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Efficiency of Fertilizing Maize Plants Through the Application of Slow Release NPK Tablet Fertilizer with Biofertilizer

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Abstract. Inefficiencies in fertilization practices have become a substantial issue within current agricultural techniques. The inappropriate use of fertilizers can negatively impact both crop productivity and soil fertility. The aim of this research is to identify the efficiency of utilizing slow-release NPK tablet fertilizers supplemented with biofertilizers in maize crops. The experimental design incorporated a randomized complete block design (RCBD) consisting of nine combinations of fertilizer dosages between NPK tablet fertilizers and biofertilizers. The efficiency of fertilizer use can be seen from the RAE value of more than 100% shown by the NPK Tablet treatment which requires only one application compared to the recommended fertilizer, urea, and NPK Phonska which requires twice applications. Furthermore, optimization of the application of biofertilizer can be seen in the RSE value of more than 100% shown in the application of LBA biofertilizer together with NPK Tablets so that the application of biofertilizer is considered capable of increasing the efficiency of using inorganic fertilizers such as NPK Tablets.

Keywords: fertilization, maize, multivariate analysis, productivity, slow release

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1. Introduction

Maize (*Zea mays* L.) is a primary commodity after rice, playing a strategic role in agricultural and economic development [1] – [2]. It serves as a main component in livestock feed and industrial raw materials [3] – [4] and is a staple food for millions of people worldwide [5]. Maize holds a crucial role in Indonesia, where it remains a staple food for the majority of the population [6]. However, the demand for maize is continuously increasing both for food and industrial raw materials, resulting in unmet needs [7].

The annual increase of demand for maize has become a challenge for the agricultural system in meeting food requirements [8]. Enhancing maize production to meet food demands is a key

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challenge in the face of a growing global population [9]. Extensive and intensive efforts are necessary to improve maize productivity [10]. Expanding cultivation through land clearing demands significant resources, and available lands may not provide adequate nutrient supply for maize growth. Moreover, there has been a considerable conversion of agricultural land into residential and industrial areas in recent years [11], leading to land reduction and degradation, resulting in decreased agricultural productivity [12]. In areas where land is limited, intensification becomes a viable approach to boost production [13].

Intensification is crucial in achieving global food security and exploring methods to optimize land and natural resource use [14]. It aims to increase crop productivity while minimizing environmental impact [15]. However, intensive agriculture faces various serious challenges [16], and most farmers have yet to adopt proper fertilization practices, resulting in suboptimal crop productivity [17]. Excessive fertilizer application poses a significant threat to soil quality and fertility, leading to severe environmental issues [18]. Inappropriate fertilizer use can exert negative pressure on crop production [19], and low fertilization efficiency is a problem in tropical regions [20]. Efficient and effective nutrient management lies at the core of best agricultural practices and facilitates sustainable intensification [21], [22]. Comprehensive maize cultivation technologies can help enhance maize production [23], and to address the challenges, controlled-release fertilizers or slow-release fertilizers have been developed [24].

Slow-release Fertilizers (SRFs) offer a more efficient, economical, and safe approach to nutrient delivery to plants [25]. They retain nutrients in the soil for longer periods, making them available to plants at desired concentration levels [26]. Effective and efficient agricultural systems can maximize resource utilization, advance overall agriculture, and ensure stable crop production [16], ultimately contributing to national food security [27]. SRFs, being environmentally friendly fertilizers, provide a straightforward method to boost crop productivity [28].

Nutrient availability for increased maize production not only relies on SRF fertilization practices but also involves the utilization of microorganisms to enhance nutrient availability for plants. Microorganisms play a vital role in promoting plant growth and production. Biofertilizers using microorganisms are commonly used to stimulate plant growth [29]. Incorporating biofertilizers in agriculture can be instrumental in increasing crop production [30]. These microorganisms interact with plants, supplying nutrients and promoting plant growth [31]. In addition to accelerating decomposition rates, biofertilizer microorganisms can fix nitrogen and solubilize P and K nutrients in the soil [32]. Several species of microorganisms can encourage plant growth, for example the species *Azospirillum* sp. which has been described naturally as producing auxin-like molecules and *Bacillus* sp. which has an antioxidant system response [33]. *Rhizobium* species and *Pseudomonas fluorescens* strains have also been reported that these species can produce cytokinin hormones [34]. However, the assessment requires a systematic approach beyond productivity evaluation.

To effectively select multi-parameter methods, multivariate analysis is recommended as a powerful tool to simplify relationships between variables [35]. This approach is instrumental in evaluating multiple characteristics simultaneously [36]. Therefore, in this study, the employed multivariate analysis aims to identify useful traits for efficient and effective fertilizer dosing. The objective of this research is to identify the efficiency of slow-release NPK tablet fertilizer with biofertilizer supplement in improving the maize cultivation.

2. Materials and Methods

2.1. Research Site

The research was conducted at the Experimental Garden of the Agricultural Standardization Body in Bajeng District, Gowa Regency, South Sulawesi, Indonesia, from March to June 2023. The research area was situated at an altitude of 91 meters above sea level with coordinates of 5º18'29"S - 119º30'28"E. and the type of rainfall was E2 according to the Oldeman climatic classification. Rainfall at the time of the study in the field was in the range of 35-280 mm per month [37].

2.2. Plant Material

The genetic material used in this study was a hybrid commercial maize variety (Bisi-18). This genotype exhibited large and uniform cobs with shiny orange-yellow kernels, making it suitable for this research. Other materials used included inorganic fertilizers ((urea, NPK Phonska (15:15:15), NPK tablet (25:7:7)), and LBA biofertilizer ((*Azospirillum* sp. (4.7 x 10^7 CFU/ml), *Bacillus* sp. (1.2 x 10^7 CFU/ml), *Pseudomonas* sp. (3.1 x 10^7 CFU/ml), *Rhizobium* sp. (1.8 x 10^7 CFU/ml), *Aspergilus* sp. (1.9 x 10^7 CFU/ml), *Streptomyces* sp. (2.2 x 10^7 CFU/ml).

2.3. Procedures

The experiment was designed using a randomized complete block design (RCBD) consisting of 9 treatment combinations of fertilizer doses (Table 1). Fertilization treatment using NPK tablets was only carried out 10 days after planting, except for the recommended fertilization treatment (p1) and fertilization treatment using spraying biofertilizer (p5, p6, p7, and p8) which was carried out twice. The recommended fertilization treatment used urea at a dose of 125 kg ha^{-1} and NPK 15:15:15 at a dose of 175 kg ha^{-1} at 10 days after planting, and with the same dose at 30 days after planting. The spraying biofertilizer treatment used at a dose 12,5 ml l^{-1} (p5 and p6) and dose 25 ml l^{-1} (p7 and p8) at 10 days after planting, and with the same dose at 30 days after planting. Each treatment was replicated three times, resulting in a total of 27 experimental units. Maize seeds were sown in plots measuring 4 x 3 meters with a planting distance of 80 x 20 cm and 1.5 meters between plots. Each planting hole received one seed corresponding to the treatment label. The research maintenance included watering, fertilization, and weeding.

The observed parameters included plant height, stem diameter, length of cob, diameter of cob, number of rows per cob, weight of harvested cob, weight of 10 cobs, weight of 10 ears, moisture content, yield, and productivity (tons per hectare). Observations were conducted on 10 maize plants for each treatment. The observation technique followed the technical guidelines for maize adaptation observation [38].

Table 1. The Dose of the Combination of Fertilization Treatments Evaluated

Rank	Treatment	Treatment dosage
1	p0	0 kg ha^{-1}
2	p1	Urea 250 kg ha^{-1} + NPK 15:15:15 350 kg ha^{-1}
3	p2	3 tablet plant hole^{-1}
4	p3	2 tablet plant hole^{-1}
5	p4	1 tablet plant hole^{-1}
6	p5	2 tablet plant hole^{-1} + 25 ml l^{-1}
7	p6	1 tablet plant hole^{-1} + 25 ml l^{-1}
8	p7	2 tablet plant hole^{-1} + 50 ml l^{-1}
9	p8	1 tablet plant hole^{-1} + 50 ml l^{-1}

2.4. Data Analysis

The observed data were then subjected to several stages of analysis. Firstly, the data were analyzed for variance using the analysis of variance (ANOVA) method with a standard error of 5%. Subsequently, the results of the analysis were used to determine the heritability values of each trait. The selection criteria were determined through Pearson correlation and path analysis to identify traits with the highest direct influence. The results of the path analysis were used to establish the selection criteria, followed by the selection of the best doses using the Tukey test at a 5% significance level. The effectiveness and efficiency of fertilization were further analyzed using the relative agronomic effectiveness (RAE) and relative substitution efficiency (RSE) methods. ANOVA and Tukey tests were conducted using the STAR 2.0.1 application [39]. Heritability values, correlation coefficients, path analysis, RAE, and RSE were analyzed using the Excel application [40].

3. Results and Discussion

3.1. Morphological Parameters and Heritability

The results obtained from the analysis of variance (ANOVA) reveal a significant influence of the applied treatments on the observed traits, with the exception of yield and moisture content (as shown in Table 2). The Coefficient of Variation (CV) percentage values for single cross hybrids in the observed traits exhibited a wide range spanning from 1.06% to 9.88%. Furthermore, it was observed that the environment played a prominent role in shaping the observed variability. This variability within the experimental context has been extensively reported by several researchers, underscoring its significance [41] – [42].

The heritability values were in the range of 0.20 to 0.95, suggesting that nearly all the observed traits can be classified as exhibiting high heritability (Table 2). Specifically, the traits of yield and moisture content demonstrated low heritability, with corresponding values of 0.20 and 0.26. In contrast, the highest heritability values were observed for the traits of plant height and weight of harvested cob, with values of 0.95 and 0.94, respectively. These findings indicate that traits displaying high heritability during selection could substantially contribute to improved outcomes.

The criteria of high heritability play a critical role in the selection process [43]. Evidence suggests that selecting based on high heritability criteria leads to noteworthy advancements [44]. In comparison, traits with low heritability criteria have proven to be less effective in selection [45]. According to Anshori et al. [46], heritability is a pivotal factor supporting a trait's suitability as a selection criterion when evaluating genotypes and cultivation technologies for crops.

Table 2. Analysis of Variance and Morphological Parameters of Observed Characters

Characters	**MS Genotype**		**MS Error**	**CV (%)**	**Vg**	**Vp**	**h^2**
PH	1197.89	**	18.98	2.04	392.97	411.95	0.95 (H)
SD	18.02	**	0.77	4.58	5.75	6.52	0.88 (H)
LC	19.37	**	0.96	5.80	6.14	7.09	0.87 (H)
DC	23.89	**	1.67	2.93	7.41	9.07	0.82 (H)
NRC	2.98	**	0.25	3.41	0.91	1.16	0.78 (H)
WHC	21.81	**	0.43	5.85	7.13	7.56	0.94 (H)
W10C	680057.54	**	30545.30	8.47	216504.08	247049.38	0.88 (H)
W10E	15698.79	**	763.06	9.88	4978.57	5741.64	0.87 (H)
Y	1.47	ns	0.84	1.06	0.21	1.05	0.20 (L)
MS	1.28	ns	0.63	3.21	0.22	0.85	0.26 (L)
P	8.43	**	0.22	6.52	2.74	2.95	0.93 (H)

Note: ** = significant effect on 1%; NS = non-significant, PH = plant height; SD = stem diameter; LC = length of cob; DC = diameter of cob; NRC = number of rows per cob; WHC = weight of harvested cob; W10C = weight of 10 cobs; W10E = weight of 10 ears; Y = yield; MS = moisture content; P = productivity; MS = mean square; CV = coefficient of variance; Vg = variance of genotypes; Vp = variance of phenotypes; H2 = heritability; H = high; L = low

3.2. Correlation Coefficient Analysis

Based on the analysis of correlation coefficients, it is evident that all observed traits demonstrate a positive correlation and hold significant associations with productivity. Notably, the weight of harvested cob exhibits the highest correlation, with a coefficient value of 1.00 (as shown in Table

3). A substantial correlation coefficient implies that the selection process would be more effective due to the interplay of each trait's influence on others.

Correlation analysis is a prevalent and frequently employed method to comprehend the interrelationships among diverse characteristics. These findings will significantly bolster the selection process in subsequent generations [47]. Moreover, the use of correlation coefficient analysis has been documented in several other studies, such as the research conducted by Pinzon-Nuñez et al. [48] investigating selenium deficiency in maize plants and Shrestha et al. [49] assessing the performance and parameter estimation of hybrid maize.

Correlation coefficient analysis serves as a fundamental tool for conducting further in-depth investigations. The outcomes of this analysis are subsequently subjected to path analysis to partition the indicated values into direct and indirect effects. Scholars, such as Suwarti et al. [50], have employed this method to study maize plants in acidic tidal swamp lands, while Priyanto et al. [51] used it to investigate agronomic traits of hybrid maize.

Table 3. Pearson Correlation Coefficients among Maize of Morphological

Characters	PH	SD	WHC	LC	DC	NRC	W10C	W10E	P
PH	1.00								
SD	0.98**	1.00							
WHC	0.97**	0.92**	1.00						
LC	0.98**	0.95**	0.98**	1.00					
DC	0.89**	0.85**	0.94**	0.92**	1.0				
NRC	0.96**	0.95**	0.93**	0.95**	0.88**	1.00			
W10C	0.96**	0.92**	0.99**	0.99**	0.97**	0.93**	1.00		
W10E	0.93**	0.90**	0.96**	0.97**	0.97**	0.90**	0.99**	1.00	
P	0.97**	0.92**	1.00**	0.98**	0.93**	0.93**	0.98**	0.95**	1.00

Note: ** = significant effect on 1%; PH = plant height; SD = stem diameter; WHC = weight of harvested cob; LC = length of cob; DC = diameter of cob; NRC = number of rows per cob; W10C = weight of 10 cobs; W10E = weight of 10 ears; P = productivity

3.3. Path Analysis

The results of path analysis revealed significant direct influences on productivity, with the weight of harvested cob and the weight of 10 cobs exhibiting the largest positive effects, with values of 1.08 and 0.29, respectively. Conversely, the weight of 10 ears demonstrated the largest direct negative impact on productivity, with a value of -0.16 (Table 4). These findings indicate that the weight of 10 ears has an adverse effect on productivity, contrasting with the positive impacts of the other two traits. The substantial direct influence of these traits suggests a significant relationship between these characteristics and productivity. Consequently, conducting direct selection based on these traits could yield an appropriate impact on productivity.

Table 4. Path Analysis of Morphological Traits in Determining Effective Traits for Selection

Characters	DE	PH	SD	WHC	LC	DC	NRC	W10C	W10E	Residual
PH	-0.04		-0.03	1.04	-0.14	-0.10	0.11	0.28	-0.15	0.00
SD	-0.03	-0.04		0.99	-0.13	-0.10	0.11	0.27	-0.14	0.00
WHC	1.08	-0.04	-0.03		-0.14	-0.11	0.10	0.29	-0.15	0.00
LC	-0.14	-0.04	-0.03	1.05		-0.11	0.11	0.29	-0.15	0.00
DC	-0.12	-0.04	-0.02	1.02	-0.13		0.10	0.28	-0.15	0.00
NRC	0.11	-0.04	-0.03	1.00	-0.13	-0.10		0.27	-0.14	0.00
W10C	0.29	-0.04	-0.03	1.06	-0.14	-0.11	0.10		-0.16	0.00
W10E	-0.16	-0.04	-0.03	1.03	-0.13	-0.11	0.10	0.29		0.00

Note: DE = direct effect; PH = plant height; SD = stem diameter; WHC = weight of harvested cob; LC = length of cob; DC = diameter of cob; NRC = number of rows per cob; W10C = weight of 10 cobs; W10E = weight of 10 ears; P = productivity; Residual = residual

Path analysis represents a multivariate approach that effectively filters several non-causal variables to calculate their individual contributions [52], [53]. When a trait exerts a significant direct influence on productivity, its use as a selection criterion proves effective and efficient [54]. Furthermore, the residual effect was found to be 0.00, suggesting minimal influence connecting productivity to factors not encompassed in this study. The residual effect pertains to impacts that cannot be attributed to direct or indirect effects on production [55]. In path analysis, direct influence assumes a specific parameter to identify supporting traits that independently influence the main traits [56]. Previous studies have extensively reported on this analysis, including Farid et al. [57] in the context of integrated maize cultivation technology and Barth et al. [58] in the genotype selection of strawberries.

3.4. Dose Selection for Fertilization

The results of the Tukey test, based on path analysis interpretation, revealed that the dosage p2 exhibited significantly higher yields when compared to other combinations of treatments (see Table 5). Treatment p2 demonstrated superior performance, resulting in a yield of 13.34 kg of weight of harvested cob, 2.51 kg of weight for 10 cobs, and 0.36 kg of weight for 10 ears. Fertilization with an appropriate dosage led to a noticeable enhancement in cob appearance, showing larger and more uniform cobs. Moreover, dose p2 achieved the highest productivity value of 8.37 t ha-1, surpassing p3 and p7 with values of 8.23 t ha-1 and 8.10 t ha-1, respectively, making it the recommended best fertilization dosage for achieving high productivity.

The relative agronomic effectiveness (RAE) calculations based on productivity (Table 5) demonstrated that treatment p2 obtained RAE values > 100, indicating a remarkable value of 117.10%. Subsequently, p7, p3, and p5 followed with values of 114.07%, 111.26%, and 107.79%, respectively. The assessment of RAE values > 100 serves as an approach to evaluate the effectiveness of various fertilization treatments [59], [60]. This concept finds support in the work of Fausiah et al. [61] regarding the use of liquid organic fertilizer as a substitute for nitrogen fertilizer and Khalaf et al. [62] concerning the recovery of phosphorus from hydrothermal carbonization of organic waste. Additionally, relative substitution efficiency (RSE) calculations yielded values > 100 for treatments p6 and p7 with values of 120.90% and 102.53%, respectively. This finding suggests that optimizing the application of biofertilizers can enhance the efficiency of inorganic fertilizer utilization. Moreover, the substitution of biofertilizer usage affects the utilization of carbon sources by microorganisms and the composition of microbial communities [63].

The utilization of slow-release NPK tablet fertilizers and biofertilizers for plant growth constitutes a promising area of research with substantial future prospects. As highlighted by Kuligowski et al. [64], comprehending the potential and effectiveness of fertilizer use is critical to minimize environmental impacts and enhance productivity. Introducing effective technologies, coupled with intensive dissemination efforts, facilitates adoption by farmers and fosters sustainable practices [65]. Fertilizers play a pivotal role in increasing production, fulfilling the nutrient requirements of plants, and maintaining soil fertility [66], [67].

The application of controlled or slow-release fertilizers represents a novel solution to reduce atmospheric pollution and nutrient leaching [68]. Slow-release fertilizers are recognized as an efficient and beneficial strategy to ensure plant production and optimize nitrogen utilization [69], [70]. Proper fertilizer application can significantly elevate crop indices [71]. By optimizing fertilization practices, we can effectively enhance productivity and achieve food security [72], [73]. Conversely, excessive fertilizer application leads to reduced plant growth and nitrogen content in plant tissues [74]. Such excessive fertilization not only results in economic losses but also poses environmental risks [75].

Table 5. Selection of Optimal Fertilization Dosage Based on Path Analysis Interpretation

Treatment	Chosen characters				RAE (%)	RSE (%)
	WHC (kg)	W10C (kg)	W10E (kg)	P (t ha^{-1})		
p0	4.49^{c}	0.89^{c}	0.11^{c}	2.96^{c}	-	-
p1	11.86^{ab}	2.16^{ab}	0.30^{ab}	7.58^{ab}	-	-
p2	13.34^{a}	2.51^{a}	0.36^{a}	8.37^{a}	117.10	-
p3	12.87^{a}	2.38^{ab}	0.33^{ab}	8.10^{a}	111.26	-
p4	10.57^{b}	2.02^{ab}	0.28^{ab}	6.74^{b}	81.82	-
p5	12.52^{a}	2.36^{ab}	0.33^{ab}	7.94^{ab}	107.79	96.89
p6	11.59^{ab}	2.09^{ab}	0.26^{b}	7.53^{ab}	98.92	120.90
p7	12.81^{a}	2.20^{ab}	0.29^{ab}	8.23^{a}	114.07	102.53
p8	10.51^{b}	1.96^{b}	0.26^{b}	6.68^{b}	80.52	98.41

Note: Numbers followed by the same letter in a column indicate no significant difference from the Tukey tests level of 5%. Abbreviations used: WHC = weight of harvested cob; W10C = weight of 10 cobs; W10E = weight of 10 nodes; P = productivity; RAE stands for relative agronomic effectiveness, and RSE stands for relative substitution efficiency

4. Conclusion

In conclusion, the efficiency of fertilizer use can be seen from the RAE value of more than 100% shown by the NPK Tablet treatment which requires only one application compared to the recommended fertilizer, urea, and NPK Phonska which requires twice applications. Furthermore, optimization of the application of biofertilizer can be seen in the RSE value of more than 100% shown in the application of LBA biofertilizer together with NPK Tablets, so the application of biofertilizer is considered capable of increasing the efficiency of using inorganic fertilizers such as NPK Tablets.

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