Jurnal Agronomi Indonesia
(Indonesian Journal of Agronomy)

ISSN 2085-2916 | e-ISSN 2337-3652
December 2023, *51*(3):312-323
DOI: https://dx.doi.org/10.24831/jai.v51i3.47806

Research Article

Cassava growth and yield on ultisol of different soil organic carbon content and NPK fertilizer levels

Syaiful Anwar [1], Edi Santosa [2,*], and Purwono [2]

[1] Agronomy and Horticulture Study Program, Graduate School of IPB University (Bogor Agricultural University), Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, INDONESIA
[2] Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University (Bogor Agricultural University), Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, INDONESIA
* Corresponding author (✉ edisang@gmail.com)

ABSTRACT

The demand for cassava tuber in Indonesia is high, however, domestic production is still limited therefore increasing production is important. Ultisol soils have the potential for cassava production, but low soil fertility in such soils needs to be improved. The research aimed to evaluate the effect of soil organic carbon (SOC) and NPK fertilizer on the growth and yield of cassava tuber in an ultisol. The experiment was conducted at the Jonggol Experimental Farm, IPB Bogor, West Java from September 2022 to January 2023. The experiment used a split-plot design with three replications. The main plot was SOC level of 1.93 (control), 2, 3, and 4%, and the subplot was NPK 15-15-15 level of 150, 300, 450, and 600 kg ha^{-1}. SOC level was increased through the application of cow manure 0, 3.59, 54.93, and 106.27 tons ha^{-1} corresponding to SOC levels of 1.93 (control), 2, 3, and 4%, respectively. Results showed that enhancing SOC up to 3% and NPK 300 kg ha^{-1} were enough to support cassava growth as shown by plant height, stem diameter, and leaf number. The leaf number was the highest in the 3% SOC+150 kg NPK, 2% SOC+300 kg NPK or+450 kg NPK, and control+600 kg ha^{-1} NPK treatment. Leaf greenness was only affected by adding NPK fertilizer; a high greenness value was obtained at NPK level of > 150 kg ha^{-1} and 300 to 600 kg ha^{-1} resulting in non-significantly leaf greenness. The status of N and K in the leaves increased by SOC and NPK treatments, while the P status was unaffected. SOC at a level of 3% and NPK at a level of 150 kg ha^{-1} stimulated cassava to produce the highest fresh tuber weight (1.85 kg per plant) at 4 months after planting. Cassava productivity in ultisol soil can be increased by applying cow manure of 54.93 tons ha^{-1} to enhance SOC up to 3% combined with NPK of 150 kg ha^{-1}.

Keywords: Extensification; food security; intensification; tuber production; nutrient uptake

Edited by:
Maya Melati
IPB University

Received:
8 June 2023
Accepted:
21 November 2023
Published online:
23 December 2023

Citation:
Anwar, S., Santosa, E., & Purwono (2023). Cassava growth and yield on ultisol of different soil organic carbon content and NPK fertilizer levels. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *51*(3), 312-323

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important source of carbohydrates in Indonesia (Wijayanti et al., 2019). The carbohydrate content in cassava reaches 33.69% (Ariani et al., 2017). In Indonesia, cassava tuber is utilized in traditional foods such as boiled or fried, chips, *tape*, and *gethuk* (Harsita & Amam, 2019) and modern foods derived from cassava flour and tapioca flour (Wiraputra et al., 2019), and it becomes an important component in the food security system in Indonesia (Indrayana et al., 2018). Recently, tapioca has been utilized as an ingredient in food industries such as instant noodles, biscuits, cookies, cakes, and muffins (Histifarina et al., 2014; Verma et al., 2022).

Such broad utilization in Indonesia causes the demand for cassava tuber is increasing steadily. Annual cassava-based flour consumption per capita increased by 3.86% with total consumption in 2020 reaching 17.75 million tons (FSA, 2020), while cassava production was 16.21 million tons (CADIS, 2022). Therefore, some consumption is still fulfilled from imports.

The effort to increase cassava production in Indonesia is through the expansion of the production area is known as extensification and increasing the yield of the existing production area is known as intensification. In the extensification program, however, cassava competes with other commodities because cassava usually is the third priority after rice and maize (Ariningsih, 2016; Adriyani et al., 2022). Therefore, cassava expansion focuses on less fertile soils because of their strong adaptability (Delaquis et al., 2018), such as ultisol soils. Ultisols in Indonesia reach 45.79 million ha (Subagyo et al., 2004). Ultisol soils have low pH, soil organic matter, and low P and K nutrients, and are less suitable for rice and maize (Zulputra et al., 2014; Sipayung et al., 2014; Munawar & Wiryono, 2019).

In general, cassava productivity can be increased with fertilizer application (Ariningsih, 2016). However, farmers commonly do not apply fertilizers properly in cassava fields (Mutiara & Bolly, 2019). As a result, cassava production is low, by about 11 tons ha^{-1} (Wijanarko & Purwanto, 2018). On the other hand, an application of 150 N + 33 P_2O_5 + 124.5 K_2O kg ha^{-1} of the fertilizer increases tuber yields to 28 tons ha^{-1} (Biratu et al., 2018). The nutrient requirement for producing 40 tons ha^{-1} roots in the Mangu variety is approximately 80 kg N, 12 kg P_2O_5, and 136 kg K_2O (Suwarto et al., 2023). Application of inorganic fertilizer improves tuber growth and development (Adiele et al., 2021), in the long run however, the continuous application of inorganic fertilizer solely may imbalance nutrients in the soil (Biratu et al., 2018), therefore, balanced application between inorganic and organic fertilizers is important.

Organic fertilizers could be applied in many forms such as manure, green manure, and biomass (Biratu et al., 2019). Organic fertilizers are the source of soil organic carbon (SOC). It is noted that low SOC level causes low cassava root production (Mutiara & Bolly, 2019). Depletion of SOC is a primary problem due to the continuous planting of cassava (Kaluba et al., 2021). In East Lampung, for example, SOC decreased by 66% as the effect of planting cassava in monoculture for 30 years (Wijanarko & Purwanto, 2018). Moreover, Wijanarko and Purwanto (2018) pointed out that cassava grown in soil with a SOC of 0.7% produces tuber by 11.7 tons ha^{-1}, while SOC of 2.06% produces tuber by 19.4 tons ha^{-1}. According to Howeler (2002), the optimal SOC level for cassava growing is around 3.2%.

Cow manure is preferable as the source of SOC because it is persistent until the end of the growing season (Pimentel et al., 2021). SOC level correlates positively with soil cation exchange capacity (CEC) (Costa et al., 2021), and it is able to maintain the availability of cations (Blanco-Canqui et al., 2013). This research aimed to determine the effect of SOC and NPK fertilizer levels on the growth and yield of cassava grown in ultisol soil.

MATERIALS AND METHODS

Research site

The research was conducted at the Jonggol Experimental Farm, IPB Bogor from September 2022 to January 2023. The soil type is ultisol according to the description by Diaguna et al. (2022). The soil has an argillic horizon with a distinct clay horizon below the soil surface indicates ultisol instead of oxisol according to Munawar and Wiryono (2019). The soil contained SOC (1.93%), pH (H_2O) 4.52, total N (0.24%), available P (8.35 ppm), K (0.23 cmol(+) kg^{-1}), and cation exchange capacity (CEC) (19.12 cmol(+) kg^{-1}). SOC and pH were low, and available P and K were medium for cassava plants (Howeler, 2002).

Research design

The research used a split-plot design. The main plot was SOC level consisting of 1.93% (control), 2%, 3%, and 4%, while the subplot treatment was the level of NPK 15-15-15 application consisting of 150, 300, 450, and 600 kg ha^{-1}. Each treatment combination was repeated three times so that there were 48 experimental units. The plot size was 5 m x 5 m for each experimental unit. Here, the SOC level was designed only at planting time. There was no maintained activity on the SOC level during the experiment; that became the limitation of the study.

The land was prepared manually at a depth of 25 cm one month before planting. Limestone 2 tons ha^{-1} was applied one week after land preparation. One week after the limestone application, a raised bed was arranged with a width of 60 cm and a height of 30 cm. Cow manure was applied one week later with its amount according to SOC level. Manure was spread over the bed and then covered with soil.

SOC calculation follows Alghifari et al. (2023). The application was based on the following conditions: soil depth for cultivation was 20 cm, initial SOC level was 1.93% (based on laboratory analysis) and organic content of cow manure was 33.60% (based on laboratory analysis). Therefore, to obtain the level of SOC 1.93%, 2%, 3%, and 4% the amount of cow manure added was 0, 3.59, 54.93, and 106.27 tons ha^{-1}, respectively. According to Alghifari et al. (2023), pH of cow manure is 7.62, and contains 2.77% nitrogen, 0.95% total phosphorus, 0.34% total potassium, 0.53% magnesium, and 0.09% sulfur.

The cassava variety used Mangu, a famous clone from Bogor. Planting material used cutting sized 25 cm in length and ±2 cm in diameter from plants aged 8 months after planting (MAP). The planting material was obtained from a farmer's field at Dramaga, Bogor. The stem was planted vertically with a spacing of 100 cm x 80 cm.

NPK fertilizer was applied twice. First, one-third of the total NPK rate was added by circle application at 2 weeks after planting (WAP). In the second NPK application, as much as two-thirds of the treatment was applied at 3 MAP. At 1.5 and 3 MAP, weeds were manually managed using a hoe. Stem branches were managed by leaving two branches with good vigor. The branch trimming was carried out at 3 MAP. Plants were harvested at 4 MAP, for early harvesting (Santos et al., 2014; Adiele et al., 2021).

Observation and data analysis

Growth variables consisted of plant height, stem diameter, and leaf number at 2 and 4 MAP. The greenness of the leaves was measured using SPAD at the 10^{th} leaf from the young at 4 MAP. SPAD value could be as an estimate for chlorophyll index (Sookchalearn & Abdullakasim, 2017). Nutrient levels of leaves were observed at the 5^{th} to 10^{th} leaf from the above, composite of each treatment. Therefore, statistical analysis was non eligible in nutrient status due to lack of repetition.

The observed yield components at 4-MAP harvest, included the weight of leaves, stems, tuber, peeled tuber, and skin tuber. Moreover, the tuber number, tuber length, and tuber diameter were also measured. All tubers with a diameter of more than 1 cm and a length of more than 10 cm were classified as harvestable ones.

Data were analyzed using the F test at the α 5% level. Data shown significantly different were tested further with Tukey's honest significant difference (HSD). Data analysis used R-studio software.

RESULTS AND DISCUSSION

Plant growth

Enrichment of SOC supported vegetative growth including plant height, stem diameter, and leaf number (Table 1). SOC significantly affected plant height and stem diameter ($P<0.01$) at 2 and 4 MAP. The leaf number was significantly affected by the SOC ($P<0.01$) at 2 MAP and significantly ($P<0.05$) at 4 MAP. SOC treatment of 3% significantly increased plant height compared to SOC 1.93% and 2% at both times of observations. The highest stem diameter consistently occurred at 3% and 4% SOC. However, the finding should be treated carefully because the source of SOC added in the present experiment was in the form of cow manure. Increasing plant height and stem diameter by increasing SOC level could probably be associated with increasing supplement nutrients from the organic fertilizers according to Biratu et al. (2018). The general cassava performances in the field are shown in Figure 1.

At the age of 2 and 4 MAP, plant height and stem diameter were affected very significantly (P<0.01) due to NPK application (Table 1). Cassava had the highest plant and biggest stem diameter after treatment of 300 kg ha^{-1}, and it was significantly different from the 150 kg ha^{-1} treatment. This finding is in line with previous research by Macalou et al. (2018). Increasing NPK levels above 300 kg ha^{-1} did not significantly increase plant height growth and stem diameter. It is noted that excessive NPK application was ineffective in affecting vegetative growth (Carine et al., 2019).

Table 1. Effect of SOC and NPK fertilizer levels on plant height, stem diameter and leaf number of cassava.

Treatments	Plant height (cm)		Stem diameter (mm)		Leaf number	
	2 MAP	4 MAP	2 MAP	4 MAP	2 MAP	4 MAP
Soil organic carbon (%)						
1.93	45.50b	130.10b	11.38c	19.17c	43.30c	77.13b
2.00	55.98b	145.93b	13.35bc	22.05b	48.66bc	87.30ab
3.00	70.87a	193.85a	16.45ab	27.28a	65.66a	96.63a
4.00	77.92a	206.78a	18.54a	29.40a	59.05ab	84.16ab
p-value	<0.001	<0.001	0.001	<0.001	0.004	0.026
Sig.	***	***	**	***	**	*
NPK (kg ha^{-1})						
150	57.65b	159.65b	14.04b	22.78b	49.95b	80.37b
300	62.81a	171.15a	14.97ab	24.92a	52.55ab	87.33a
450	64.25a	171.70a	15.82a	24.94a	60.35a	85.90ab
600	65.55a	174.16a	14.88ab	25.26a	53.83ab	91.63a
p-value	<0.001	0.001	0.003	<0.001	0.023	<0.001
Sig.	***	**	**	***	*	***

Note: Values followed by the different letters in the same column are significantly different in the Tukey test α = 0.05 (*), α = 0.01 (**), and α =0.001 (***).

(a) 2 MAP (b) 3 MAP

Figure 1. Cassava performance at Jonggol Experimental Farm. (a) Plant aged 2 months after planting (MAP); (b) Plant aged 3 MAP.

Irrespective of NPK fertilizers, cassava grown in 3% SOC had the highest leaf number (Table 1). The 3% SOC treatment is equivalent to a dose of 52 tons ha^{-1} of manure. In previous research, Maryana and Suwardi (2022) stated that manure application at a level of 20 tons ha^{-1} did not increase the leaf number. Although Maryana and Suwardi (2022) did not mention soil type in their experiment, it is evident that in ultisol soil about 52 tons ha^{-1} manure is sufficient to stimulate more leaf production.

On the other side, irrespective of SOC level, NPK fertilization had a significant effect with a p-value <0.5 at 2 MAP and very significantly with a p-value <0.001 at 4 MAP (Table 1). Plants treated with 450 kg ha^{-1} had a significantly higher leaf number than 150 kg ha^{-1} at 2 MAP. At 4 MAP, fertilizer application at the rate of 300 kg ha^{-1} increased significantly the leaf number compared to 150 kg ha^{-1}. Carine et al. (2019) revealed that cassava supplemented with 100 kg ha^{-1} NPK (12-11-18) had higher leaf numbers than that without fertilizer.

At 4 MAP, however, there was an interaction effect between SOC and NPK on the leaf number (Table 2). The highest leaf number was observed in plants supplemented with 3% SOC and 600 kg ha^{-1} NPK (99.87 leaves), followed by the 3% SOC treatment and 300 kg ha^{-1} NPK (98.40 leaves). According to Chandhana and Kerketta (2021), leaf production of cassava increases more markedly in the present combination of organic and NPK fertilizers. In the present experiment, cassava grown in 1.93% SOC produced more leaves when supplemented with 450 kg NPK ha^{-1} as compared to 150 kg ha^{-1}. It means that SOC level and NPK fertilizers are important factors to stimulate leaf growth in ultisol soil.

Table 2. SOC and NPK levels interaction on leaf number of cassava at 4 MAP.

Soil organic carbon (%)	NPK level (kg ha^{-1})			
	150	300	450	600
	Leaf number			
1.93	62.80c	78.27bc	80.67b	86.80ab
2.00	78.53bc	89.07ab	89.20ab	92.40ab
3.00	93.73ab	98.40a	94.53ab	99.87a
4.00	86.40ab	83.60ab	79.20bc	87.46ab

Note: Values followed by the different letters are significantly different in the Tukey test α = 0.05

Leaf greenness and NPK status

NPK application affected the level of leaf greenness (Table 3). Plants from the treatment of 150 kg ha^{-1} showed the lowest leaf greenness as compared to other treatments. NPK application at a level of 300 to 600 kg ha^{-1} had no significant differences in leaf greenness. Here, NPK 300 kg ha^{-1} was considered sufficient to maintain high leaf greenness. The amount of nitrogen for NPK 300 kg ha^{-1} is 15% of 300 kg equal to 45 kg N ha^{-1}. Such an amount is lower than the finding of Biratu et al. (2018) where the cassava required 100 kg N ha^{-1} to improve the chlorophyll index or greenness at 12 MAP. Different sampling times might probably affect the nitrogen requirement, i.e., 4 MAP in the present research. It is interesting to note that adequate leaf N content in cassava varies among authors. According to Howeler (2002), the N content at 5.1-5.8% of cassava leaves is considered sufficient. On the other hand, Santos et al. (2014) mentioned that the N content of cassava leaves is sufficient in the range of 0.3-0.6%. In the present study, the N content of the leaves showed an adequate amount in the NPK treatment of 450 kg ha^{-1} or more. Thus, a dose of 450 kg ha^{-1} was considered optimal for leaves.

Cassava leaves grown in soil with SOC 1.93% and 2% tended to have relatively low N levels (Table 3), in contrast to plants with SOC 3% and 4%. However, statistically, there was no significant effect of SOC levels on NPK status. It is speculated that low SOC levels might cause low levels of N. SOC plays an important role in balancing the presence of soil cations for helping the availability of N (Biratu et al., 2019; Kaluba et al., 2021). An improvement in the greenness of the leaves is associated with higher N uptake (Kamarianakis & Panagiotakis, 2023). High N levels in leaves supported vegetative growth (Omondi et al., 2019a).

Phosphorus levels of leaves in both SOC and NPK fertilizers were 0.29-0.32% (Table 3), and it is considered deficient based on Howeler (2002). It means that SOC and NPK applications did not affect the P status in cassava leaves. This finding is in line with Biratu et al. (2018) where organic and NPK fertilizers application does not improve the P uptake of leaves. In the present research, it seems that the application of SOC and NPK was unable to improve P availability in the soil. According to Hartono et al. (2022) P absorption by the plant is determined by its availability. It needs further study on the availability of P in ultisol soils because in the present study amount of P added is relatively high, e.g., 90 kg P ha^{-1} in 600 kg NPK ha^{-1} treatment and 212.5 kg P_2O_5 ha^{-1} from cow manure for SOC 4%.

Table 3. Effect of SOC and NPK levels on leaf greenness and NPK status at 4 MAP.

Treatment	Leaf greenness	Nitrogen		Phosphorus		Potassium	
		N (%)	Status[z]	P (%)	Status[z]	K (%)	Status[z]
Soil organic carbon (%)							
1.93	44.98	4.94	L	0.30	D	1.44	S
2.00	44.03	4.89	L	0.29	D	1.52	S
3.00	44.58	5.24	S	0.32	D	2.43	VH
4.00	45.87	5.43	S	0.32	D	2.56	VH
p-value	0.558	-		-		-	
Sig.	ns	-		-		-	
NPK (kg ha^{-1})							
150	42.67b	4.89	L	0.31	D	1.83	S
300	45.70a	5.03	L	0.31	D	1.99	H
450	45.28a	5.23	S	0.31	D	1.99	H
600	45.81a	5.35	S	0.31	D	2.14	H
p-value	0.007	-		-		-	
Sig.	**	-		-		-	

Note: Values followed by the different letters in the same column are significantly different in the Tukey test α=0.05, ns-non significant, ** significant at α=0.01; [z]Nutrient status according to Howeler (2002), D-deficient, L-low, S-sufficient, H-high, VH-very high; '-' data not available due to no replication.

K levels of leaves in control SOC were sufficient (Table 3). Plants absorbed more K nutrients to leaves until they reached a very high status due to an increase in SOC up to 3% and 4%. However, such very high K levels of leaves in both treatments did not show differences in plant height, stem diameter, and leaf number (Table 1). Santosa et al. (2011) noted that the application of K_2O does not affect much on leaf number in *Amorphophallus*, but the application markedly increases the rachis length of the leaf. According to Subandi (2011), potassium levels in upper biomass range from 48.6% to 74.4% relative to nitrogen. Thus, in the present experiment, it seems that cassava absorbed excessive K (luxury consumption) in 3% and 4% of SOC. However, increasing NPK levels higher than 300 kg ha^{-1} increased K absorption as stated by Biratu et al. (2018) where the application of NPK fertilizer improved the efficiency of K uptake.

Yield components

SOC and NPK fertilization did not affect the fresh weight of leaves, while the fresh weight of stems was only affected by the SOC treatment (Table 4). SOC levels of 3% and 4% caused plants to have a significantly higher stem weight (P<0.001) than SOC 1.93% and 2%. The data is in line with plant height and stem diameter as shown in Table 1 where the highest value is derived from 3% and 4% SOC treatments.

The interaction between SOC and NPK treatments on fresh weight of tuber, peeled tuber, and tuber skin was significant (data not shown). Plants had the highest weight of tuber, peeled tuber, and tuber skin due to 3% SOC treatment and 150 kg ha^{-1} NPK, whereas 3% SOC and 600 kg ha^{-1} NPK treatment of plants caused the lowest weight in the three observed variables (Table 5). At 3% SOC, the addition of NPK fertilizer reduced the fresh weight of the tuber. Such reduction could be related to excessive growth of leaves at 4 MAP as shown in Table 2.

The plant with treatment of 3% SOC and 600 kg ha^{-1} NPK, had the highest leaf number (Table 2). It is noted that the leaf number after a certain number correlated negatively with tuber weight in cassava (Amarullah et al., 2016). Physiologically, cassava expresses a tendency that in the presence of excess leaf production, the assimilate is allocated to maintain the leaf resulting in tuber growth inhibition (Omondi et al., 2019a).

Table 4. Effect of SOC level and NPK fertilizer on fresh weight of leaves and stems at 4 MAP.

Treatments		Fresh weight (g plant^{-1})	
		Leaves^z	Stem^z
Soil organic carbon (%)	1.93	755.00	652.17b
	2.00	862.33	797.33b
	3.00	1143.67	1349.67a
	4.00	1175.33	1713.50a
	p-value	0.139	<0.001
	Sig.	ns	***
NPK (kg ha^{-1})	150	953.75	1068.50
	300	1006.33	1135.83
	450	992.33	1180.00
	600	983.91	1128.33
	p-value	0.908	0.688
	Sig.	ns	ns

Note: Values followed by the different letters in the same column are significantly different in the Tukey test α=0.05, ns-non significant, *** significant at α=0.001; ^{z} On statistical analysis, data was transformed using formula $\sqrt{x + 0{,}5}$.

Table 5. Effect of SOC level and NPK fertilizer on yield component at 4 MAP.

Treatments		Fresh weight (g plant^{-1})			Increasing tuber (%)^x	Tuber (tons ha^{-1})^y
SOC (%)	NPK (kg ha^{-1})	Tuber	Peeled tuber	Skin tuber		
1.93	150	963.00b	783.14b	179.86b	0	12.04
	300	1101.67ab	884.69ab	216.97ab	14	13.77
	450	1074.33ab	866.74ab	187.59ab	12	13.43
	600	1137.67ab	929.23ab	207.44ab	18	14.22
2.00	150	1030.00ab	835.04ab	194.96b	7	12.88
	300	1136.33ab	923.20ab	213.13ab	18	14.20
	450	1174.00ab	967.47ab	207.53b	22	14.68
	600	1358.33ab	1092.52ab	265.81ab	41	16.98
3.00	150	1853.00a	1527.07a	325.93a	92	23.16
	300	1023.33ab	833.35ab	189.98b	6	12.79
	450	1122.00ab	916.42ab	205.58b	17	14.03
	600	922.33b	749.04b	173.30b	-4	11.53
4.00	150	1308.00ab	1081.64ab	226.36ab	36	16.35
	300	1213.00ab	970.53ab	242.47ab	26	15.16
	450	1297.66ab	1080.54ab	217.13ab	35	16.22
	600	1101.66ab	886.33ab	215.33ab	14	13.77
p-value		0.027	0.043	0.003	-	-
Sig.		*	*	**	-	-

Note: Values followed by the different letter in the same column are significantly different in the Tukey test α=0.05, * significant at α=0.05, ** significant at α=0.01; ^{x}Compared to weight of SOC 1.93% and 150 kg ha^{-1} treatment; ^{y}Considering a population of 12,500 plants ha^{-1}.

Table 6 shows that tuber number per plant and tuber length were affected by the level of SOC but not by the level of NPK. Tuber diameter was not affected by SOC and NPK levels. High SOC levels of up to 4% significantly increased the tuber number. The finding is in line with previous research where high organic matter increases the tuber number (Sharara & El-Aal, 2016). On the other side, increasing SOC levels tended to decrease tuber length. The tuber length from the plant treated with 4% SOC was significantly lower than the control SOC. The effect of organic fertilizer that reduces tuber length was also noted by Ros et al. (2020), where the application of organic fertilizer at the rate of 12 tons ha^{-1} reduces tuber length by 4.1 cm as compared to without organic fertilizer application.

Table 6. Effect of SOC level and NPK fertilizer on tuber number, length and diameter of cassava at 4 MAP.

Treatments	Tuber number (root plant^{-1})	Tuber length (cm)	Tuber diameter (cm)
SOC (%)			
1.93	8.7b	28.74a	2.65
2.00	11.7ab	24.38ab	2.37
3.00	11.3ab	21.42ab	2.62
4.00	13.3a	19.76b	2.37
p-value	0.028	0.042	0.255
Sig.	*	*	ns
NPK (kg ha^{-1})			
150	10.7	24.72	2.60
300	12.9	22.65	2.42
450	10.7	23.05	2.61
600	10.7	23.89	2.39
p-value	0.291	0.822	0.249
Sig.	ns	ns	ns

Note: Values followed by the different letters in the same column are significantly different in the Tukey test α=0.05, ns-non significant, * significantly different.

Pearson's correlation

Pearson correlation matrix of traits from cassava grown in different levels of SOC and NPK fertilizer showed a weak correlation because of a value below 0.5 for all traits (Table 7). The fresh weight of leaves correlated significantly with the leaf number (r = 0.462), tuber number (r = 0.404), and tuber yield (r = 0.314). The tuber number correlated very significantly with yield (r = 0.441) and tuber length (r = -0.383). The negative correlation between the tuber number and tuber length is interesting, it means that plants that produce more tuber had shorter tuber as compared to the plant that produce less tuber number. It is known that tuber length is affected by genotype (John et al*.,* 2020; Misganaw & Bayou, 2020). According to John et al*.* (2020), genotype H-1687 produces fewer tuber but long sizes while the 7-III-E3-5 genotype produces many tubers with short sizes.

The present study shows that cassava cultivation through increasing SOC and NPK fertilizers was prospective in ultisol soil to alter low soil fertility. Radjit et al. (2014) stated cassava production could be improved through organic manure application. In the present research, such a recommendation was confirmed as shown by the significant increase weight of cassava tuber per plant (Table 5). Nevertheless, the findings should be treated carefully because first, the harvest in the present study was conducted at 4 MAP. Although there is a note that biomass production and total nutrient absorption of cassava at 4 MAP can be used as predictors of biomass at final harvest (Santos et al., 2014; Adiele et al., 2021). Table 5 shows that the highest tuber yield derived from 3% SOC and 150 kg NPK ha^{-1} was 1.85 kg of plants at 4 MAP. Using the formula by Santos et al. (2014) the amount of yield at 10 MAP is 6.91 kg per plant or 86.38 tons ha^{-1}. Such estimation is about 100% higher than the yield reported by Abrori (2016) for the Mangu variety planted in 2.14% SOC supplemented with 90 kg N+ 54 kg P_2O_5 kg + 54 kg K_2O ha^{-1} produces 42.70 tons fresh tuber at 10 MAP. The sharp increase in tuber yield at 6 to 10 MAP according to De Souza et al. (2017) was due to optimum assimilate translocation from leaves to tubers. Therefore, it is important to evaluate further the yield at full maturity of harvest for the Mangu variety.

Table 7. Pearson correlation matrix of traits from cassava grown in different levels of SOC and NPK fertilizer at 4 MAP.

	NL	GL	FWL	NT	TL	Y
NL	-					
GL	0.112ns	-				
FWL	0.462***	0.003ns	-			
NT	0.180ns	0.166ns	0.404**	-		
TL	-0.202ns	-0.140ns	-0.124ns	-0.383**	-	
Y	0.138ns	0.016ns	0.314*	0.441**	0.161ns	-

Note: MAP: months after planting; ns: no significant, *significant at α 0.05, **significant at α 0.01, ***significant at α 0.001; NL: leaf number at 4 months after planting, GL: leaf greenness, FWL: fresh weight of leaves, NT: tuber number, L; tuber length, Y: yield.

Second, leaves had high NK nutrients and higher tuber yield after the plant received SOC 3% and 150 kg NPK ha^{-1} (Table 5), however, plant height, leaf greenness, stem diameter, and leaf number were highest after receiving 3% SOC and 300 kg NPK ha^{-1}. Here, it is concluded that for optimum vegetative growth, 150 kg NPK ha^{-1} is required in addition to 3% SOC. For farmers, increasing SOC up to 3% is not easy in both logistics and finances, because for every 1% of SOC the farmer should prepare about 55 tons ha^{-1} of manure. It is important in the future to study the effectiveness of the gradual application of manure in several planting seasons on the growth of cassava.

Third, ultisols in some cases also associated with limited soil moisture availability (Mao et al., 2020). It has been known that high SOC level also increases soil capacity to hold moisture (Bilong et al., 2022). Increasing tuber weight by about 92% from cassava received 150 kg NPK ha^{-1} with 3% SOC relative to 1.93% SOC (control) is supported by higher plant and leaf numbers. Higher cassava plants have higher photosynthesis (Diaguna et al., 2022). The leaf number directly correlated positively with tuber weight (Rao et al., 2017), and the leaves played a vital role in photosynthesis (De Souza et al., 2017). In the field, it is interesting that no drought symptoms were apparent although monthly rainfall was below ideal (data not shown), indicating that SOC might contribute to maintaining soil humidity. Unfortunately, soil moisture was not recorded in the present experiment. Evaluating the soil moisture in the future will envisage a better understanding of the relationship between SOC and ultisols for sustainable production.

Finally, the correlation between total tuber yield and tuber number as shown in Table 7 is not new (see Amarullah et al., 2016). However, increasing the tuber number by increasing SOC is an interesting fact (Table 6). The growing tuber is the strong sink in cassava (Omondi et al., 2019b; Omondi et al., 2020). Thus, plants with more tuber need more nutrients and assimilate to support growing tuber (Chua et al., 2020). In modern cassava cultivation using mechanization, plants produce more tuber with a reasonable size is desirable. Tuberization is affected by phosphorus levels (Omondi et al., 2019b). As the leaf phosphorus showed deficiency in the present study (Table 3), it is necessary to evaluate the relationship between phosphorus status on tuber characteristics to support efficiency in mechanization.

CONCLUSIONS

Growth and yield of cassava in ultisol soil were affected by SOC and NPK 15-15-15 levels. SOC and NPK interaction was present for leaf number and tuber fresh weight, the interaction was insignificant for other traits. The cassava leaves had the highest NK nutrient under 3% and 4% SOC, and 400 kg ha^{-1} NPK. Leaf number was significantly higher than control under 3% SOC + 300 kg NPK ha^{-1} and 3% SOC + 600 kg NPK ha^{-1}. On the other side, the plant produced the highest tuber weight, i.e., 1.85 kg per plant at 4 months after planting (MAP) under 3% SOC and 150 kg NPK ha^{-1}. It is interesting in the future to evaluate the SOC application on tuber number concerning phosphorus status to sustain cassava production in ultisols.

ACKNOWLEDGEMENTS

The authors thank the Ministry of Finance of the Republic of Indonesia for funding through the LPDP Scholarship.

REFERENCES

Abrori, A. F. (2016). *Growth and production of cassava (Manihot esculenta Crantz) in intercropping with yam bean (Pachyrhizus erosus* L*.).* (In Indonesian.). [Undergraduate thesis]. IPB University. https://repository.ipb.ac.id/handle/123456789/86378

Adiele, J. G., Schut, A. G. T., Ezui, K. S., Pypers, P., & Giller, K. E. (2021). Dynamic of N-P-K demand and uptake in cassava. *Agronomy for Sustainable, 41*(1), 1-14. https://doi.org/10.1007/s13593-020-00649-w

Adriyani, N. P., Gunawan, B., & Harahap, J. (2022). Political ecology of cassava cultivation in the Arjasari Subdistrict, Bandung District, West Java Province. (In Indonesian.). *Aceh Anthropological Journal, 6*(2), 137-151. https://doi.org/10.29103/aaj.v6i2.8040

Alghifari, A. F., Santosa, E., & Susila, A. D. (2023). Growth and production of beneng taro genotypes (*Xanthosoma undipes* K. Koch) on different soil organic carbon. *Indonesian Journal of Agronomy, 51*(1), 17-26. https://dx.doi.org/10.24831/ija.v51i1.44975

Amarullah, Indradewa, D., Yudono, P., & Sunarminto, B. H. (2016). Correlation of growth parameters with yield of two cassava varieties. *Agricultural Science*, *1*(3), 100-104. https://doi.org/10.22146/ipas.10706

Ariani, L. N., Estiasih, T., & Martati, E. (2017). Physicochemical characteristics of cassava (*Manihot utilisima*) with different cyanide level. (In Indonesian.). *Jurnal Teknologi Pertanian*, *18*(2), 119-128.

Ariningsih, E. (2016). Area-based increase in cassava production in West Java and South Sulawesi Provinces. (In Indonesian). *Analisis Kebijakan Pertanian*, *14*(2), 125-148.

Bilong, E. G., Abossolo-Angue, M., Ajebsone, F. N., Anaba, B. D., Madong, B. A., Nomo, L. B., & Bilong, P. (2022). Improving soil physical properties and cassava productivity through organic manures management in southern Cameroon. *Heliyon, 8*(6), e09570. https://doi.org/10.1016/j.heliyon.2022.e09570

Biratu, G, K., Elias, E., & Ntawuruhunga, P. (2019). Soil fertility status of cassava fields treated by integrated application of manure and NPK fertilizer in Zambia. *Environmental System Research, 8*(3), 1-13. https://doi.org/10.1186/s40068-019-0131-7

Biratu, G. K., Elias, E., Ntawuruhunga, P., & Sileshi, G. W. (2018). Cassava response to the integrated use of manure and NPK fertilizer in Zambia. *Heliyon*, *4*(1), 1-23. https://doi.org/10.1016/j.heliyon.2018. e00759

Blanco-Canqui, H., Shapiro, C. A., Wortmann, C. S., Drijber, R. A., Mamo, M., Shaver, T. M., & Ferguson, R. B. (2013). Soil organic carbon: The value to soil properties. *Journal of Soil and Water Conservation, 68*(5), 129-134.

CADIS [Center for Agricultural Data and Information Systems]. (2022). *Bulletin of food consumption.* (In Indonesian.). Ministry of Agriculture, Republic of Indonesia.

Carine, T. N., Ajebesone, N., & Ngalle, E. (2019). Appropriate fertilizer (NPK) rates for cassava (*Manihot esculenta* Crantz) production in the humid forest agroecological zone of Cameroon. *African Journal of Agricultural Research, 14*(35), 2017-2022. https://doi.org/10.5897/AJAR2019.14186

Chandhana, N. S., & Kerketta, A. (2021). Effect of organic manures and inorganic fertilizer on growth and tuber yield of cassava (*Manihot esculenta*) CV. M4. *The Pharma Innovation Journal, 10*(11), 1826-1829.

Chua, M. F., Youbee L., Oudthachit, S., Khanthavong, P., Veneklaas E. J., & Malik, A. I. (2020). Potassium fertilization is required to sustain cassava yield and soil fertility. *Agronomy, 10*(8), 1103*.* https://doi:10.3390/agronomy10081103

Costa, A. G., Souza, L. S., Xavier, S., Cova, A. M. W., da Silva, E. F., & Bonfim, M. R. (2021). Characterization of soils cultivated with cassava under different managements. *Brazilian Journal of Agricultural and Environmental Engineering, 25*(11), 764-771. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n11p764-771

De Souza, A. P., Massenburg, L. N., Jaiswal, D., Cheng, S., Shekar, R., & Long, S. P. (2017). Rooting for cassava: insights into photosynthesis and associated physiology as a route to improve yield potential. *New Phytologist, 213,* 50-65*.*

Delaquis, E., de Haan, S., & Wyckhuys, K. A. G. (2018). On-farm diversity offsets environmental pressures in tropical agroecosystems: A synthetic review for cassava-based system. *Agriculture, Ecosystems and Environment, 251*, 226-235.

Diaguna, R., Suwarto, Santosa, E., Hartono, A., Pramuhadi, G., Nuryartono, N., Yusfiandayani, R., & Prartono, T. (2022). Morphological and physiological characterization of cassava genotypes on dry land of ultisol soil in Indonesia. *International Journal of Agronomy, 2022*, 3599272. https://doi.org/10.1155/2022/3599272

FSA [Food Security Agency]. (2020). *Analysis of Food Availability in Indonesia's Food Ingredients Balance 2018-2020.* (In Indonesian.). Ministry of Agriculture, Republic of Indonesia.

Harsita, P. A., & Amam. (2019). Consumer attitude analysis of cassava processed product attributes. (In Indonesian.). *Agrisocionomics, 3*(1), 19-27.

Hartono, A., Barus, B., Anwar, S., Arasyati, K., & Ghosh, J. (2022). Soil properties and phosphorus sorption characteristics due to land use change from pepper-based agroforestry to cassava in North Lampung, Indonesia. *International Conference on Modern and Sustainable Agriculture.* IOP Publishing. https://doi.org/10.1088/1755-1315/1133/1/012022

Histifarina, D., Sunandar, N., & Sukmaya. (2014). Study of noodle processing using wheat flour substituted with cassava flour. (In Indonesian.). *Buletin Hasil Kajian, 4*(4), 29-33.

Howeler, R.H. (2002). Cassava mineral nutrition and fertilization. In R. J. Hillocks et al. (Eds). *Cassava: Biology, Production and Utilization* (Pp. 115-147). CAB International.

Indrayana, K., Sirappa, M. P., & Ricky, M. (2018). Diversification of cassava processing in improving food security in West Sulawesi. (In Indonesian.). *Jurnal Agrotan*, *4*(1), 37-45.

John, K. S., Sreekumar, J., Sheela, M. N., Beegu, S. U. S., More, S. J., & Suja, G. (2020). Pre evaluation of cassava (*Manihot esculenta* Crantz) germplasm for genotypic variation in the identification of K efficient genotypes through different statistical tools. *Physiology and Molecular Biology of Plants, 26*(9), 1911-1923. https://doi.org/10.1007/s12298-020-00867-2.

Kaluba, P., Mwamba, S., Moualeu-Ngangue, D. P., Chiona, M., Munyinda, K., Winter, E., Stutzel, H., & Chishala, B.H. (2021). Cropping practices and effects on soil nutrient adequacy levels and cassava yield of smallholder farmers in Northern Zambia. *International Journal of Agronomy*, *2021*, 1325964. https://doi.org/10.1155/2021/1325964

Kamarianakis, Z., & Panagiotakis, S. (2023). Design and implementation of a low-cost chlorophyll content meter. *Sensors, 23*, 2699. https://doi.org/10.3390/s23052699

Macalou, S., Mwonga, S., & Musandu, A. (2018). Performance of two cassava (*Manihot esculenta* Crantz) genotypes to NPK fertilizer in ultisols of Sikasso Region, Mali. *International Journal of Sciences: Basic and Applied Research, 38*(2), 189-206.

Mao, N., Li, W., Wei, X., & Shao, M. (2020). Soil moisture-and texture-dependent effects of soil deposition on evaporation and carbon emission. *Soil and Tillage Research, 204*, 104703. https://doi.org/10.1016/j.still.2020.104703

Maryana, & Suwardi. (2022). Growth and yield of cassava leaves to the dose of manure and the position of planting stem cuttings. *Journal Techno, 8*(2), 147-158.

Misganaw, C. D., & Bayou, W. D. (2020). Tuber yield and yield component performance of cassava (*Manihot esculenta*) varieties in Fafen District, Ethiopia. *International Journal of Agronomy, 2020,* 5836452. https://doi.org/10.1155/2020/5836452

Munawar, A., & Wiryono. (2019). Soil as a fundamental element of silviculture for sustainable tropical rain forest management. *IOP Conf. Series: Earth and Environmental Science, 394*, 012035. https://doi.org/10.1088/1755-1315/394/1/012035

Mutiara, C., & Bolly, Y. Y. (2019). Identification of agricultural activities and soil fertility in the cultivation area of nuabosi cassava. *Caraka Tani: Journal of Sustainable Agriculture*, *34*(1), 22-30.

Omondi, J. O., Lazarovitch, N., Rachmilevitch, S., Yermiyahu, U., & Sperling, O. (2019a). High nitrogen availability limits photosynthesis and compromises carbohydrate allocation to storage in roots of *Manihot esculenta* Crantz. *Frontiers in Plant Science*, *10*, 1041. https://doi.org/10.3389/fpls.2019.01041

Omondi, J. O., Lazarovitch, N., Rachmilevitch S, & Yermiyahu, U. (2019b). Phosphorus affects storage root yield of cassava through root numbers. *Journal of Plant Nutrition*, *42*(17), 2070-2079. https://doi.org/10.1080/01904167.2019.1655033

Omondi, J. O., Lazarovitcha, N., Rachmilevitcha, S., Kukew, T., Yermiyahuc, U., & Yasuor, H. (2020). Potassium and storage root development: focusing on photosynthesis, metabolites, and soluble carbohydrates in cassava. *Physiologia Plantarum, 169*(2), 169-178. https://doi.org/10.1111/ppl.13060

Pimentel, M. L., Reis, I. M. S, de Castro, J. S., Portela, V. S., Romano, M. P. L. C., Vildoso, C. I., Gasparin, E., & de Sia, E. F. (2021). Cassava yield indicators and total organic carbon in tropical soils under different fertilization treatments. *Australian Journal of Crop Science*, *15*(10), 1325-1331. https://doi.org/10.21475/ajcs.21.15.10.p3291

Radjit, B. S., Widodo, Y., Saleh, N., & Prasetiaswati, N. (2014). Technology to increase the productivity and profits of cassava farming in ultisol dry land. (In Indonesian.). *Iptek Tanaman Pangan*, *9*(1), 51-62.

Rao, B. B., Swami, D. V., Ashok, P., Babu, B. K., Ramajayam, D., & Sasikala, K. (2017). Correlation and path coefficient analysis of cassava (*Manihot esculenta* Crantz) genotypes. *International Journal of Current Microbiology and Applied Sciences, 6*(9), 549-557. https://doi.org/10.20546/ijcmas.2017.609.066

Ros, A. B., Narita, N., Hirata, A. C. S., & Creste, J. E. (2020). Effects of limestone and organic fertilizer on cassava yield and on chemical and physical soil properties. *Revista Ceres, 67*(1), 23-29. https://doi.org/10.1590/0034-737X202067010004

Santos, N. S., Alves, J. M. A., Uchoa, S. C. U., Oliviera, N. T., & Albuquerque, J. A. A. (2014). Absorption of macronutrients by cassava in different harvest dates and dosages of nitrogen. *Revista Ciência Agronômica, 45*(4), 633-640.

Santosa, E., Setiasih, I., Mine, Y., & Sugiyama, N. (2011). Nitrogen and potassium applications on the growth of *Amorphophallus muelleri* Blume. *Jurnal Agronomi Indonesia, 39*(2), 124-130.

Sharara, M. S., & El-Aal, H. A. A. (2016). Effect of some bio-fertilizers on growth, productivity, chemical composition and processing of cassava tubers. *Alexandria Journal of Agricultural Sciences, 61*(6), 529-539.

Sipayung, E. S., Sitanggang, G., & Damanik, M. M. B. (2014). Improvement of the physical and chemical properties of ultisol soil at Simalingkar, Pancur Batu Sub-district with supernasa organic fertilizer and rock phosphate and its effect on crop production (*Zea mays* L.). (In Indonesian.). *Jurnal Online Agroteknologi. 2*(2), 393-403.

Sookchalearn, T., & Abdullakasim, W. (2017). A low-cost sensor for measuring and MSTping chlorophyll content in cassava leaves. *Chiang Mai University Journal of Natural Sciences, 16*(3), 183-190.

Subandi. (2011). Management of potassium nutrients for cassava in dry, acid land. (In Indonesian.). *Buletin Palawija, 22,* 86-95.

Subagyo, H., Suharta, N., & Siswanto, A. B. (2004). Agricultural lands in Indonesia (In Indonesian.). In A. Adimiharja et al. (Eds). *Indonesian Land Resources and Their Management* (Pp. 21-66). Center for Soil and Agro-climate Research and Development.

Suwarto, Diaguna, R., Santosa, E., Hartono, A., Prambudi, G., & Nuryantono, N. (2023). Analysis of NPK nutrient content and the nutrient balance of cassava for sustainable high productivity in Ultisols soil. *Australian Journal of Crop Science, 17*(2), 206-214. https://doi.org/10.21475/ajcs.23.17.02.p3796

Verma, R., Chauhan, N., Singh, B. R., Samsher, Chandra, S., & Sengar, R. S. (2022). Cassava processing and its food application: A review. *The Pharma Innovation Journal, 11*(5), 415-422.

Wijanarko, A., & Purwanto, B. H. (2018). Effect of long land use and cropping system on soil fertility and cassava yield. *Journal of Degraded and Mining Lands Management, 5*(4), 1327-1334. https://doi:10.15243/jdmlm.2018.054.1327

Wijayanti, P. D., Harianto, & Suryana, A. (2019). The demand for carbohydrate source food in Indonesia. (In Indonesian.). *Analisis Kebijakan Pertanian, 17*(1), 13-26.

Wiraputra, D., Abdullah, K., & Jyoti, M. D. (2019). Review: product development of cassava in food industry. (In Indonesian.). *Majalah Teknologi Agro Industri*, *11*(2), 44-53.

Zulputra, Wawan, & Nelvia. (2014). Response of upland rice (*Oryza sativa* L.) on the application of silicate and phosphate fertilizer on ultisol (Indonesian.). *Jurnal Agroteknologi, 4*(2), 1-10.

Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher(s) and/or the editor(s).

Copyright: © 2023 by the authors. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).