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Growth and yield of cassava in low fertility Latosol soil with various doses of NPK fertilizer

Suwarto[1], Gani Nurrazaq[1], Ikhlasul Amal[2], Said Arsandi Naim Harahap[1], Ridwan Diaguna[1]

[1]Departement of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, 16680, Indonesia
[2]Department of Agrotechnology, Faculty of Agriculture, Juanda University, Bogor 16680, Indonesia

***Corresponding author: warto_skm@apps.ipb.ac.id**

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Abstract: High cassava productivity needs adequate soil nutrients. This study is to determine the optimum dose of NPK fertilizer in cassava on Latosol soil with low fertility. This experiment used the dose of NPK fertilizer as a single treatment factor. Five treatment levels of the fertilizer dose, namely 0%, 50%, 100%, 150%, and 200% of NPK standard dose tested using a randomized block design and four replications. The NPK standard dose was 135-72-130 kg ha-1. The experimental plot of 8 m x 5 m was divided into 8 beds with a length of 5 m and planted with 40 cuttings. Fertilizer sources used were NPK (17-6-25), Urea (45% N), and SP-36 (36% P2O5). The three kinds of fertilizer were mixed and applied in the grooves around the plants at a distance of 10 cm. At planting time, the plants fertilized with 1/3 dose of NPK (17-6-25), 1/2 dose of Urea, and 1 dose of SP-36. At 2 months after planting (MAP), the plants fertilized with 1/3 dose of NPK (17-6-25) and 1/2 dose of Urea. The 1/3 dose of NPK (17-6-25) fertilized to plants at 4 MAP. Plant height, stem diameter, number of leaves, lobe length, and lobe width were observed every month from 2 to 5 MAP. The number and weight of tubers were observed at 6, 7, 8, 9, and 10 MAP. There was a quadratic response of stem diameter, number of leaves, number of tubers, and tuber weight to the dose of NPK. The response of the variable is used to determine the optimum NPK dose. The optimum NPK dose of cassava on Latosol low fertile soil is 126% of the standard NPK dose, namely 170 kg N, 91 kg P, and 164 kg K per hectare. The optimum NPK dose produced 53.8 tons ha-1 of cassava tubers.

Keywords: *number of tuber, optimum dose, potensial yield, weight of tuber.*
Abbreviations: MAP_*month after planting*, NPK_*nirogen-phosporous-kalium.*

Introduction

Parmar et al. (2017) stated that cassava tuber is used to food, feed, and industrial uses. Many types of food are produced from fresh cassava tubers or tapioca flour to meet the caloric needs of millions of people in the tropical regions of America, Africa, and Asia for food security (Shacelford et al., 2018). The use of tapioca flour in the manufacture of animal feed produces the best pellets (Ripyono, 2015) and the best complete ration wafers based on palm oil fronds (Prastyani et al., 2020). Nguyen (2023) reported that tapioca starch is a versatile material that has many potential applications in the textile industry.

In the 10 countries with the highest rank of cassava productivity, all are still below 40 tonnes per hectare (ReportLinker Research, 2021). Average cassava root yields worldwide, in the 5 years, from 2011 to 2015 was 11.6 ton ha^{-1} (FAO, 2018). The productivity was lower than potential cassava yields. Better farming practices could help to close these yield gaps, e.g., root yields of 60 ton ha^{-1} have been reported in parts of Africa (Fermont et al. 2009; Kintché et al., 2017). One component of better farming practices is optimum dose of fertilizers.

Latosol land in Indonesia is dominated by agricultural land, including cassava cultivation. This soil is acidic (pH 4.5-6.5), contains very low organic matter, and has moderate to low fertility (Soepraptohardjo, 1958). This soil is erodible by high rainfall (Sukartaatmadja et al., 2003) which reduces its fertility. Farmers generally cultivate cassava on this land continuously throughout the year so that soil fertility and productivity will decrease if not followed by adequate fertilization (Sok et al., 2017).

Plant growth and maximum yield are strongly influenced by the availability of N, P, and K nutrients in soil (Marschner, 2012). Cassava requires sufficient Nitrogen (N), Phosphorus (P), and Potassium (K) nutrients to produce high tuber growth and productivity (Howeler, 2018). Kang et al. (2020) stated that N is one of the significant factors affecting cassava yield. At low pH, phosphorus (P) is one of the most difficult nutrients for plants to acquire because of its low content in the soil solution (Omondi et al., 2019). Cassava tuber yield was significantly affected by their varieties, potassium (K) fertilizer rate, and cropping system (Umeh et al., 2014).

Howeler (2002) classifies soil nutrient levels into very low, low, medium, high and very high for cassava production. Soil characteristics with pH 3.5-4.5, P 2-4 ppm, 0.10-0.15 meq 100/g K are categorized as low fertility soil. On soil with low fertility, cassava needs to be fertilized with doses of 100-200 kg N, 200-400 kg P_2O_5, and 100-200 kg K_2O per hectare. In Alfisols soil, Saleh et al. (2016) reported that the optimal dose of cassava was 135 kg N, 30 - 60 kg P_2O_5, and 60 - 90 kg K_2O per hectare. For Ultisols soil, Suwarto et al. (2023) used fertilizer at 169 kg N, 84 kg P, and 170 kg K per hectare. The

Table 1. Response of cassava plant height to the dose of NPK fertilizer at 1 – 5 MAP.

% NPK Dose	NPK Dose (kg ha^{-1})			Plant height (cm)				
	N	P	K	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP
0	0	0	0	48.5	96.5	115.38a	128.7a	136.3a
50	67	36	65	54.0	98.2	120.78abc	129.4abc	1390ab
100	135	72	130	52.7	102.1	16285c	186.5c	212.6c
150	203	108	194	53.9	102.0	165.20c	184.1c	209.2c
200	270	144	259	39.0	90.2	138.05abc	172.7c	203.3c
Response				ns	ns	Q**	Q**	Q**

Note: Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%; MAP= month after planting, ns = not significance, Q** = siqnificantly quadratic response.

Table 2. Response of cassava stem diameter to the dose of NPK fertilizer at 1 – 5 MAP.

% NPK Dose	NPK Dose (kg ha^{-1})			Stem diameter (cm)				
	N	P	K	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP
0	0	0	0	0.91	1.55	1.81a	2.05a	2.4a
50	67	36	65	0.93	1.56	1.86ab	2.21ab	2.6ab
100	135	72	130	0.92	1.72	2.19abc	2.56bc	3.1c
150	203	108	194	0.97	1.62	2.37c	2.79c	3.3c
200	270	144	259	0.71	1.51	2.16abc	2.57bc	3.2c
Response				ns	ns	Q**	Q**	Q**

Note: Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%; MAP= month after planting, ns = not significance, Q** = significantly quadratic response.

type and fertility of soil determines the optimum fertilizer of cassava. Determining the optimum fertilizer is important for economic and environmental considerations (Miguez and Poffenbarger, 2022). This study aims to determine the optimum NPK dosage for cassava in Latosol soil.

Results

The dose of NPK fertilizer had a significant effect on the growth and yield of cassava. The dose of NPK fertilizer significantly affected stem height and diameter (3, 4, and 5 MAP), number of leaves (4 MAP), lobe length (2, 4, and 5 MAP), and lobe width (2, 3, 4, and 5 MAP). The dose of NPK fertilizer had a significant effect on the number of tubers at ages 7, 8 and 9 MAP and on tuber weight at ages 6, 7, 8 and 9 MAP.

Plant height, stem diameter, and number of leaves

The height of the cassava plant increases with the age of the plant. The dose of NPK fertilizer showed a very significant effect on plants aged 3 to 5 MAP (Table 1). The response of plant height to doses of NPK fertilizer is quadratic. The quadratic equation for the response of plant height (y) to % dose of NPK fertilizer (x) at 5 MAP is: $y = -0.0027x^2 + 0.9453x + 125.8$ (R^2=0.7938).

The plant height of the Mangu cassava plant at 5 MAP ranged from 136 to 212 cm with an average of 180 cm. It is similar to that reported by Diaguna et al. (2022), that Mangu variety at the age of 6 MAP is 190 cm. However, it was higher than the Malang 4 variety with an average of 160 cm at the age of 5 MAP (Taufiq et al., 2012).

Response of cassava stem diameter was similar to the height of the cassava plant. Stem diameter also increases with the age of the plant. The dose of NPK fertilizer showed a very significant effect on stem diameter at 3 to 5 MAP (Table 2). The response of stem diameter to doses of NPK fertilizer is quadratic. The quadratic equation for the response of stem diameter (y) to % dose of NPK fertilizer (x) at 5 MAP is $y = -0.00003x^2 + 0.0096x + 2.3316$ (R^2=0.9951).

The number of cassava leaves increased from 1 to 4 MAP. At the age of 5 MAP, the leaves number decreased because some of the leaves began to fall (Table 3). The response of the number of cassava leaves (y) to the % dose of NPK fertilizer (x) at the age of 4 MAP is quadratic with the equation $-0.0011x^2 + 0.297x + 80.482$ (R^2=0.9994).

Length and width of leaf lobe

The leaf lobe is the central part of the cassava leaf. The length and width of the leaf lobes are influenced by genetics and soil fertility (Fukuoda et al., 2010). Leaf lobe length showed a quadratic response to NPK fertilizer doses at 2, 3, and 5 MAP (Table 4). The length of the leaf lobes ranged from 19.1 – 21.24 cm, almost the same as the length of the leaf lobes of the Mangu variety at 5 MAP (20.32 cm) (Diaguna et al., 2022). The response of leaf lobe length (y) to % dose of NPK fertilizer (x) at 5 MAP is quadratic with the equation $y = -0.0001x^2 + 0.026x + 19.465$ (R^2= 0.5005).

Width of leaf lobe also showed a quadratic response to NPK fertilizer doses at 2, 3, 4 and 5 MAP (Table 4). Lobe length of Mangu ranged from 5.43 to 6.40 cm. Diaguna et al. (2022) reported that the lobe width of Mangu at 5 MAP is 5.87 cm. The quadratic response of lobe width (y) to % dose of NPK fertilizer (x) at 5 MAP is $y = -0.00005x^2 + 0.0097x + 5.628$ (R^2= 0.4014).

Number and weight of tuber

Cassava with various doses of NPK fertilizer produced number of tuber ranged from 7.7 to 18.8 tubers with the average of 12.9 $\pm$ 4.3 tubers; Diaguna et al. (2022) reported 11.0 $\pm$ 1.6 tubers. The number of cassava tubers (y) showed a quadratic response to the % dose of NPK fertilizer (x) at ages 6, 7, 8, 9, and 10 MAP (Table 5). The quadratic equation with the highest coefficient of determination (R2) is at the age of 8 MAP; $y = -0.001x^2 + 0.2027x + 7.6905$ with R^2= 0.9998. The weight of cassava root of various doses of NPK fertilizer ranged from 2.2 to 5.9 kg plant-1 with an average of 4.2 $\pm$ 1.5 kg $plant^{-1}$. The cassava tuber weight was normal, similar to that reported by Suwarto et al. (2020) with an average weight of cassava tubers was 4.8 kg $plant^{-1}$. The weight of cassava tubers (y) showed a quadratic response to the % dose of NPK fertilizer (x) at ages 6, 7, 8, 9, and 10 MAP (Table 5). The quadratic equation with the highest coefficient of determination (R2) is at the age of 10 MAP; $-0.0003x^2 + 0.0646x + 2.0029$ with R^2= 0.9636.

Discussion

Table 1 shows that almost growth and yield variables of cassava responded significantly to the NPK dose treatment. Luar et al. (2018) stated that although cassava can grow better than other plants in infertile soil, this plant responds

Table 3. Response of number of cassava leaves to the dose of NPK fertilizer at 1 – 5 MAP.

% NPK Dose	NPK Dose (kg ha^{-1}) N	P	K	Number of cassava leaves (leaves) 1 MAP	2 MAP	3 MAP	4 MAP	5 MAP
0	0	0	0	23.5	52.1	72.1	80.6a	79.0
50	67	36	65	24.1	56.2	80.5	92.2b	87.5
100	135	72	130	23.6	54.2	87.2	99.0b	92.3
150	203	108	194	23.4	51.2	86.6	99.5b	85.7
200	270	144	259	16.8	46.2	78.8	94.3b	93.3
Response				ns	ns	ns	Q**	ns

Note: Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%; MAP= month after planting, ns = not significance, Q** = significantly quadratic response.

Table 4. Response of length of leaf lobe and width of leaf lobe to the dose of NPK at 1 – 5 MAP.

% NPK Dose	NPK Dose (kg ha^{-1}) N	P	K	Plant age (MAP) 1	2	3	4	5
				Length of leaf lobe (cm)				
0	0	0	0	16.1	18.4ab	19.8a	20.5	19.1a
50	67	36	65	17.2	20.6c	22.1c	22.1	21.4b
100	135	72	130	16.8	19.1abc	20.9ab	21.0	20.0b
150	203	108	194	17.5	19.4abc	21.3bcd	21.5	20.3b
200	270	144	259	13.0	17.9a	20.9abc	21.3	19.4b
Response				ns	Q**	Q**	ns	Q**
				Width of leaf lobe (cm)				
0	0	0	0	5.2	5.4b	5.6ab	5.7ab	5.6ab
50	67	36	65	5.4	5.8b	6.0bc	6.0abcd	6.0a
100	135	72	130	5.3	5.6b	5.8abc	5.8abc	5.8abc
150	203	108	194	5.3	5.7b	6.4c	6.4d	6.4c
200	270	144	259	4.3	4.7a	5.4a	5.5a	5.4c
Response				ns	Q**	Q**	Q**	Q**

Note: Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%; MAP= month after planting, ns = not significance, Q** = siqnificantly quadratic response.

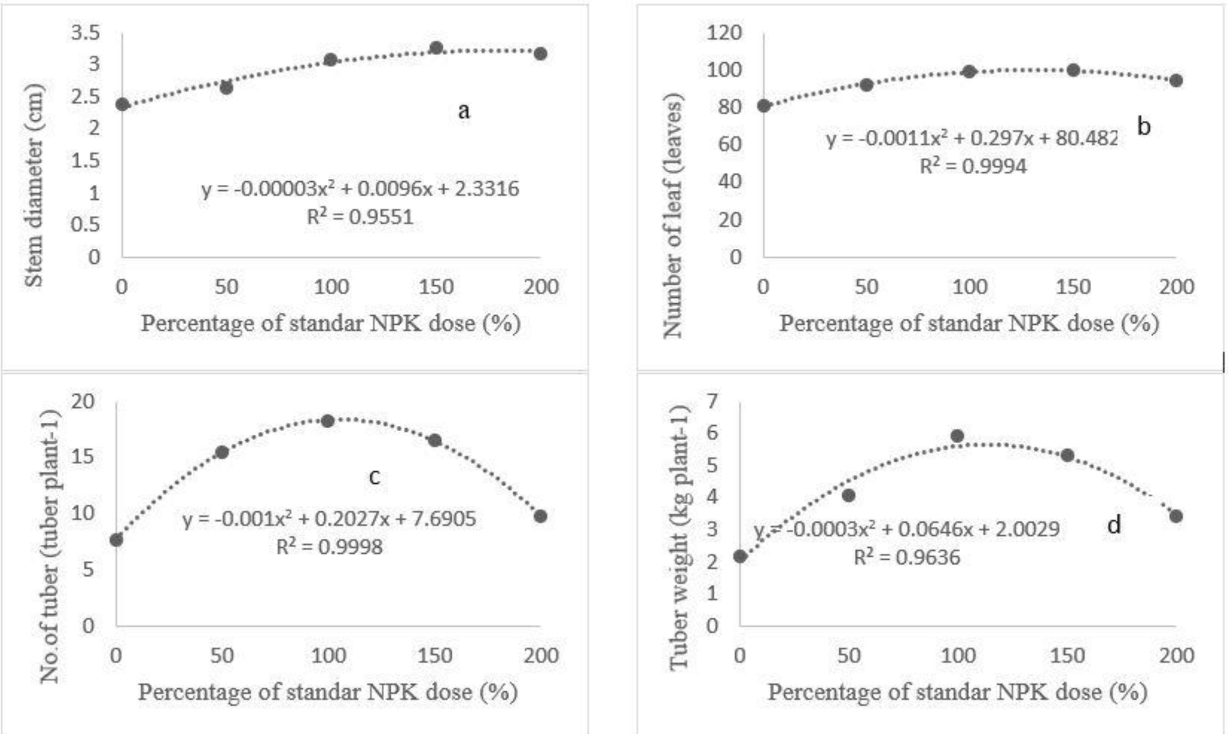

Fig.1. Response of stem diameter at 5 MAP (a), number of leaves at 4 MAP (b), number of tuber at 8 MAP (c), and weight of tuber at 10 MAP (d) of cassava to NPK fertilizer dose.

well to fertilizer application. Cassava yield can be increased greatly through fertilizer application.

Technical approach in determining optimum NPK fertilizer refer to Naher et al. (2011). A quadratic response to N and K nutrients were best fitted for rice, while response to P was linear plateau. As shown in Tables 2, 3, and 4, NPK dose gave a quadratic response to plant height (R^2=0.7938), stem diameter (R^2=0.9951), and number of leaves (R^2=0.9994). Table 5 shows that NPK fertilizer doses gave a quadratic response to the leaf lobe length (R^2=0.5005) and leaf lobe width (R^2=0.4014) variables. The number of tubers and weight of tuber (Table 5) also showed a quadratic response to the dose of NPK fertilizer with a value of R^2 = 0.9998 and

Table 5. Response of number and weight of tuber to the dose of NPK fertilizer at 6 – 10 MAP.

% NPK Dose	NPK Dose (kg ha^{-1})			Number of tuber (tubers $plant^{-1}$)				
	N	P	K	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP
0	0	0	0	8.5a	7.0a	7.7a	7.4a	6.8a
50	67	36	65	13.8b	14.5bc	15.5c	12.4b	12.5c
100	135	72	130	15.5b	15.3bc	18.3c	15.3bc	18.8bc
150	203	108	194	13.8b	17.0c	16.5c	14.4bcd	13.8bc
200	270	144	259	13.5b	12.0b	9.8ab	11.7b	12.5c
Response				Q**	Q**	Q**	Q**	Q**
				Weight of tuber (kg $plant^{-1}$)				
0	0	0	0	1.5a	1.6a	2.3a	2.3a	2.2a
50	67	36	65	2.6ab	3.0bc	3.8abc	3.7b	4.1bc
100	135	72	130	3.0b	3.5bcd	5.2c	5.0c	5.9d
150	203	108	194	3.6b	4.1d	5.1c	5.1c	5.3cd
200	270	144	259	2.6ab	2.5ab	3.0ab	3.7b	3.4ab
Response				Q**	Q**	Q**	Q**	Q**

Note: Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%; MAP= month after planting, ns = not significance, Q** = siqnificantly quadratic response.

Table 6. Optimum NPK fertilizer dosage for cassava growth and yield variables.

Variables	Equation	R^2	Optimum NPK dose (%)	Optimum NPK dose (kg ha^{-1})
Stem diameter	$y = -0.00003x^2 + 0.0096x + 2.3316$	0.9551	160	(216-115-208)
No. of leaf	$y = -0.0011x^2 + 0{,}297x + 80{,}482$	0.9994	135	(182-97-176)
No. of tuber	$y = -0.001x^2 + 0{,}2027x + 7{,}6905$	0.9998	101	(136-72-131)
Weight of tuber	$y = -0.0003x^2 + 0{,}0646x + 2{,}0029$	0.9636	108	(146-78-140)
Average			126	(170-91-164)

Table 7. The amount of fertilizer applied and its source of the each of NPK dose.

% NPK Dose	NPK Dose (kg ha^{-1})			Source of fertilizer (kg ha^{-1})		
	N	P	K	NPK (17-6-25)	Urea (45%N)	SP36 (26%P_2O_5)
0	0	0	0	0	0	0
50	67	36	65	240	59	60
100	135	72	130	480	119	120
150	203	108	194	720	178	180
200	270	144	259	960	237	240
				Application at 0 MAP (g $plant^{-1}$)		
0	0	0	0	0	0	0
50	67	36	65	8	3	6
100	135	72	130	16	6	12
150	203	108	194	24	9	18
200	270	144	259	32	12	24
				Application at 2 MAP (g $plant^{-1}$)		
0	0	0	0	0	0	0
50	67	36	65	8	3	0
100	135	72	130	16	6	0
150	203	108	194	24	9	0
200	270	144	259	32	12	0
				Application at 2 MAP (g $plant^{-1}$)		
0	0	0	0	0	0	0
50	67	36	65	8	0	0
100	135	72	130	16	0	0
150	203	108	194	24	0	0
200	270	144	259	32	0	0

R^2 = 0.9636. According to Turney (2022) R^2 is a measure of goodness of fit. The coefficient of determination (R^2) measures how well a statistical model predicts an outcome.
Economic yield of cassava is tuber weight. There is a strong correlation between tuber weight and tuber number (r =0.93*), stem diameter (r =0.67*), and number of leaves (r =0.55*). A correlation coefficient is a number between -1 and 1 that tells the strength and direction of a relationship between variables (Bhandari, 2021). Based on the strong correlation coefficient between tuber weight and these three variables, the optimum NPK fertilizer is determined from the average optimum NPK fertilizer for tuber weight, stem diameter, number of leaves, and number of tubers.

The value of R^2 that is closer to 1 will be more appropriate to explain reality, dependent variable by independent variable (Turney, 2002). The optimum NPK dose for cassava was determined from the average equation of the variables with R^2 values close to 1, namely the stem diameter (Fig.1a), number of leaves (Fig.1b), number of tubers (Fig.1c) and tuber weight (Fig. 1d.). The optimum NPK fertilizer according to these variables is shown in Table 6. The average of optimum fertilizer is 126% standard NPK dose, namely 170 kg N, 91 kg P, and 164 kg K per hectare.
The optimum NPK dose (170-91-164) resulted in a tuber weight of 5.38 kg $plant^{-1}$ or equival to 53.8 ton ha^{-1}. This productivity is twice the average cassava productivity in

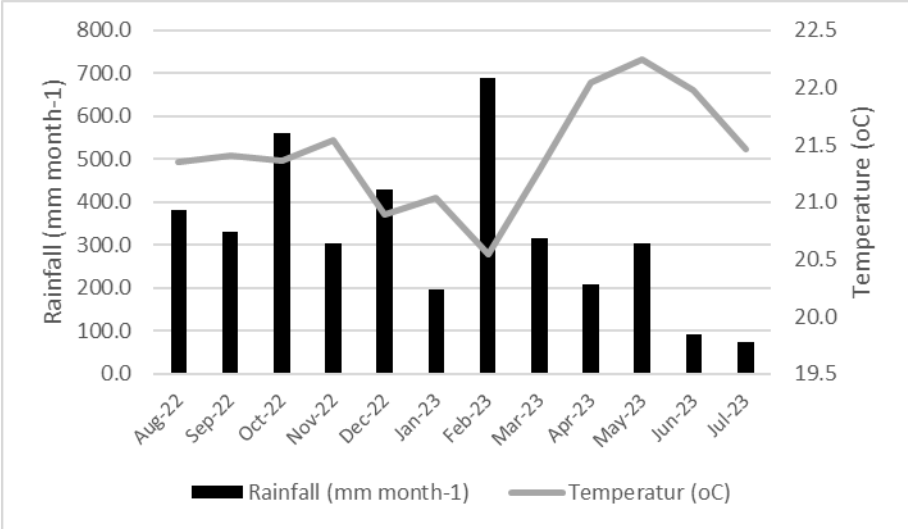

Fig.2. Rainfall and temperature during the experiment (August 2022 – July 2023).

Indonesia (24.7 tonnes ha-1) in 2017 (MARI, 2022). Pampolino and Oberthur (2018) report that the average yield of cassava in Southeast Asia ranges from 4 to 27 tons ha^{-1}. This productivity is very closely related to the dose of fertilization, especially the primary nutrients N, P, and K. The dose of NPK fertilizer applied by farmers is generally low. The dosage of NPK fertilizer in Indonesia is 0 - 90 kg N , 0 - 36 kg P_2O_5 , and 0 - 60 kg K_2O per hectare (MARI, 2022). Similarly in Cambodia, farmers cultivate cassava 0 - 7 kg N, 0 - 11 kg P_2O_5, and 0 kg K per hectare (Sopheap et al., 2012). PSA (2014) also found minimal NPK fertilization in the Philippines, namely 0 - 109 kg N, 0 - 26 kg P_2O_5, and 0 - 29 kg K_2O per hectare. This shows that it is important to determine the optimal dose of NPK fertilizer for a particular soil type and location.

Materials and methods

Field experiment

The most common method for estimating the optimum fertilizer rate is to design a field experiment with several fertilizer rates and fit a regression model to the yield observations (Miguez and Poffenbarger, 2022). The experiment was conducted at the Cikabayan Experimental Station, IPB University, from September 2022 to July 2023. It is located in Bogor Regency, West Java, Indonesia, at 6°18'0"–6°47'10" South Latitude and 106°23'45"–107°13'30" East Longitude. It is shown in Fig.2. that rainfall at all growing season of cassava was high (> 200 mm month-1) and at the end season prior to harvest was low (< 100 mm month-1). The relative humidity was above 80%. The climatic conditions are suitable for cassava. The soil type was Latosol with low fertility. The soil chemical properties were pH (4.26), total-N (0.19%), total P (4.32 ppm), K (23.98 mg K_2O/100g), and cation exchange capacity (14.94 cmol kg^{-1}) and soil organic carbon (1.35%). The pH, total N, and total P were categorized as low, and K was moderate for cassava (Howeler 2018).

This experiment used the dose of NPK fertilizer as a single treatment factor. The experiment used a randomized block design with 4 replications. The five dose levels of NPK fertilizer applied are 0%, 50%, 100%, 150%, and 200% of the standard dose of NPK. The standard dose of NPK fertilizer is 135-72-130 kg ha^{-1}, referring to Ultisol soil (Suwarto et al, 2023). There are a total of 24 trial plots. The experimental plot was 8 m x 5 m divided into 8 beds with a length of 5 m. The experimental plot was planted with 40 cassava cuttings of the Mangu variety. This variety is the most popular in West Java.

The fertilizers used were NPK (17-6-25), Urea (45% N), and SP-36 (36% P_2O_5). The fertilizer applied in the grooves around the plants with a distance of 10 cm. At planting fertilized 1/3 dose of NPK (17-6-25), 1/2 dose of Urea, and 1 dose of SP-36. At the age of 2 months after planting (MAP), fertilized with 1/3 dose of NPK (17-6-25) and 1/2 dose of Urea. At the age of 4 MAP fertilized 1/3 dose of NPK fertilizer (17-6-25). The amount of fertilizer applied to each dose level of NPK fertilizer is in Table 7.

Data collecting

Plant growth

In each experimental plot, 10 cassava plants were taken randomly as samples. Variables of plant height, stem diameter, number of leaves, leaf lobe length, and leaf lobe width were observed every month, from 1 month after planting (MAP) to 5 MAP. The time of this observation refers to Lebot (2009) that the development of stems and the formation of full leaf crowns occurs at 90 - 180 DAP. The observation of these variables refers to the morphological characterization descriptors of cassava by Fukuda et al. (2010).

Tuber yield

The translocation of carbohydrates to the tuber occurs between 180 and 300 DAP (Lebot 2009) or 6 and 10 MAP. One cassava sample from each experimental plot was removed every month at the age of 6 to 9 MAP. The cassava tubers from the sample plants were counted and weighed. At the final harvest (10 MAP), the number of tubers and tuber weight was determined from the average of 10 sample plants.

Data analysis

Analysis of variance (Larson, 2008) was used to determine the effect of NPK dose on variables of cassava growth and yield. Duncan's Multiple Range Test (DMRT) was used to compare the differences in the variables mean of the NPK dose. To determine the response of the variables to NPK dose used mathematical regression responses and the analysis of polynomial orthogonal (Hubert, 1973) was conducted. Quadratic response of variables to NPK dose was used to determine optimum NPK fertilizer (Naher et al. 2011).

The quadratic response of the variable with a high coefficient of determination (R2 > 0.9) or fit (Turney (2022) was chosen to determine the optimum dose of NPK fertilizer. Evaluation of the quadratic response was conducted to variables that are strongly related (Bhandari, 2021) to the weight of cassava tubers. Furthermore, the optimum dose of NPK fertilizer is determined from the average of optimum dose of NPK of these strongly correlated variables.

Conclusion

The optimum dose of NPK fertilizer needs to be determined for each soil type and location. The optimum dose of NPK fertilizer for acidic Latosol soil (pH = 4.26) with low total N nutrients (0.19%) and low available P (4.32 ppm P_2O_5), and medium potential K (23.98 mg K2O /100g) is 170 kg N, 91 kg P, and 164 kg K per hectare. The optimum dose of NPK fertilizer produced 53.8 ton ha^{-1} of cassava tubers.

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