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New balanced nitrogen and potassium for cassava after common practices in Malaysia

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Abstract

Cassava is one of the most important food crops and is known to be the highest producer of carbohydrates among staple crops. Crop genetics, planting practices, and productivity have evolved over the last decade. New, high-yielding cassava varieties may have different nutrient requirements compared to older ones. Reevaluating fertiliser rates enables adjustments to new farming practices and more efficient nutrient utilisation. Hence, we studied the effects of three rates of nitrogen and potassium (0, 100, 200 kg/ha) on the growth and yields of two cassava varieties (Sri Kanji 2 and Sri Pontian) under clay and peat soils. A randomised complete block design with two replications was used. In Serdang (clay soil), nitrogen did not influence the fresh root yield. In Pontian (peat soil), an increase in nitrogen significantly increased fresh root yield, of which 200 kg N/ha produced 97.4 t/ha, followed by 100 kg N/ha (47.4 t/ha) and 0 kg N/ha (22.6 t/ha). Potassium (K) significantly increased cassava fresh root yield from 0 kg/ha (55.3 t/ha) to 200 kg/ha (71.2 t/ha) by 28.8%. There was no difference between 0 kg K/ha and 100 kg K/ha (61.4 t/ha). The fresh root yield of Sri Kanji 2 (65.2 t/ha) was slightly higher than Sri Pontian (60.1 t/ha) by 8.5% but did not differ. For optimum yield and to avoid nutrient depletion for long-term cassava cultivation, the rates (N: P_2O_5:K_2O) of 100:50:100 and 200:100:200 for clay and peat soil are recommended.

Keywords: *cassava, starch production, root yield, nutrient, Manihot esculenta*

Introduction

Cassava (*Manihot esculenta* Crantz) is a cash crop rich in carbohydrates and carotene and one of the most important food sources in some Asian countries and tropical Africa (Khairol and Wan Zaki 2013). Cassava cultivation under marginal soils produces reasonable root yields and is easy to plant at a low-cost production. Mostly used as food or processing, one of the most beneficial is its tuber production. Thus, it has become one of the most popular crops in Laos, Vietnam, and Thailand (NurulNahar and Tan 2016). The volume of cassava-based starch imports to Malaysia totalled 136,465 mt in 2021 with a worth of RM 258,205,381 (*Figure 1*). Total import volume increased from 2015 until it peaked in 2017 before showing a significant decline in 2019. The increases in volume import coincided with the decrease in the total planted area from 2015 to 2018 before slightly increasing in 2019 (*Figure 2*). Based on the cassava root yield production and planted area from 2015 – 2021, an average of 17.2 t/ha is a significant result of a high volume of imports to Malaysia to support starch industries that are highly demanding because of low production in smallholder farmers' fields.

The 'bitter' types are varieties with high cyanide content and starch content, which is preferable for starch processing. 'Sweet' or edible varieties are used for food and food products (NurulNahar and Tan 2016). This study presents (*Table 1*) cassava varieties released by MARDI (Howeler and Ceballos 2000; Tan 2001a; Tan and Abd Rahman 2001). From 1988 to 2003, all released cultivars had a high root yield with an average yield of 35.7 t/ha. The differences between potential or attainable and actual yields, known as yield gaps, are enormous for cassava (Ezui et al. 2017). Yields of fresh roots in smallholder farmers' fields average only 17.2 t/h which is far less than

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yields of an average 35.7 t/ha for all released varieties in Malaysia. The primary constraint is poor soil fertility or negligible nutrient inputs. Balanced nutrients can maintain high and sustainable yields with a ratio of N: P_2O_5: K_2O of 2:1:2 or 2:1:3 (Howeler 2007). Cassava requires nitrogen (N) and potassium (K), both of which are in short supply in most soils (Thummanatsakun and Yampracha 2018). Currently, cassava recommendations in Malaysia for mineral soils are 60 kg N, 30 kg P_2O_5, and 160 kg K_2O while for peat soil it is 250 kg N, 30 kg P_2O_5, and 160 kg K_2O (Tan 2001b) which are both at the ratio of 2:1:5 and 8:1:5 based on studies conducted in 1983 and 1989, respectively. Thus, re-evaluating fertiliser recommendations for high-yielding cassava cultivars is crucial. This study reports the appropriate rates of fertilisers on two local varieties, Sri Kanji 2 and Sri Pontian, which are considered 'bitter' and 'sweet' cultivars, respectively.

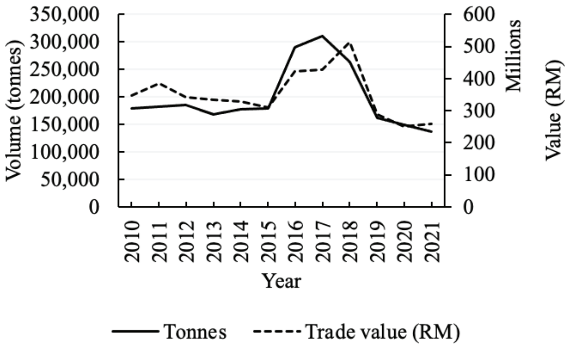

Figure 1. Malaysia imports of cassava-starch based product in terms of volume and value (Source: UN Comtrade; HS110814)

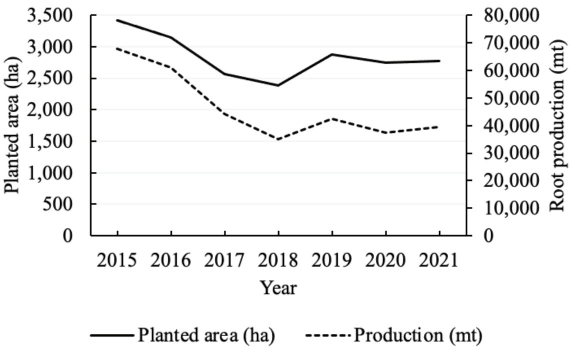

Figure 2. Total planted area (ha) and root production (mt) in Malaysia from 2015 to 2019 (Source: DOA 2022)

Table 1. Performances of selected cultivar released by MARDI at 12-month planting

Varieties	Year released	Starch content (%)	Root yield (t/ha)
Perintis	1988	22.8	40.9
MM92	1992	20.9	36.4
Sri Kanji 1	2003	26.7	37.6
Sri Kanji 2	2003	26.9	32.2
Sri Pontian	2003	26.4	31.6
Average		24.7	35.7

Materials and method

Site location

The field trials were conducted at MARDI Research Station in Pontian (peat soil) and Serdang (mineral soil). Topsoil samples (0 – 20 cm) were collected using an auger from the experimental site and bulked together to get a homogenised composite sample for each experimental site before planting. *Table 2* presents the results of soil analysis for the two research stations and their suitability for optimal cassava growth based on Biratu et al. (2019) and Imakumbili et al. (2019). Comparing the actual nutrient levels with the recommended values for cassava, the soil in Serdang exhibited lower total nitrogen (N) and exchangeable potassium (K) than the optimum requirements for optimal cassava growth.

Planting material

The mature stems of Sri Kanji 2 and Sri Pontian cassava were taken from the hardwood portion of the stems, leaving at least a 30 cm stump above the ground. These cuttings were harvested from the mother plants at 12 months of age. The stems were cut into sets of 25 cm in length and planted about 5 cm below the soil surface.

Experimental design and yield components

A randomised complete block design with two replications was used. Each plot comprised 36 plants (6 m x 6 m plot size with plants at 1 m x 1 m spacing), and only the central 16 plants per plot (4 x 4) were harvested for data collection. Data related to growth performance, root yield and starch contents were collected 12 months after planting.

A total of 18 treatments in factorial combinations of two varieties (Sri Kanji 2 and Sri Pontian), three nitrogen rates (0, 100, 200 kg/ha) and three potassium rates (0, 100, 200 kg/ha) were tested. Nitrogen was applied as urea (46%) and potassium was applied as muriate of potash (60%). Fertilisers were applied as side dressings along the cassava rows at planting time. Soil bunds were constructed around each experimental plot to prevent lateral fertiliser contamination between plots.

Table 2. Physicochemical properties of topsoil (0–20 cm depth) of the two experimental sites

Parameters	Serdang	Pontian	Optimum requirement
pH	4.6	5.9	4.5–7.0
CEC (cmol$_{(+)}$ kg^{-1})	8.2	114	
Electrical conductivity (mS/m)	6.96	22.32	
Total N (%)	0.15	1.6	0.20–0.50
Total P (%)	0.02	0.06	< 4.2
Exchangeable K (cmol$_{(+)}$ kg^{-1})	0.12	0.84	0.15–0.25
Exchangeable Na (cmol$_{(+)}$ kg^{-1})	0.069	0.178	
Exchangeable Ca (cmol$_{(+)}$ kg^{-1})	0.796	49.145	0.25–1
Exchangeable Mg (cmol$_{(+)}$ kg^{-1})	0.187	15.064	0.40–1.00
Available Mn (ppm)	26.77	59.57	1.2–3.5
Available Zn (ppm)	25.44	39.4	1.0–3.0
Soil texture	Clay	Peat	

Cassava starch contents (SC) were measured based on the specific gravity (SG) method.

SC (%) = SG - 1.00906/0.004846
SG = weight of 5 kg cassava in the air / (weight of 5kg cassava in the air - weight of 5kg cassava in the water)

Cyanide content (HCN) was estimated based on Cuvaca et al. (2015). The roots were peeled, washed, and cut into roughly 3-mm slices before being air/sundried and dried in an oven to a consistent weight (75°C for 72 hours). Each sample was ground into flour and then homogenised with a No. 40 mesh screen to ensure the dispersion of HCN in the sample was uniform. After that, a 5 g subsample was taken, and each subsample was combined with 50 mL of distilled water and agitated in a shaking water bath for 16 hours (35°C). After that, extracts were taken to be analysed. A technique with alkaline picrate was used to determine the tuber HCN content (Nwokoro et al. 2009). The concentration of cassava HCN was evaluated using a spectrophotometer (Cary 60 UV-Vis, Agilent Technologies) that measured absorbance at 510 nm.

The soluble solid concentration (SCC) was determined using a digital refractometer (model Atago, 0% – 32%) calibrated at room temperature and values were expressed in percentage. A composite sample was dropped onto the prism and data was taken.

Statistical analysis

The analysis of variances was based on Moore and Dixon (2015), the location was set as fixed while the varieties, nitrogen and potassium were set as random effects using Statistical Analysis Software (SAS 9.3). The mean comparison was compared by LSD at $p < 0.05$.

Results and discussion

Analysis of variance in plant performances and fresh root yield is presented in *Table 3*.

There was a significant effect of N and K on plant height. Cassava plant height increased by 6.2% as N levels increased from 0 (control) to 200 kg/ha. Similar to K, it increased by 8.9% as K levels increased from 0 kg/ha to 200 kg/ha. N and K did not have a positive effect between 0 kg/ha and 100 kg/ha. There was a significant interaction between location and varieties (*Table 3*). Varieties did not influence cassava plant height at Pontian (*Figure 3*). The average plant heights were 284 cm and 291 cm for Sri Kanji 2 and Sri Pontian, respectively. However, in Serdang, Sri Pontian (258 cm) had a significantly higher plant height by 15.8% than Sri Kanji 2 (223 cm). As a result, it showed that N and K play an essential role in plant height. However, it requires higher rates of N and K to increase plant height even though the increase in plant height was slightly around 6 – 9%. This result is in harmony with the findings of de Oliveira et al. (2017), Thummanatsakun and Yampracha (2018) and Uwah et al. (2013) that N at high rates and K improved cassava plant height. The increase in photosynthetic tissue contributes to cell multiplication by producing carbohydrates in plant stems (Uwah et al. 2013) consequently increasing the size and length of the cassava stem. In addition, Gyasi Santo et al. (2021) reported that sufficient nutrients at the early vegetative stage contributed to the highly efficient partitioning of dry matter to enhance cell elongation, resulting in higher cassava plant height. According to Agyeman et al. (2022), high moisture content enhanced nutrient uptake, and photosynthate accumulation promoted the cassava plant height. The peat soil has a high natural moisture content, and the water holding capacity of Malaysian peat soil varies between 96% to 220%, but in Pontian, it recorded around 898.91% (Wahab et al. 2022). In this study, the lower plant height of Sri Kanji 2 compared to Sri Pontian cultivated at Serdang (clay soil) could be the phenotypic expression that showed that Sri

Kanji 2 dry matter partitioning in shoot and stem was lower under moisture stress. Our results confirm that Sri Kanji 2 generally had lower fresh leaves and stem weight *(Table 3)*. On the other hand, in Pontian (peat soil), both had similar heights.

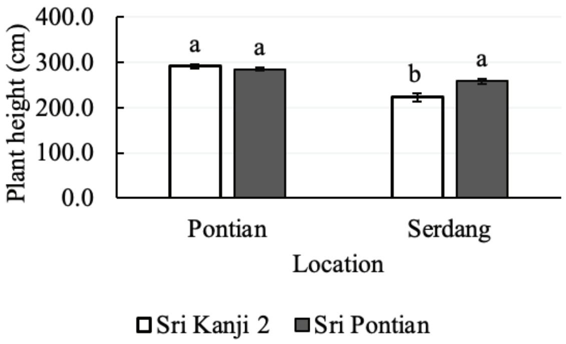

Figure 3. Performance of plant height in different locations

The location significantly affected the weight of the fresh leaves. In Pontian (10.7 t/ha), cassava leaves production was significantly higher by 42.7% than cassava grown in Serdang (7.5 t/ha). Fresh stem weight in Pontian (35.9 t/ha) was significantly higher by 61% than in Serdang (22.3 t/ha). Plant height positively correlated with leaves weight because a higher plant provides great light interception and leaf area index, thus increasing the aboveground plant biomass (Mwamba et al. 2021). Thus, significant fresh leaf weight in Pontian than Serdang was contributed by plant height. In this study, variety did not influence the fresh leaves (*Table 3*) however, Sri Pontian had a higher weight of fresh leaves. Leaf formation is an important indicator for cassava to maintain growth and is associated with high root yields where leaf formation is consider a genetic trait (Imakumbili et al. 2019). Generally, higher shoot weight relatively having a larger stem girth translates to high-yielding cultivars (Adetoro et al. 2021). It is possible that both varieties (Sri Kanji 2 and Sri Pontian), locally known for high-yielding cultivars, have a similar genotype for leaf traits to sustain high root yield production. Thus, both varieties had similar fresh leaf weights. Our findings showed that greater fresh leaf weight in Sri Pontian does not necessarily produce a significant root yield than Sri Kanji 2. High N rates promote greater plant above-ground biomass and increased nitrogen uptake from the soil. As a result, the available nutrients in the soil were reduced (Sun et al. 2020). Excessive N results in cassava canopies becoming overly demanding, forcing plants to limit transpiration, photosynthesis, carbohydrates, and, ultimately reducing the root yields (Omondi et al. 2019). According to Adetoro et al. (2021), most photosynthesis activities were used to maintain the vegetative parts and not converted to root formation. Thus, having greater aboveground biomass may only sometimes have a positive impact on cassava root yield production.

There was a significant effect of location on fresh stem weight (*Table 3*). Stem weight at Pontian (35.9 t/ha) was higher by 61% than cassava grown at Serdang (22.3 t/ha), and taller plant height in Pontian may contribute to the significant differences. Variety did not influence the fresh stem weight. Nitrogen significantly increased fresh stem weight from 0 kg/ha (25.4 t/ha) to 200 kg/ha (31.6 t/ha) by 24.4% (*Table 3*). In addition, K also significantly influenced the fresh stem weight by 20.2% from 0 kg to 200 kg/ha. Proportions of biomass in leaves, stems, and roots vary with nutrient supply at various growth stages however, fertiliser application significantly improved leaf biomass, resulting in a greater leaf area index (Adiele et al. 2022). N is hugely vital in various physiological functions. It gives plants a dark green colour and helps them grow and develop their leaves, stems, and other vegetative parts (Leghari et al. 2016). In cassava, partitioning and utilisation of carbohydrates depend on photosynthesis and the plant's ability to accumulate the carbohydrate for root development (Duque and Setter 2019). Our results suggest the significant contribution of N and K in fresh stem weight might be cassava plants' importance in optimising plant vigour. Nitrogen is needed for high-yielding varieties to improve plant vigour to sustain a high photosynthesis rate and maximise carbohydrate production through more significant leaf numbers and greater cassava stem size (plant height) for carbohydrate storage. While K also plays a role in the supply and regulation of water in the plant and starch synthesis and translocation activities in the plant (Leghari et al. 2016). Thus, more vigorous stem size translates to fresh stem weight which is necessary for carbohydrate storage.

Cassava planted in Pontian was significantly higher in SSC (2.79%), than Serdang (2.74%) by 1.8%. The varieties, N and K, did not influence SSC. Our result corroborates the findings of Biratu et al. (2022) who reported no effect of SSC (%) content in cassava root planted at different locations following several combinations of NPK fertiliser, and is in line with Otache et al. (2017) who reported that the SSC content was 4.02 – 5.58% for the three cassava varieties studied. Plant sugar (SSC) levels play a vital role in regulating plant growth and development (Shi et al. 2016). Soluble sugars are extremely sensitive to environmental factors that affect the flow of carbohydrates from source organs to sink organs (Rosa et al. 2009). As the tuberous roots developed from the vegetative to the ripening stage, the soluble solid concentration in the leaves decreased while starch accumulation in the root tubers increased (Luo and Huang 2011). The present study indicates that the environment (location) in which cassava was grown in peat soil performed better than clay soil in SSC production. Low SSC (2.77%) also had considerably higher starch content (26.9%). The present results could indicate that low SSC in roots due to sugar has been synthesised to starch at the maturity stage and it appears to be a function of environment that might play a role in determining the SSC rather than nutrients.

Table 3. Analysis of variance on cassava performances under different locations, N and K rates

Source	df	Mean square								
		Plant height (cm)	Fresh leaves weight (t/ha)	Fresh stem weight (t/ha)	Soluble solid conc. (%)	Cyanide content (ug/g)	Starch content (%)	Fresh root yield (t/ha)	Starch yield (t/ha)	Harvest index
Location (L)	1	39340.13**	4.959**	30.0352**	0.040139**	1692.65**	0.6235ns	23.3342**	278.087**	0.629**
Serdang		240.9	7.5	22.3	2.74	13.4	27	69.5	18.9	0.7
Pontian		287.6	10.7	35.9	2.79	23.1	26.8	55.8	14.9	0.51
Variety (V)	1	3635.77*	0.061ns	0.5927ns	0.003472ns	69.82ns	0.1335ns	1.5591ns	35.420ns	0.037*
Sri Pontian		271.3	9.1	29.9	2.76	17.2	26.9	60.1	16.2	0.59
Sri Kanji 2		257.1	9	28.2	2.78	19.2	27.0	65.2	17.6	0.63
Nitrogen (N)	2	1543.72*	0.822*	2.0798*	0.001667ns	165.66*	0.1685ns	37.9051**	609.269**	0.0582*
0 kg/ha		255.9b	7.9b	25.4b	2.76	15.3b	26.9	47.4c	12.8c	0.57b
100 kg/ha		265ab	9.1ab	30.3a	2.78	19.2a	27.0	56.8b	15.4b	0.60b
200 kg/ha		271.8a	10.2a	31.6a	2.77	20.2a	26.8	83.8a	22.5a	0.66a
Potassium (K)	2	3366.69*	0.369ns	1.94*	0.005417ns	95.97*	1.0001*	7.0306**	103.111*	0.0185*
0 kg/ha		254.9b	8.9	27.1b	2.77ab	16.9b	26.8b	55.3b	14.9b	0.58b
100 kg/ha		260.3b	8.4	27.6b	2.79a	20.5a	27.1a	61.4b	16.7b	0.62a
200 kg/ha		277.6a	9.9	32.6a	2.76b	17.2b	26.8b	71.2a	19.0a	0.63a
L x V		7987.64**	0.463ns	0.042ns	0.000139ns	55.65ns	0.0501ns	0.0151ns	0.101ns	0.0059ns
V x N	2	35.29ns	0.177ns	0.4287ns	0.003889ns	78.49*	0.0185ns	0.0386ns	1.690ns	0.0012ns
V x K	2	24.03ns	0.226ns	1.5918ns	0.006806ns	30.26ns	0.0035ns	0.0874ns	2.513ns	0.0019ns
L x N	2	28.93ns	0.503ns	1.3309ns	0.000556ns	190.16ns	0.0476ns	41.3351**	637.693*	0.0732**
L x K	2	2713.95ns	0.169ns	0.0064ns	0.006806ns	123.12ns	1.2876*	5.6571ns	94.459*	0.0444*
N x K	4	535.44ns	0.073ns	0.1682ns	0.002708ns	21.06ns	0.0614ns	0.7753ns	19.634ns	0.0008ns
L x N x K	4	417.36ns	0.235ns	0.4837ns	0.001597ns	66.30ns	0.1055ns	0.3949ns	21.772ns	0.0059ns
Error	44	437.02	0.206	0.5554	0.002051	23.08	0.2335	0.5402	11.743	0.0052
Corrected total	71									
CV		7.9	15.4	14.1	1.6	26.4	1.8	9.6	20.3	11.8
Mean		264.2	9.1	29.1	2.77	18.2	26.9	62.6	16.9	0.6

Cyanide content in Pontian (23.1 ug/g) was significantly higher by 72.4% than in Serdang (13.4 ug/g). Cyanide concentration in cassava leaves and roots appears to be under genetic control, and environmental stress could limit cyanide production (Tan 1995) and identical genotypes exhibited different concentrations than those from lowland and highland areas (Mushumbusi et al. 2020). The significant differences in the cyanide content in Pontian and Serdang observed in the study corroborate Ndam et al. (2019), who described the potential of cyanide content in the roots varied due to different agro-ecological environments because of different soil types, humidity, temperature and climatic conditions during the time of harvest. Variety did not influence the cyanide content (*Table 3*). However, there was a significant interaction between the cultivar and N (*Figure 4*). Application of 100 kg N/ha showed the highest cyanide content (20.13 ug/g) in Sri Pontian. In contrast, cyanide content increased as N levels increased from 0 (16.57 ug/g) to 200 kg/ha (22.85 ug/g) in Sri Kanji 2. Although there was a significant interaction in how N determined the cyanide content in both varieties, the level of cyanide was not different in individual varieties. In addition, cyanide content in the roots tested at 12 months' growth showed a significant response to K fertilizers. The cyanide content in roots from 0 kg K/ha (16.9 ug/g) to 100 kg K/ha (20.5 ug/g) increased by 21.3% and later decreased at 200 kg K/ha (17.2 ug/g). Our results contradict the findings of Cuvaca et al. (2015) and Biratu et al. (2022), who reported no effects of cyanide content following fertiliser treatments. Reduction in the cyanide content is crucial because the consumption of unprocessed cassava roots could cause cyanide toxicity and lead to chronic and acute health problems due to cyanide poisoning (Ndubuisi and Chidiebere 2018). According to Imakumbili et al. (2019), low K in soils contributes to increased cyanide content, but this sometimes occurs. Jansson (1980) reported that an abundance of nitrogen often increases the presence of toxic elements in cassava, while and a balanced supply of K effectively mitigates the negative effects of excess nitrogen on quality, thus reducing cyanide content in cassava roots. Our studies suggest that applying either low or high levels of N and K to sweet cassava varieties could lower the cyanide content.

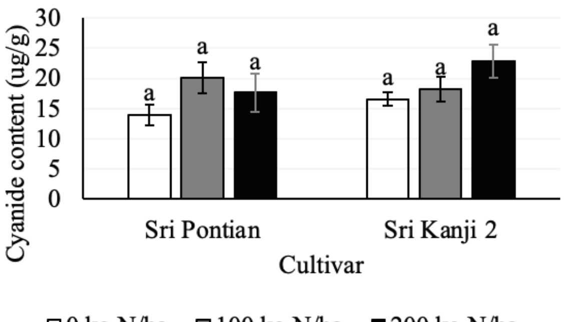

Figure 4. *Cyanide content (ug/g) in Sri Pontian and Sri Kanji 2 as affected by nitrogen levels*

According to Chimphepo et al. (2022) starch content could be influenced by genetic and environment (G x E) interaction because the appreciable influence of location supports the cassava genotypes depending on soil properties that affect the diversity of organisms living in the soil environment and agronomic conditions. A study conducted by Phun-iam et al. (2018) found that starch content tended to increase with the increasing rate of N from 0 kg/ha to 125 kg/ha however, it decreased with added organic waste at 12.5 t/ha and a more considerable amount because N mineralisation may have occurred, and N excess in soil causes the reduction of starch accumulation in the roots. Exceeding a critical K in soil and receiving higher K inputs contributed to the lower starch content (Chua et al. 2020). Starch content is negatively associated with high soil N and Mg (Tan and Mak 1995). In the present study, the physicochemical properties of the soil in Pontian showed that N and K had exceeded the optimum requirement for optimal cassava growth, in which the starch content supposedly decreased significantly. While the starch content supposedly increased in Serdang due to additional N and K supply, as the N and K were lower than the optimum requirement in the soil. However, starch content in fresh cassava roots was not influenced by location, variety, and N levels (*Table 3*). The present study may explain that environment (location) and nitrogen may not play a role in starch contribution in cassava root because different soil conditions (i.e., physical and chemical properties) did not influence starch content. Despite that, there was a significant interaction between location and K. In Pontian, starch content in fresh roots decreased as K levels increased, the starch content was 26.9% (0 kg/ha), 26.8% (100 kg/ha) and 26.7% (200 kg/ha), but each K level had no difference (*Figure 5*). On the other hand, cassava planted in Serdang showed that at 100 kg K/ha significantly produced the highest starch content of 27.5%. There was no difference between 0 kg K/ha (26.7%) and 200 kg K/ha (26.8%). For N and K interactions, synergistic interactions are widely recognised; they are significant for the yield and explain how the two affect root growth (Rietra et al. 2017). In contrast, plants must maintain a homeostatic balance between K^+ and Mg^{2+} in response to changing nutrient status in the soil in order to grow and develop to their full potential. This is due to the antagonistic interactions of K^+ and Mg^{2+} in their absorption, translocation, and distribution, but there are also shows of synergistic effects of K and Mg on photosynthesis, carbohydrate transport, and allocation (Xie et al. 2021). This study shows that the high Mg content in the soil, as recorded in Pontian, does not significantly interact with increasing K levels. However, as K increases, there is a reduction in starch content. On the other hand, in Serdang, the low Mg content shows a synergistic interaction between 0 kg/ha - 100 kg/ha, while an antagonistic effect occurs when K is given at a very high rate (200 kg/ha). This study suggests that moderate K (100 kg/ha) can be considered to ensure optimum starch production.

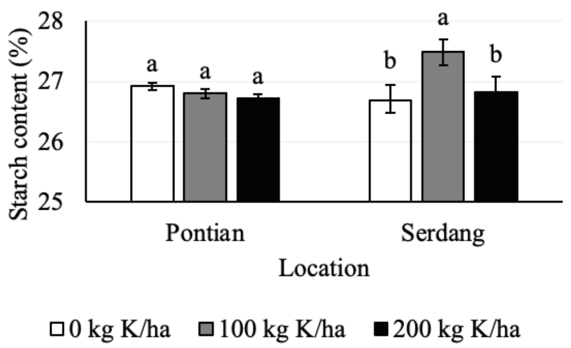

Figure 5. Starch content (%) in Pontian and Serdang as affected by potassium levels

There was a significant effect of location on fresh root yield (*Table 3*). However, there was also a significant interaction between location and N treatments. N levels did not influence fresh root yield for cassava grown in Serdang (*Figure 6*), but the fresh root yield was 72.2 t/ha (0 kg N/ha), 66.2 t/ha (100 kg N/ha) and 70.2 t/ha (200 kg N/ha). While in Pontian, an increase of N significantly increased fresh root yield. The highest fresh root yield in Pontian was produced with 200 kg N/ha (97.4 t/ha), followed by 100 kg N/ha (47.4 t/ha) and 0 kg N/ha (22.6 t/ ha).

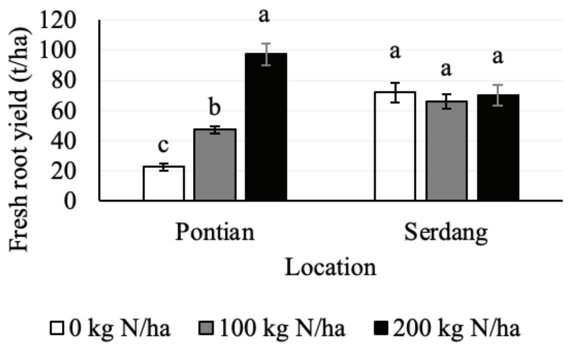

Figure 6. Fresh cassava root yield (t/ha) in Pontian and Serdang as affected by nitrogen levels

The nitrogen content of tropical peat soils is high, but it is in organic form because of the slow N mineralisation, and the acidity of peat soils, the availability of inorganic N is low (Choo et al. 2020). However Zhang et al. (2015) found that excessive N fertilisation can significantly increase net N mineralisation. The low inorganic N availability for plant uptake in the peat soil could be enhanced by applying a substantial amount of N fertilisers (Choo et al. 2022). Tuberisation is the process through which a fibrous root becomes a tuberous root designed to store carbohydrates by an increase in root thickness and occurs three months after planting (Figueiredo et al. 2015). The current study suggests that the high application of N in Pontian may benefit fresh root yield production. The possible reason was that slow mineralisation in peat soil could benefit in terms of N availability releasing slowly but continuously in the soil in an inorganic form and available to be taken by the cassava continuously from the beginning of the tuberisation process until ready for harvest. In contrast, the application of N in clay soil (Serdang) did not induce larger cassava fresh root yield increases, this could be due to poor structure soils. In poorly structured soil with restricted aeration, N limitation due to gaseous losses via denitrification and high organic carbon is needed in the clay soil to maintain soil structural stability and N uptake efficiency (Soinne et al. 2021). Variety did not influence the fresh root yield (*Table 3*). The fresh root yield of Sri Kanji 2 (65.2 t/ha) was slightly higher than Sri Pontian (60.1 t/ ha) by 8.5%. This can be expected because Sri Kanji 2 and Sri Pontian do not show significant differences based on the characterisation of the fresh root yield (*Table 1*). K levels significantly increased cassava fresh root yield from 0 kg/ha (55.3 t/ha) to 200 kg/ha (71.2 t/ha) by 28.8%. There was no difference between 0 kg K/ha and 100 kg K/ha (61.4 t/ha). In potatoes, K tends to increase photosynthesis, directly giving favours high energy for timely and appropriate nutrient translocation and water absorption by roots (Zelelew et al. 2019), facilitating the translocation of assimilates from the leaves to the tuber (Torabian et al. 2021). In sweet potatoes, K plays an essential role in the formation of tubers (Garfansa et al. 2018), favouring enzymatic processes, assimilating translocation, amino acid synthesis (Silva et al. 2022), carbohydrate formation and transformation (Zelelew et al. 2016). Focusing on cassava, the harvested storage roots contain relatively large amounts of K compared to other plant parts (Chua et al. 2020), which translates to the importance of K in yield development. Based on these previous studies for root crops, K is essential for root (tuber) production.

Starch yield (t/ha) is the product of starch content (%) multiplied by the fresh root yield (t/ha). There was a significant effect of location on starch yield (*Table 3*). However, there was also a significant interaction between location and N and between location and K. Nitrogen levels varied in starch production in both locations. In Pontian, the starch yield increased significantly in line with the N levels (*Figure 7*). Control (0 kg N/ha) significantly produced the lowest starch yield of 6.1 t/ ha, while 100 kg N/ha and 200 kg N/ha produced 12.7 t/ ha and 26.0 t/ha, respectively. N did not influence starch yield in Serdang. The starch yield was 19.5 t/ha, 18.0 t/ha and 19.0 t/ha with the application of 0 kg N/ha, 100 kg N/ha and 200 kg N/ha, respectively. Similarly, K significantly affected starch yield in Pontian but not in Serdang (*Figure 8*). The starch yield in Pontian was significantly highest, with K applied at the rate of 200 kg/ha (19.1 t/ha) but did not differ from 100 kg/ha (14.7 t/ha). The lowest starch yield of 11.0 t/ha was produced with 0 kg K/ha. On the other hand, in Serdang, the K rate does not positively impact starch yield production. K rates at 0 kg/ha, 100 kg/ha and 200 kg/ha yielded 19.5 t/ha, 18.0 t/ha and 19.0 t/ha of the starch yield, respectively (*Figure 8*). Variety did not influence cassava starch yield.

However, the starch yield of Sri Kanji 2 (17.6 t/ha) was higher than Sri Pontian (16.2 t/ha) by 8.6% because of the more outstanding fresh root yield production. As starch yield is a product of fresh root yield and starch content, it is not surprising that the trends are similar to fresh root yields.

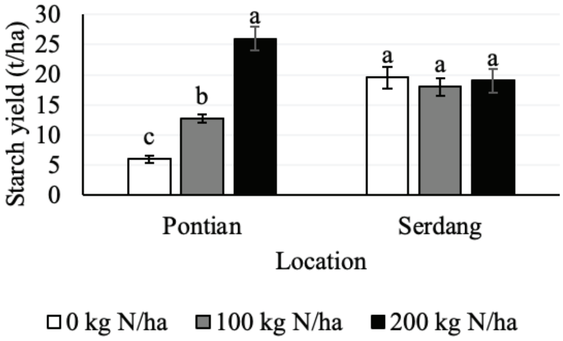

Figure 7. Cassava starch yield (t/ha) in Pontian and Serdang as affected by nitrogen levels

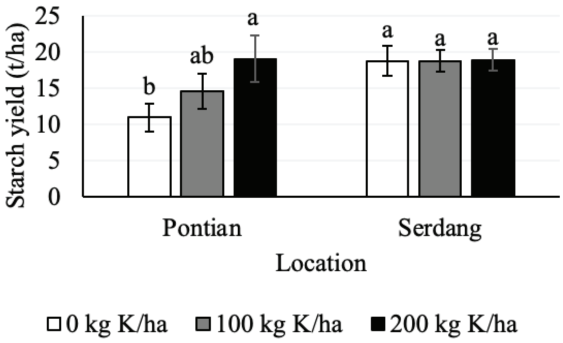

Figure 8. Cassava starch yield (t/ha) in Pontian and Serdang as affected by potassium levels

Harvest index (HI) was calculated as the ratio of fresh root yield to fresh total biomass. The HI is closely related to higher commercial yields due to the quantity produced and quality of the obtained product (Henrique Campos de Almeida et al. 2016). There was a significant effect of variety on HI. Sri Kanji 2 (0.63) significantly has a much higher harvest index than Sri Pontian (0.59). The present study indicates that Sri Kanji 2, the bitter cultivar, may also be used for food and food products such as an edible cultivar (sweet variety) due to its lower cyanide content. There was a significant interaction between location and N and location and K. In Pontian, HI significantly increased with the N increases (*Figure 9*). The HI was 0.42 (0 kg N/ha), 0.51 (100 kg N/ha) and 0.62 (200 kg N/ha), respectively. On the other hand, N did not influence the HI in Serdang. The harvest index was 0.72 (0 kg N/ha), 0.70 (100 kg N/ha) and 0.69 (200 kg N/ha), which indicates that the HI decreased as the N rates increased. We found similar results for K applied to the cassava plants in Pontian and Serdang. K significantly improved the harvest index in Pontian (*Figure 10*). K at the rate of 200 kg/ha produced the highest HI of 0.57, followed by 100 kg/ha (0.54) and 0 kg/ha (0.44). In Serdang, the HI was 0.72 (0 kg K/ha), 0.71 (100 kg K/ha) and 0.68 (200 kg K/ha). The harvest index (HI) is the ratio of a crop's economic yield to its biomass production, assessed 12 months after planting. In this study, higher aboveground (fresh leaves and stem weight) over fresh root yield of cassava grown in Pontian led to lower HI than in Serdang. An increase in N and K in Serdang may lead to lower HI. In contrast, an increase in N and K improved HI for cassava grown in Pontian.

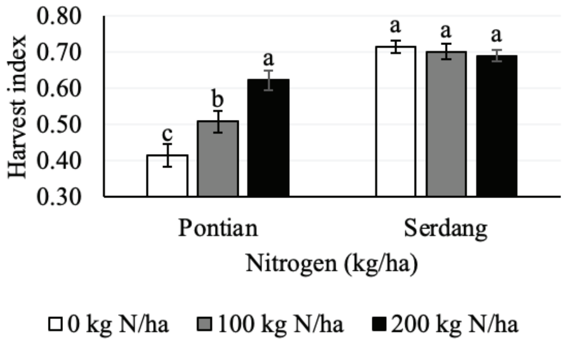

Figure 9. Harvest index in Pontian and Serdang as affected by nitrogen levels

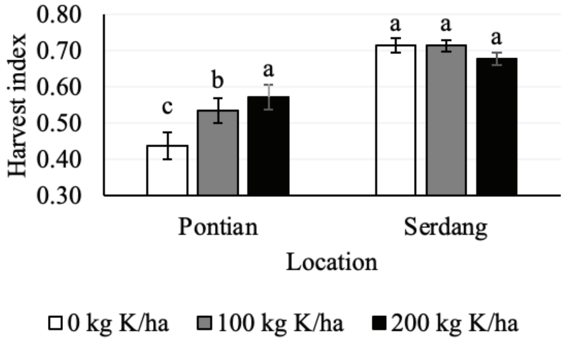

Figure 10. Harvest index in Pontian and Serdang as affected by potassium levels

Conclusion

The effectiveness of nitrogen and potassium in cassava growth, quality, and root production by different locations (i.e., clay and peat soils) and varieties was compared in the present study. Plant height differed according to significant interaction between location and variety, indicating that the contributions of the plant varied due to soil types. The increases of N and K improved the plant height. The fresh leaves' weight differed according to location and N supply to the cassava plants. High N increased the leaves' weight. Similar findings in the fresh stem weight, but an additional K supply to cassava increases the stem weight. Cassava root quality, such as soluble solid concentration, only differed between locations indicating that the environment might play a role in determining the SSC rather than nutrients. Applying either high or low N and K could lower the cyanide content, while moderate N and K tend to increase the cyanide content. Starch content differed according to the significant interaction between location and K. The present study suggests moderate K (100 kg/ha) promotes optimum starch production. The fresh root yield differed according to the significant interaction between location and N and differed according to K levels. Sri Kanji 2 and Sri Pontian had similar fresh root weights of 62.6 t/ha. N levels did not influence fresh root yield for cassava grown in Serdang. While in Pontian, an increase of N significantly increased fresh root yield. K levels significantly increased cassava fresh root yield from 0 kg/ha (55.3 t/ha) to 200 kg/ha (71.2 t/ha) by 28.8%. These results indicated that soil conditions are important in deciding N management, but K is essential for root development. As starch yield is a product of fresh root yield and starch content, it is not surprising that the trends are similar to fresh root yields. In this study, higher aboveground (fresh leaves and stem weight) over fresh root yield of cassava grown in Pontian led to lower HI than in Serdang. An increase in N and K in Serdang may lead to lower HI. In contrast, an increase in N and K improved HI for cassava grown in Pontian. To avoid nutrient depletion for long-term cassava cultivation and based on NPK requirements for cassava at a ratio of 2:1:2 or 2:1:3, we recommend 100:50:100 and 200:100:200 for clay soil and peat soil, respectively.

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