Analysis

The fresh weight of the roots refers to the wet weight of the roots immediately upon harvest, without any drying process. The fresh weight of the roots was assessed by gently uprooting the sweet corn plants to ensure that the roots did not break off and remain in the soil. The roots were then washed and cleaned of any soil or debris that remained attached. After cleaning the sweet corn roots, they were separated from the plant by cutting and were weighed using analytical scales with gram units.

2-6-2- Root Dry Weight Analysis

Plant dry weight refers to the overall outcome of CO_2 uptake during plant growth and development [32]. Plant growth can be thought of as an increase in both fresh weight and dry matter accumulation. As a result, as the plant grows, the dry weight increases. The root dry weight was measured by uprooting the sweet corn plants, carefully washing the roots, drying them in the sun, covering them in paper, and then baking the roots at 70 °C until the weight was consistent. The root dry weight was measured using analytical scales with gram units.

2-6-3- Crown Fresh Weight Analysis

The fresh weight of the crown represents the accumulation of plant photosynthates as well as the amount of water in the plant crown tissue. The crown fresh weight was measured shortly after harvest by cutting the plants apart from the roots. The crown fresh weight was measured three times during the life cycle of the maize plants at 14 DAP, 28 DAP, and 49 DAP. The crown fresh weight was measured using analytical scales with gram units.

2-6-4- Crown Dry Weight Analysis

The crown dry weight reflects the quantity of biomass that the plant can absorb. The difference in crown dry weight yield is controlled not only by the fresh weight of the crown but also by the number of leaves because leaves are the location of plant photosynthates accumulation. The dry weight of the crown was measured by first drying the crown in the sun, wrapping it in paper, and baking it at 70 ºC until the weight remained constant. Finally, the stalks were weighed using an analytical scale with gram units.

2-6-5- Root Length Analysis

Roots have an equally crucial part in plant growth as the crown. For example, the crown provides carbohydrates through the process of photosynthesis, whereas the roots provide nutrients and water during plant metabolism [33]. The longer the plant roots, the better the plant's ability to absorb water and nutrients; this results in optimal growth in terms of plant height, number of stalks, and number of leaves. The higher the number and length of plant roots, the greater their ability to absorb water and nutrients for plant development and production. Root growth can be inhibited by a deficiency in P and N [34]. The root length measurements were obtained by disassembling the sample plants. The roots were removed from the media and air-dried before being measured from the base of the stem to the tip of the longest root. Root length measurements were performed using a ruler.

2-6-6- Leaf Area Index Analysis

The leaf area index is an important crop management metric. In crop simulation modeling, the leaf area index is used to calculate the amount of solar radiation absorbed by the leaves for photosynthesis; this index determines plant biomass production. The leaf area index is an important measure for determining agricultural productivity [35]. The leaf area index was measured using a leaf area meter (Figure 5).

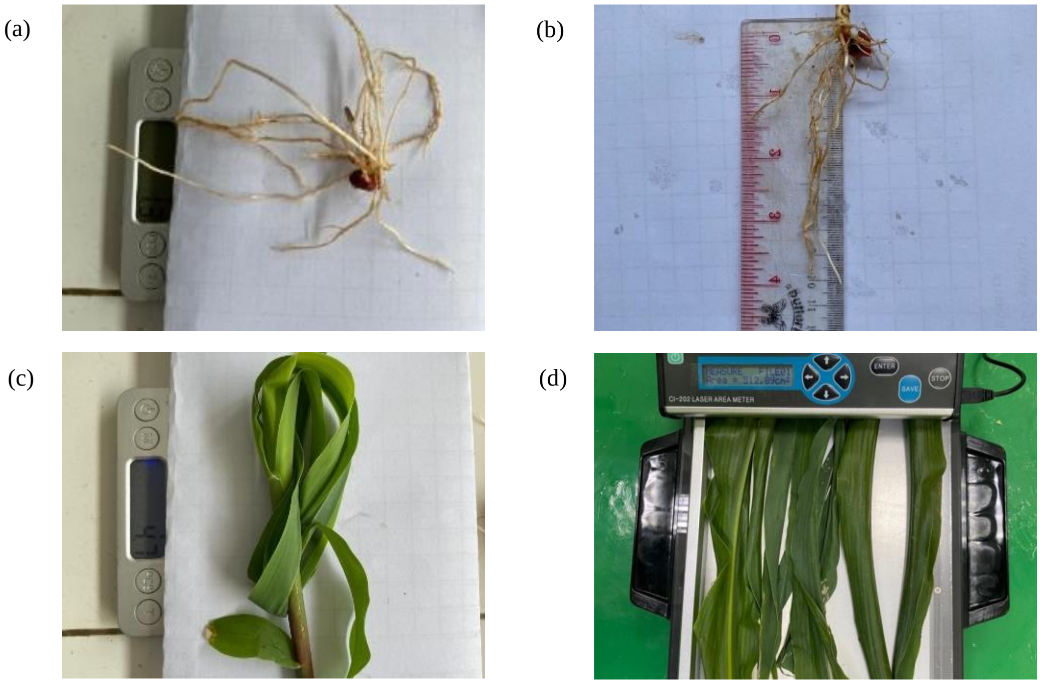

Figure 5. Plant biomass data collection: (a) Root weight measurement; (b) Root length measurement; (c) Crown weight measurement; (d) Calculation of leaf area index using a leaf area meter

2-7- Yield Component

Hand-picking was used to gather the sweet corn. Harvesting occurs when the sweet corn plants are 70 days old, as indicated by filled cobs and brown corn hair.

2-7-1- Corn Cob Length Analysis

The level of cell division that occurs in the cob organ itself has a substantial influence on the formation of the cob of the maize plant. Furthermore, sweet corn cob length is significantly impacted by genetic variables, and the ability of a plant to generate genetic features is influenced by environmental factors [36]. Using a ruler or meter, the length of the sweet corn cob was measured after it had been peeled from the skin (husk). The cob length was measured from one end to the other.

2-7-2- Corn Cob Diameter Analysis

The diameter of the cobs was measured after they had been unhusked or peeled. The diameter of a corn cob is measured at the most inflated region of the cob (which is presumed to represent the largest diameter). The corn cob diameter was measured using a digital caliper.

2-7-3- Corn Weight Analysis (with Husk)

Nutrients influence cob weight, particularly seeds, because nutrients ingested by plants are used to build proteins, carbs, and lipids, which are then stored in seeds, increasing cob weight [36]. The weight of the corn with husk was measured using analytical scales with gram units.

2-7-4- Corn Weight Analysis (without Husk)

The weight of the sweet corn cob after peeling was measured using analytical scales with gram units.

2-7-5- Corn Sweetness Level Analysis

The potassium elements in the fertilizer are responsible for the high amount of sweetness in sweet corn cobs. The higher the nutrient content absorbed by plants, the higher the sweetness level; therefore, it is assumed that K improves sweetness [37]. Sweetness level measurements were carried out using a brix-meter. The corn seed juice was measured in degrees Brix (°Brix) and was obtained by dripping it onto a refractometer. The measurement steps are provided in Figure 6.

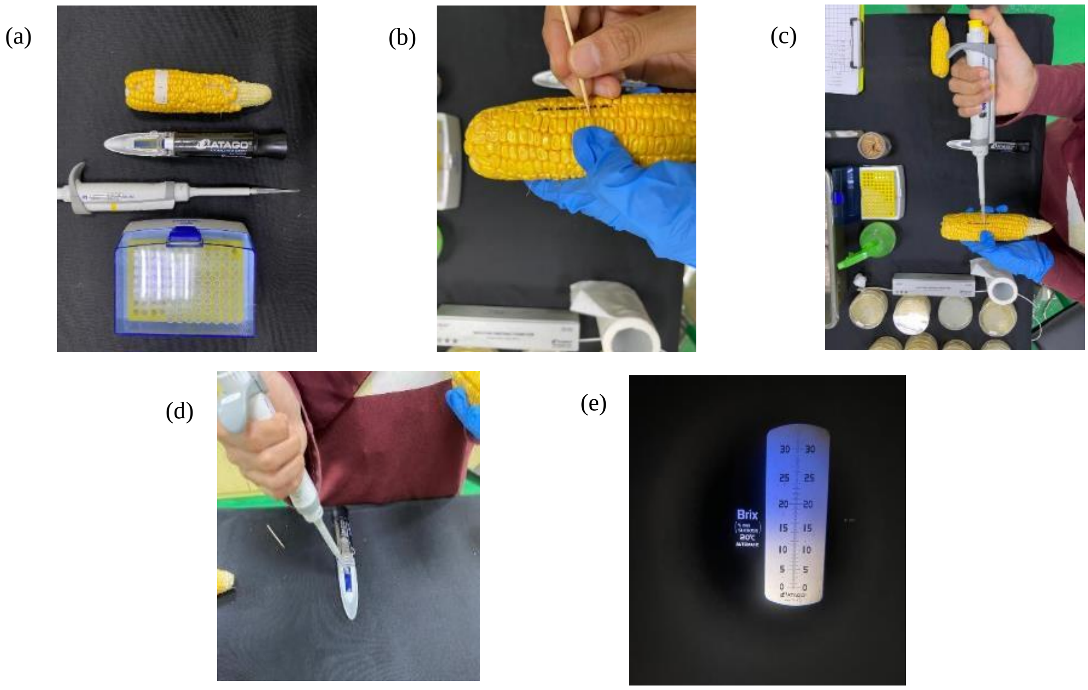

Figure 6. Plant biomass data collection: (a) Preparation of sweetness measurement using a micropipette and a brix-meter; (b) Selection of the corn parts that contained water, followed by piercing; (c) Extraction of the liquid on the corn kernels using a micropipette; (d) Placement of the sample on the transparent part of the brix-meter, followed by covering; (e) Sweetness level of the sweet corn ranging from 10–15 °Brix.

2-8- Data Analysis

All research data on plant growth, biomass, and yield component characteristics were examined using one-way analysis of variance (ANOVA) in R Studio (version 4.1.2). Tukey's HSD test was used to determine whether or not there were statistically significant differences between the groups [38]. The statistical significance level was chosen at P 0.05. The data are displayed as mean standard deviation (SD) to show the range of variance around the arithmetic mean.

3- Result and Discussion

3-1- Soil Nutrient

Table 4 lists the original nutritional level of the environment and the soil conditions of the study site before the research was conducted. The analysis results show that the soil had a loam texture and a slightly alkaline hydrogen potential (pH). The carbon-organic (C-organic) and nitrogen content were both low, while the cation exchange capacity (CEC) was moderate. During the study, there was no abiotic stress in the form of nutrient deficiencies or biotic stress in the form of pests and diseases. Plant-disrupting organism populations were low, and climatic conditions facilitated healthy plant growth. According to the research findings (see Table 4), the NP fertilizer tablet treatment widened the soil surface because of its sandy texture. Before and after treatment, there was no discernible difference in N content. N is required for the synthesis of chlorophyll, protein, and amino acids. As a result, sufficient nitrogen is required, especially when growth reaches the vegetative phase.

3-2- Plant Growth

During plant growth, at least 90% of the dry matter in plants is produced through photosynthesis. Biomass is a useful metric for assessing a plant's potential to produce photosynthate. The biomass ratio of different portions to overall biomass is frequently utilized to provide a good overview of the division data [39].

3-2-1- Plant Height

The plant height measurement results are shown in Table 5. The plant height differed significantly between treatments at 14, 28, 42, 49, and 56 DAP, indicating that all treatments had a positive effect on plant height. At 14, 28, 42, 49, and 56 DAP, the sweet corn plants showed significantly different responses to the NP fertilizer tablet + KCl compared to standard NPK. Table 4 depicts the treatment growth dynamics. Treatment E generally indicates plants with the highest stand growth rate, while treatment A indicates plants with the lowest. Increasing the liquid organic fertilizer dose had a significantly different effect on plant height than the control treatment during the maximum growth period. However, the values were similar to those of standard fertilizer.

Table 4. Soil test before and after application

Analysis	Before	After fertilizer application						Unit
		A	B	C	D	E	F	
Fraction and sand	10.62	38.57	44.39	42.24	40.29	39.93	41.90	%
Dust	42.83	34.71	26.90	30.93	32.89	35.07	31.11	%
Clay	46.55	26.71	28.71	26.84	26.82	25.00	26.99	%
C-organic	8.21	7.78	7.60	7.64	7.53	7.45	7.43	%
N	0.88	0.98	1.05	1.05	1.03	0.99	1.04	%
CEC	34.87	34.45	34.79	36.78	35.34	33.19	37.19	Cmol(+)/kg[4]
CEV[1]-sodium	7.30	2.49	2.00	2.53	2.59	2.39	2.54	Cmol(+)/kg
CEV-potassium	10.10	8.17	7.79	8.10	7.74	7.38	9.44	Cmol(+)/kg
CEV-calcium	11.16	33.13	34.05	33.69	35.70	36.80	39.75	Cmol(+)/kg
CEV-magnesium	11.48	13.93	14.28	13.33	13.32	12.04	13.88	Cmol(+)/kg
Zinc	40.04	137.03	137.24	138.32	136.99	130.71	132.41	ppm[5]
Al-dd[3]	0.00	0.21	0.11	0.21	0.11	0.21	0.21	Cmol(+)/kg
P_2O_5-available	0.46	302.68	300.37	337.63	325.59	187.72	308.42	%
Potassium oxide	1.11	0.46	0.43	0.43	0.42	0.41	0.40	%
Boron	6.61	7.19	6.28	6.08	6.13	5.92	6.81	ppm
pH	7.8	6.98	6.84	6.65	7.11	7.14	7.20	

Note: Test results from the Service Laboratory Indonesian Oil Palm Research Institute at Bogor.[1] Cation exchange value; [2] Atomic absorption spectroscopy; [3] Aluminum content in the soil; [4] Centimoles per kilogram; [5] Part per million.

Table 5. Plant height

Treatment	Plant height				
	14 days	28 days	42 days	49 days	56 days
A	35.72 a	103.81 a	182.83 a	206.23 a	202.43 a
B	33.24 a	98.93 a	181.14 a	196.20 a	200.20 a
C	37.83 a	104.89 a	187.38 a	206.45 a	203.73 a
D	38.26 a	107.63 a	187.83 a	210.03 a	212.23 a
E	36.46 a	106.39 a	194.91 a	210.18 a	211.45 a
F	32.90 a	103.04 a	189.91 a	209.80 a	212.55 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different, according to the Honest Differential Test (Tukey) at the 5% level.

3-2-2- Stem Diameter

Based on the statistical testing of stem diameter results, the treatment effect does not differ significantly from the stem diameter parameters listed in Table 6. The NP fertilizer tablet treatment had the same effect on the stem diameter parameter. It is suspected that the N and P content of NP fertilizer tablets was higher than that of conventional NPK fertilizers, particularly in the D and E treatments, which have bigger stem diameters than other NP fertilizers.

Table 6. Stem diameter of sweet corn

Treatment	Stem diameter (cm)				
	14 days	28 days	42 days	49 days	56 days
A	0.42 a	1.52 a	1.66 a	1.76 a	1.77 a
B	0.40 a	1.53 a	1.66 a	1.74 a	1.78 a
C	0.55 a	1.56 a	1.72 a	1.80 a	1.81 a
D	0.56 a	1.61 a	1.70 a	1.80 a	1.83 a
E	0.54 a	1.58 a	1.76 a	1.80 a	1.84 a
F	0.43 a	1.50 a	1.67 a	1.77 a	1.83 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different, according to the Honest Differential Test (Tukey) at the 5% level.

3-2-3- Chlorophyll Content

According to the results, the treatments did not affect the corn leaf chlorophyll levels (see Table 7). Over time, fertilization can significantly increase the chlorophyll content of the leaves. However, when compared to the other nutrients in the fertilizer, N had the greatest influence on the chlorophyll content. The SPAD meter captured a reflection of leaf color; the greener the leaf, the more N was contained in the leaf organs. This was due to the high N uptake by plants and the high N content of the soil.

Table 7. Chlorophyll content

Treatment	Chlorophyll content				
	14 days	28 days	42 days	49 days	56 days
A	37.34a	42.21a	45.26a	45.85a	46.08a
B	37.33a	41.67a	45.14a	45.28a	46.75a
C	36.20a	41.92a	45.88a	46.74a	47.06a
D	37.45a	41.10a	44.53a	45.56a	47.34a
E	36.59a	41.36a	45.51a	45.81a	47.44a
F	36.29a	41.70a	44.68a	45.76a	47.18a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different according to the Honest Differential Test (Tukey) at the 5% level.

Chlorophyll level is a vital measure of plant health, photosynthetic ability, and growth condition. Since leaf chlorophyll levels are related to plant conditions, they can be used to assess how much fertilizer plants require [40]. Nitrogen aids in the development of proteins and chlorophyll, both of which are necessary for photosynthesis [41, 42], which directly influences plant output and yield. Chlorophyll measurement is one method for determining the level of plant development and fertility and can be used to forecast plant production [43].

3-3- Plant Biomass

Sweet corn plant biomass indicators include crown fresh weight, root fresh weight, crown dry weight, root dry weight, root length, and leaf area index.

3-3-1- Root Fresh Weight

There were no statistically significant differences between the tested treatments (Table 8). The addition of NP fertilizer tablets met the macro- and micronutrient requirements of the plant. This shows that different NP fertilizer tablet concentrations have the same effect on the fresh weight of the roots. Using NP fertilizer tablets on corn plants produces the same results in terms of average root fresh weight and root growth. This progression is possible since every available element needed for each treatment has been provided in an equal amount. If the soil structure is in good condition, root development will be enhanced, allowing for maximum nutrient absorption.

Table 8. Root fresh weight and dry weight

Treatment	Root fresh weight (g)			Root dry weight (g)		
	14 days	28 days	42 days	14 days	28 days	42 days
A	0.684 a	7.96 a	24.48 a	0.0496 a	0.6496 a	4.512 a
B	0.683 a	7.43 a	31.24 a	0.0559 a	0.6540 a	5.060 a
C	0.751 a	8.72 a	32.63 a	0.0573 a	0.7910 a	6.090 a
D	0.775 a	9.99 a	35.26 a	0.0646 a	0.8798 a	6.303 a
E	0.676 a	9.43 a	35.56 a	0.0478 a	0.8351 a	5.838 a
F	0.652 a	8.50 a	30.31 a	0.0510 a	0.7293 a	5.247 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different according to the Honest Differential Test (Tukey) at the 5% level.

3-3-2- Root Dry Weight

The analysis revealed no statistically significant differences between the tested treatments (see Table 8). However, the data obtained revealed an increase in root biomass over time. The metabolic processes in the plant body, one of which is distributed to the roots, cause plant growth. Despite the lack of a statistically significant difference, the C and D treatments outperformed the other treatments.

3-3-3- Crown Fresh Weight

Table 9 shows that there was no statistically significant difference between the tested treatments. The D and E treatments produced a higher crown fresh weight than the other treatments tested. The variation in crown fresh weight is due to nutrient availability. Nutrient availability can influence plant growth and development, affecting crown fresh weight [44].

Table 9. Crown fresh and dry weight

Treatment	Crown fresh weight (g)			Crown dry weight (g)		
	14 days	28 days	42 days	14 days	28 days	42 days
A	2.950 a	89.64 a	239.23 a	0.249 a	7.133 a	66.47 a
B	3.225 a	78.00 a	253.93 a	0.290 a	6.433 a	68.70 a
C	3.225 a	80.98 a	303.26 a	0.289 a	6.592 a	86.00 a
D	3.433 a	98.38 a	310.10 a	0.319 a	8.500 a	96.49 a
E	3.083 a	91.07 a	320.63 a	0.278 a	7.450 a	103.72 a
F	2.442 a	78.11 a	289.63 a	0.226 a	6.892 a	83.59 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different according to the Honest Differential Test (Tukey) at the 5% level.

This means that the nutrients in the nitrogen (N_2) treatment can be accessed or absorbed by plants via the roots, influencing photosynthesis results and, as a result, the crown fresh weight. The higher the biomass of a plant, the more nutrients it absorbs from the soil.

3-3-4-Crown Dry Weight

Table 8 shows that the D and E treatments produced more dry weight than the other tested treatments. The statistical tests, however, revealed no statistically significant difference in crown dry weight between the treatments. Since the leaves were the location of plant photosynthate accumulation, the difference in crown dry weight results is influenced not only by the fresh weight of the crown but also by the number of leaves. Increased photosynthesis produces more photosynthetic products in the form of organic compounds, which are distributed to all plant organs and affect plant dry weight [45].

3-3-5- Root Length

For the root length parameter, the analysis results show no significant differences between the treatments (see Table 10). There was no discernible difference in treatment based on soil type or root length. Root development is influenced by nutrient availability, soil temperature, texture, water availability, aeration, and other factors

Table 10. Root length and leaf area index

Treatment	Root length (cm)			Leaf area index		
	14 days	28 days	42 days	14 days	28 days	42 days
A	12.83 a	33.78 a	36.28 a	446.30 a	906.47 a	932.55 a
B	12.83 a	30.06 a	41.27 a	444.46 a	916.50 a	931.83 a
C	13.25 a	28.33 a	45.17 a	466.54 a	930.29 a	958.28 a
D	11.67 a	29.70 a	46.04 a	459.52 a	938.40 a	959.34 a
E	10.92 a	31.41 a	46.90 a	451.95 a	945.66 a	961.41 a
F	13.21 a	30.86 a	40.40 a	407.03 a	921.77 a	935.40 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different according to the Honest Differential Test (Tukey) at the 5% level.

A water-stressed environment reduces the volume of roots, preventing root development [31]. Two aspects of root growth that are influenced by media and environmental factors are root elongation and root widening. Factors influencing plant growth media are closely related to its root growth carrying capacity as an organ that absorbs water and nutrients. Plant root systems can be affected by soil conditions and plant-growing media [46].

3-3-5- Leaf Area Index

Table 9 shows the effect of various fertilizer treatments on plant growth as measured by the leaf area index and plant growth rate. The E treatment had the highest leaf area index at 28 and 49 DAP, which decreased because the N content in fertilizer C was lower than that in A. The leaf area, on the other hand, showed no statistically significant effect from the NP fertilizer tablet treatment.

3-4- Yield Components

3-4-1- Corn Cob Length

The statistical analysis revealed that there was no significant difference in corn cob length between the treatments. Table 11 displays the average length of a corn cob.

Table 11. Yield components

Treatment	Corn cob length (cm)	Corn cob diameter (cm)	Corn weight (with husk) (g)	Corn weight (without husk) (g)	Corn sweetness level (°Brix)
A	13.45 a	13.45 a	133.00 a	106.50 a	9.00 a
B	14.21 a	14.21 a	135.75 a	109.38 a	9.67 a
C	14.64 a	14.64 a	134.50 a	110.00 a	9.67 a
D	15.11 a	15.11 a	153.75 a	125.75 a	11.42 a
E	15.36 a	15.36 a	153.50 a	125.75 a	11.17 a
F	14.39 a	14.39 a	150.13 a	108.00 a	10.08 a

Note: Treatment mean numbers in the same column marked with the same letter (a) indicate not significantly different according to the Honest Differential Test (Tukey) at the 5% level.

3-4-2- Corn Cob Diameter

Table 11 shows that the application of NP fertilizer tablets at different doses has the same effect on corn cob diameter as that of NPK chemical fertilizer. Plants require phosphorus to grow strong stems and roots. This element helps the plant reach maturity and produces healthy and normal flowers and fruits. It is also related to the number of leaves that support cell metabolism and the use of sunlight to obtain energy for cell division, which increases the amount of water and photosynthate produced by photosynthesis and results in a wider cob (Figure 7).

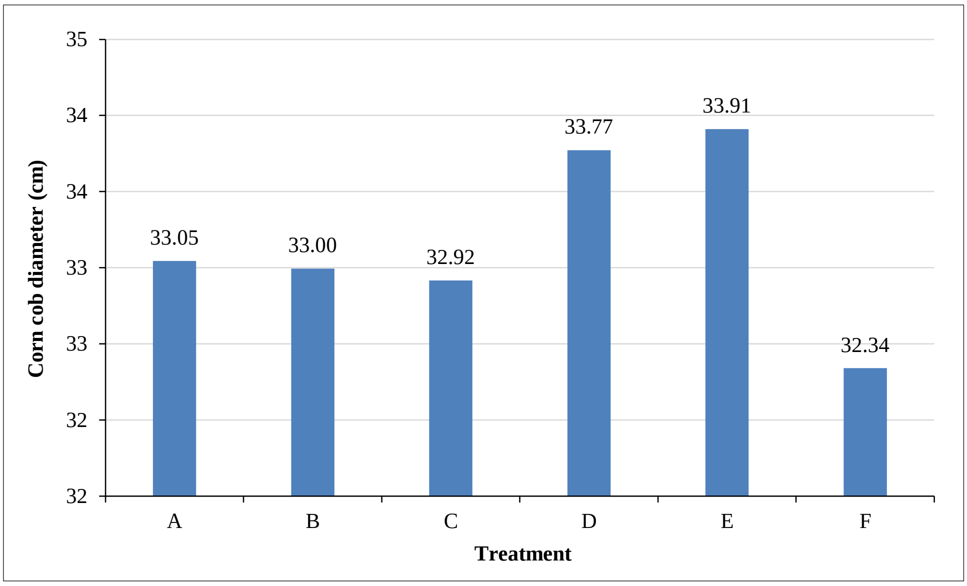

Figure 7. Corn cob diameter data obtained from different sample treatment groups

3-4-3- Corn Weight (with Husk)

Table 11 demonstrates that the D and E treatments produced more dry weight than the other treatments tested. Statistical tests, however, revealed no statistically significant difference in crown dry weight between the treatments (Figure 8).

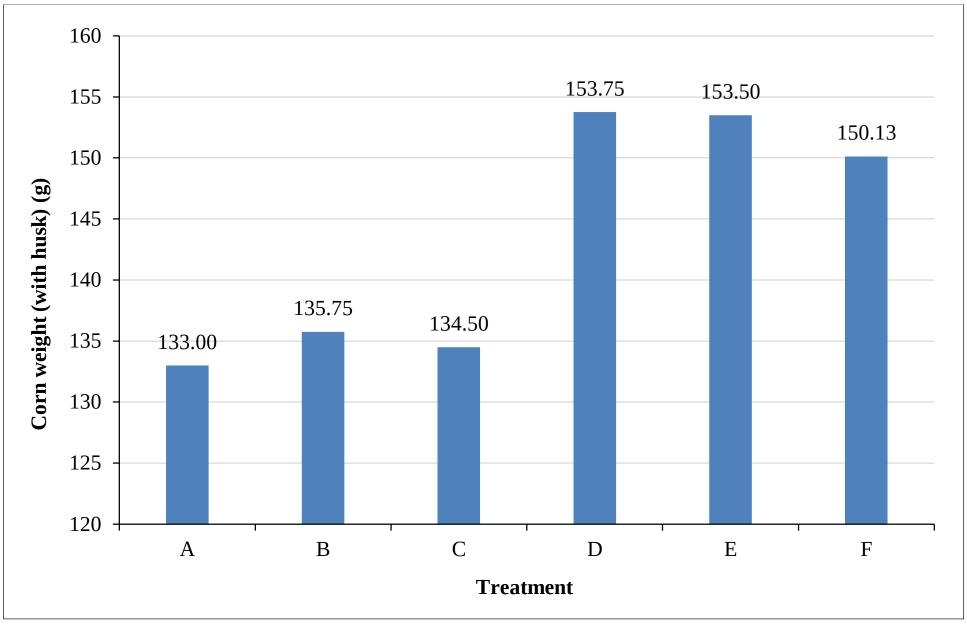

Figure 8. **Corn weight (with husk) data obtained from different treatment groups of samples**

3-4-4- Corn Weight (without Husk)

Table 10 shows that the D and E treatments yielded more corn weight than the other treatments tested. Statistical tests, however, revealed no statistically significant difference in corn weight without husk between treatments (Figure 9).

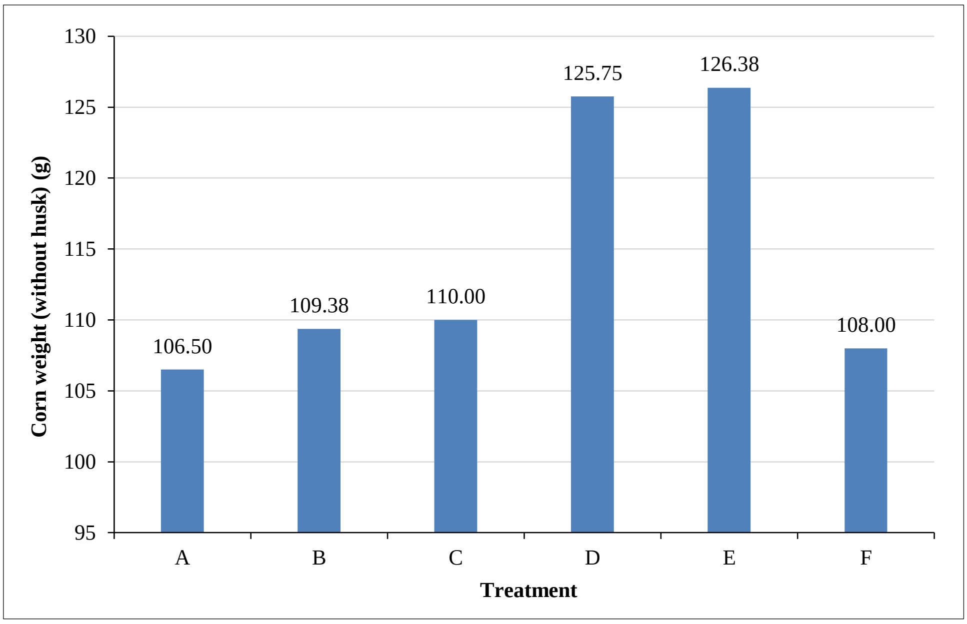

Figure 9. **Corn weight (without husk) data obtained from different treatment groups of samples**

3-4-5- Corn Sweetness Level

The sugar content or sweetness of sweet corn is the primary indicator of its quality. The higher the quality, the greater the sweetness. Tenderness and sweetness are quality indicators for fresh and processed sweet corn [47]. According to Table 11, the D and E treatments produced more corn sweetness than the other treatments tested. Statistical tests, however, revealed no statistically significant difference in corn sweetness levels between the treatments (Figure 10).

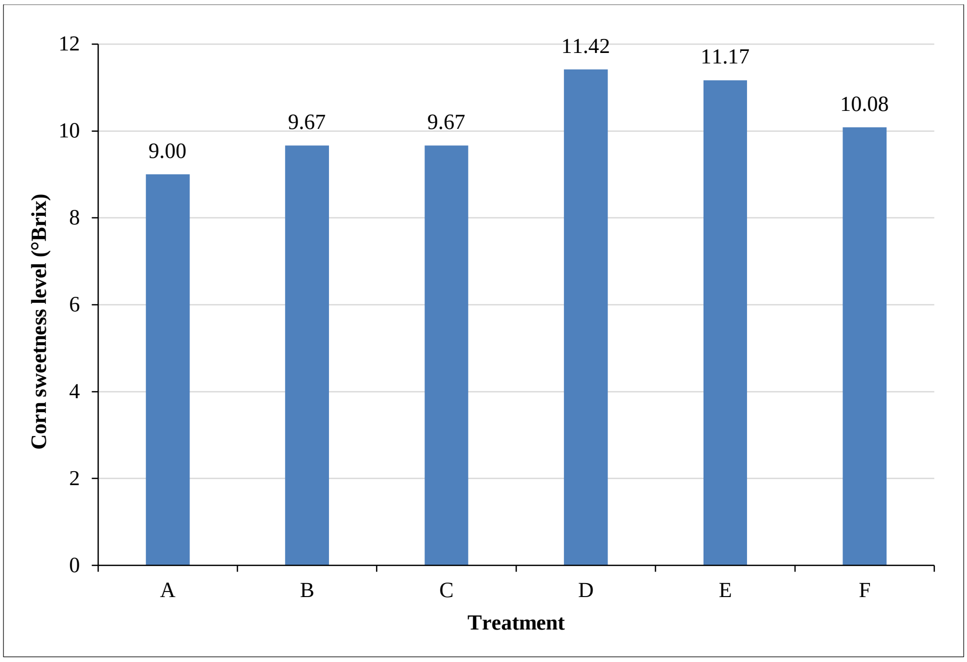

Figure 10. **Corn sweetness level data obtained from different treatment groups of the samples**

3-5- Analysis

The NP fertilizer tablets mixed with KCl types D and E outperformed commercial NPK fertilizers in practically all sweet corn growth indicators, including plant growth, plant biomass, and plant yield. The soil test findings demonstrated that NP fertilizer tablets enhanced the soil quality before and after treatment. The findings support the conclusion that the development of small-scale and dispersed green ammonia production will be a suitable technology if it is combined with the manufacturing of NP fertilizer tablets that take advantage of the low-level potential of local phosphate.

Inorganic fertilizers can improve the amount of nutrients available for plant growth. According to Syamsiyah et al. [48], the greater the plant's age, the greater the need for nutrients; since this need cannot be met by the bare soil in which it grows, adding fertilizers can increase the availability of nutrients, particularly nitrogen, which is required for plant vegetative growth. Nitrogen is required for corn plant growth, particularly stem (plant height), branch, and leaf growth. In terms of plant growth, biomass, and yield components, NP fertilizers combined with KCl yielded the same results as NPK fertilizers. This was because the total nitrogen content of both applications was measured at the same level, but the total volume of fertilizer differed. The low nitrogen content in the NP fertilizer tablet formula results in a small and distributed volume of green ammonia production. Furthermore, this was done to reduce the possibility of ammonia gas exposure to the environment. The formulation of fertilizer in tablet form is one method for slow fertilizer release [49].

Slow nitrogen release, combined with low losses due to NH_3 volatilization and leaching, improved nitrogen uptake from tablets. Farmers are expected to use the simple NP fertilizer tablet production technology to reduce their reliance on inorganic fertilizers imported from other regions. Green ammonia down-streaming in the form of NP fertilizer tablets will benefit countries that are unfamiliar with the use of ammonia-based fertilizers. The NP fertilizer tablet application test results show that mixing ammonia solution into NP fertilizer tablets with low nitrogen contents (N to P ratio of (2.33% N, 6.2% P) to (3.06% N, 6.2% P)) can match the performance of standard NPK fertilizer (15% N, 15% P, and 15% K) with additional KCl fertilizer applied separately.

According to Fasihi et al. [50], island nations have appropriately developed green ammonia production for fertilization. Large-scale, high-temperature ammonia production has also been reported [51, 52]. As a result, skepticism about green ammonia production technology based on catalytic reactions at ambient temperatures on a small scale is understandable. The low efficiency (%) and production rate of green ammonia under ambient conditions [53] are significant barriers to building a sustainable future. The downstream model of green ammonia to tableted fertilizer is depicted in Figure 11.

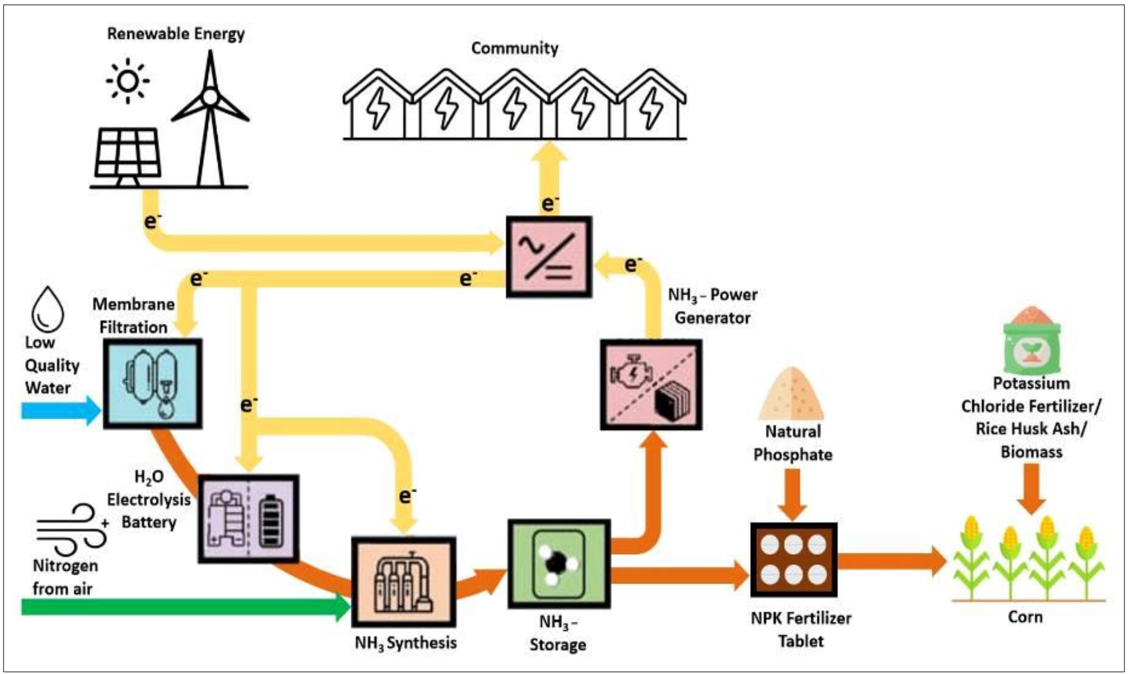

Figure 11. Downstream model flowchart of the sustainable green ammonia production technology

Future food security may be increased by utilizing green ammonia down-streaming, which combines ammonia with local phosphate to fertilize at least NP fertilizer-type food crops. Sustainability factors such as low energy, low cost, low carbon, ease of operation, and farmer safety make technology integration suitable for small-scale industry implementation in rural communities. Furthermore, converting downstream green ammonia into sustainable fertilizer for rural communities could aid the government in meeting the Sustainable Development Goals (SDGs). Green ammonia contributes significantly to eight of the seventeen key goals, among others. From the 17 SDGs, SDG 2: Zero Hunger; SDG 3: Good Health and Wellbeing; SDG 6: Clean Water and Sanitation; SDG 7: Affordable and Clean Energy; SDG 8: Decent Work and Economic Growth; SDG 9: Industry, Innovation, and Infrastructure; SDG 12: Responsible Consumption and Production; and SDG 13: Climate Action [54].

4- Conclusion

Our findings suggest that the formulation of fertilizer tablets promotes the effective absorption of nutrients needed by plants, as indicated by the comparison between soil test results before and after application. Owing to the low cost, low carbon, and low renewable energy consumption of NP fertilizers, it is now possible to develop small or micro-scale green ammonia production technology with the primary goal of meeting the fertilizer needs of rural communities. The inability of Indonesian rural communities to solve the scarcity of fertilizer supplies jeopardizes the country's food security. The paradox of plenty phenomenon can arise not only from the use of non-renewable natural resources but also from the utilization of renewable energy sources to facilitate the export of low-carbon goods to developed nations. Fertilizers are desperately needed in Indonesia since it is an agricultural nation made up of islands. Additionally, there is a need for agriculture support in order to create jobs for rural peasants.

In addition to decreasing global and supply chain challenges, small-scale green ammonia distribution near peasants can provide additional benefits such as local employment, local resource utilization, technology transfer, knowledge transfer, crop intensification with customized fertilizer production, and environmental benefits due to the use of cleaner energy sources. Our study contributes to the existing literature by showing how to provide suitable technology for green ammonia down-streaming using low energy, low cost, low carbon, ease of operation, and farmer safety as appropriate sustainability factors that can be implemented as a small industry in rural communities. We also provide empirical evidence of how small-scale green ammonia production would benefit peasants in Indonesia if it is down streamed into simple tableted fertilizers using local phosphate. Opportunities should be sought to commercialize the findings of this research.

As with any study, our research has limitations. We did not use financial indicators to measure the affordability of green hydrogen production and small-scale ammonia production, and we did not assess the importance of cultural development strategies in technology acceptance by rural communities. Future studies should use more indicators to measure appropriate technologies for down-streaming green ammonia to tablet compound fertilizer.

5- Declarations

5-1- Author Contributions

Conceptualization, T.L. and R.H.K.; methodology, T.L. and S.K.; software, T.L.; validation, T.L., S.K., and H.S.; formal analysis, T.L.; investigation, T.L.; resources, T.L.; data curation, T.L.; writing—original draft preparation, T.L.; writing—review and editing, T.L. and S.K.; visualization, T.L.; supervision, R.H.K. and S.K.; project administration, T.L.; funding acquisition, R.H.K. All authors have read and agreed to the published version of the manuscript.

5-2- Data Availability Statement

The data presented in this study are available in the present article.

5-3- Funding

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5-4- Acknowledgements

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5-5- Institutional Review Board Statement

Not applicable.

5-6- Informed Consent Statement

Not applicable.

5-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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