Australian Journal of Crop Science

AJCS

AJCS 17(2):206-214 (2023) ISSN:1835-2707
doi: 10.21475/ajcs.23.17.02.p3796

Analysis of NPK nutrient content and the nutrient balance of cassava for sustainable high productivity in Ultisols soil

Suwarto[1], Ridwan Adiguna[1], Edi Santosa[1], Arief Hartono[2], Gatot Pramuhadi[3], Nunung Nuryantono[4]

[1]Departement of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, 16680, Indonesia.
[2]Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Bogor 16680, Indonesia.
[3]Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor 16680, Indonesia.
[4]Department of Economics, Faculty of Economics and Management, IPB University, Bogor 16680, Indonesia

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

Abstract

The decline in soil fertility and productivity has been a problem in cassava cultivation. The plant biomass transported from cassava fields at harvest losses several nutrients. This study aimed to determine the nitrogen (N), phosphorous (P), and potassium (K) nutrient content of plant parts of cassava and the nutrient balance. The cassava varieties of UK1 Agritan, Malang 4, Barokah, UJ-5, and Mangu were grown in 3 replications using a completely randomized design. Two harvesting methods, the farmer's harvest method (FHM) and the harvest method introduced (HMI) were applied. The FHM transported all tuber and other plant parts biomass, and the HMI transported all tuber and 60% of the stem from the cassava field. Each replication was one row of plants 20 m long and a spacing of 1 m. The cassava fertilized at 169 kg N, 84 kg P, and 170 kg K per hectare in grooves around the plant. The leaves of the five varieties contain higher N, P, and K than the petiole, stem, and tuber. At harvest, the N and P nutrients were mainly transported from the leaves, and K nutrients from the tubers. For a yield of 40 tons ha^{-1} fresh tubers, the FMI resulted in an average nutrient balance for N (-222 kg ha^{-1}) and K (-103 kg ha^{-1}) and P (48 kg ha^{-1}), the HMI resulted in an average nutrient balance of 305 kg N, 56 kg P, and 82 kg K per hectare. The HMI is recommended for sustainable soil fertility and high productivity of the cassava field.

Keywords*:* biomass, fresh tuber, soil fertility, transported biomass.
Abbreviations: FHM_farmer's harvest method, HMI_harvest method introduced.

Introduction

Cassava is a very important tuber crop in Asia (Sangakkara and Wijesinghe, 2014). Howeler (2018) reported that the largest area of cassava in Asia (55.1%) and in Latin America (27.0%) was in Ultisols soil. Prasetyo et al. (2001) stated that most of the marginal soils in Indonesia found on dryland were Ultisols. The Ultisols soil was acidic to very acidic, had a low content of macronutrients (including N, P, and K), and had little organic matter. The cultivation of cassava is widespread in dry land on the Ultisols. Nitrogen nutrient (N) is one of the significant factors affecting cassava yield (Kang et al., 2020). Howeler (2018) reported that cassava requires sufficient N, P, and K nutrients to produce high tuber growth and productivity. Without specifying the name of the variety, the yield of 35.5 tons ha^{-1} fresh tuber removed 55 kg N, 13.2 kg P, and 112 kg K nutrients from the field. At low pH in the Ultisols soil, 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).

Sange (2021) reported that Indonesia was the third-largest cassava-producing country in the world, with production reaching 24.01 million tons, after Nigeria (52.40 million tons) and Brazil (25.35 million tons). Cassava is harvested 8-10 months after planting (ILETRI, 2016). In the center of production, cassava is grown continuously on the same land over the year. The average productivity of cassava in Indonesia in 2018 was 24.4 tons ha^{-1} (Ministry of Agriculture Republic of Indonesia, 2018), lower than the potential productivity of 35-60 tons ha^{-1} (ILETRI, 2016). Sok et al. (2017) stated that continuous cassava planting on the same land decreased soil fertility and productivity if not followed by adequate fertilization and proper biomass management at harvest. Each cassava variety can grow and produce different tuber biomass and other plant parts (Akongo et al., 2021). Morphologically, the cassava plant consists of leaves, petioles, stems, and roots/tubers that differ among varieties (Fukuda et al., 2010). Each part of the plant contains different N, P, and K nutrients (Howeler, 2018).

The types of cassava grown by small-scale farmers are bitter and non-bitter cassava. The bitter cassava is to be a raw material for the tapioca industry. The non-bitter cassava is for direct consumption from fresh tubers. The decline in productivity and land degradation processes in the cassava field occur very quickly (Yuniwati et al., 2015). The continuous planting of cassava that is not accompanied by adequate fertilization and the minimum return of biomass resulted in soil nutrient depletion (Sok et al., 2017) and low organic matter of 1.91% (Suwarto and Asih, 2021). The retention of crop residues in the field is necessary to sustain intensive agriculture (Nango et al., 2022). Crop residues are needed to improve soil fertility (Otieno et al., 2021). Most small-scale farmers harvest their cassava by transporting all plant parts; tubers as an economic yield, stems for planting material and firewood, and leaves for animal feed; it was minimal or no retention of crop residues in the field. The study aimed to analyze the nutrient content of N, P, and K in the plant parts of cassava and the balance of these nutrients with two harvesting methods. The harvest method by transporting only all tuber as an economic yield and 60% of the stem for planting material was hypothesized could maintain soil fertility for sustainable high productivity of cassava (40 tons ha^{-1}).

Results

Plant part biomass and harvest index

Plant part biomass of 5 cassava varieties showed significant differences. The fresh weight and dry weight of stem, petiole, and tuber biomass of the UK 1 Agritan variety were the highest (Table 1). The total fresh and dry weight biomass of the UK 1 Agritan were 16,155 g plant-1 and 5,661 g plant-1, respectively.

The fresh-weight biomass distributed to tubers at harvest was the highest, except UJ-5 (Table 2). In the UJ-5 variety, the biomass allocated to the stem was the highest (52.9%), so it had the smallest harvest index (0.37). The highest allocation of the fresh-weight biomass to tubers was on the Mangu variety resulting in a harvest index of 0.64.

NPK Nutrient content in plant parts biomass

The plant parts (stems, leaves, petiole, and tubers) among the variety showed different N, P, and K nutrient content (Table 3). The content of N, P, and K in the leaves of all varieties was the highest, followed by the petiole, stem, and tuber parts.

The amount of N, P, and K nutrients in plant parts biomass (Table 4) were calculated by multiplying the dry weight of plant parts biomass (Table 1) and the nutrients content of the plant parts (Table 3). There were differences in the amount of nutrients among cassava varieties and the plant parts (stems, leaves, petiole, and tubers) within a cassava variety. The amount of N, P, and K nutrients in the leaves for all cassava varieties was higher than in other plant parts, while the amount of K nutrients in the tuber was higher than N and P.

Producing one ton of fresh tubers needs the amount of N, P, and K in the plant parts as shown in Table 5. K nutrient was the highest in tubers, range of 1.80-4.00 kg ton^{-1}, than other plant parts. Table 6 shows the amount of N, P, and K nutrients transported from the field through tubers at a yield of 40 tons ha^{-1} of fresh tubers. The nutrients transported from the field ranged from 44 - 80 kg N, 8 - 12 kg P, and 72 - 160 kg K per hectare, respectively.

NPK nutrient transported from the cassava field

Table 6 shows the total amount of N, P, and K nutrients transported from the cassava field of 1 ton of tubers yield at harvest. Based on data in Table 5, producing fresh tubers of 40 tons ha-1 transported the amount of N, P, and K nutrients as shown in Table 7. The amount of nutrient N, P, and K transported by the FHM- all plant parts biomass transported from the field is higher than the HMI- all tubers and 60% of stems for planting material transported from the cassava field. The number of nutrients transported from the cassava field in the FHM was 298.4-579.2 kg N ha-1, 30.0-50.4 kg P ha-1, and 181.2-432.8 kg K ha-1. The transported nutrients from the cassava field decreased in the HMI to 88.1-125.3 kg N ha-1, 13.9 - 18.1 kg P ha-1, and 108.3-192.0 kg K ha-1. The HMI left 40% of stems and all leaves and petioles as residues biomass in the field.

NPK nutrient balance

Fertilizers of 300 kg Urea (45% N), 200 kg SP-36 (36% P_2O_5), 200 kg KCl (60% K_2O), and 200 kg NPK (17-6-25) per hectare were applied to cassava. It contains 169 kg N, 84 kg P, and 170 kg K. The nutrient balance is shown in Fig.1. The N and K nutrient balances in the FHM that transported all of the plant parts biomass were in a deficit for N and K (Fig.1(1)). In the HMI that transported all of the tuber biomass and 60% of the stem biomass, the nutrient balance was a surplus for N, P, and K (Fig.1(2)).

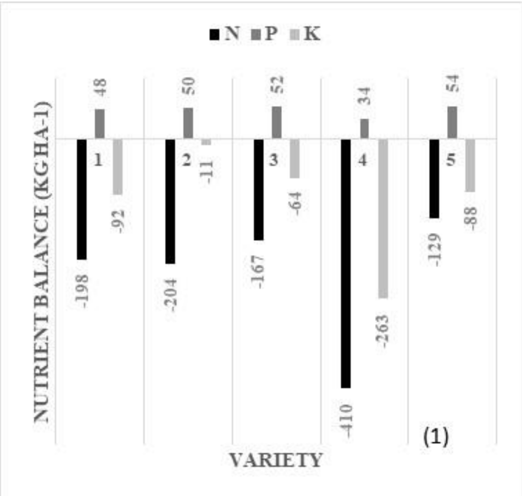
Discussion

The varieties showed differences in growth. Table 1 shows the differences in plant parts biomass weight and tuber yields, and Table 2 shows the harvest index.

Table 1. Fresh weight and dry weight of biomass of five cassava varieties by plant part.

Varieties	Fresh weight biomass (g plant^{-1})				
	Stem	Leaves*	Petiole*	Tuber	Total
UK 1 Agritan	5,040^{a}	1,805	1,629^{a}	7,680^{a}	16,155^{a}
Malang 4	3,900^{ab}	1,427	1,043^{b}	5,850^{ab}	12,220^{ab}
Barokah	3,510^{ab}	1,340	893^{b}	4,440^{bc}	10,183^{b}
UJ 5	3,030^{b}	1,615	989^{b}	2,310^{c}	7,945^{b}
Mangu	2,760^{b}	1,301	896^{b}	5,790^{ab}	10,747^{b}
Varietas	Dry weight biomass (g plant^{-1})				
	Stem	Leaves*	Petiole*	Tuber	Total
UK 1 Agritan	1,829^{a}	705	367^{a}	2,761^{a}	5,661^{a}
Malang 4	1,374^{ab}	618	282^{ab}	2,480^{ab}	4,754^{ab}
Barokah	1,539^{ab}	553	200^{b}	1,498^{bc}	3,79^{ab}
UJ 5	1,043^{b}	606	280^{ab}	984^{c}	2,913^{b}
Mangu	1,057^{b}	537	214^{b}	2,186^{ab}	3,994^{ab}

Means in the same column and the same variable followed by the same superscript letter are not significantly different by DMRT 5%; * is calculated as the accumulation of fallen leaves for 9 months and attached leaves at harvest.



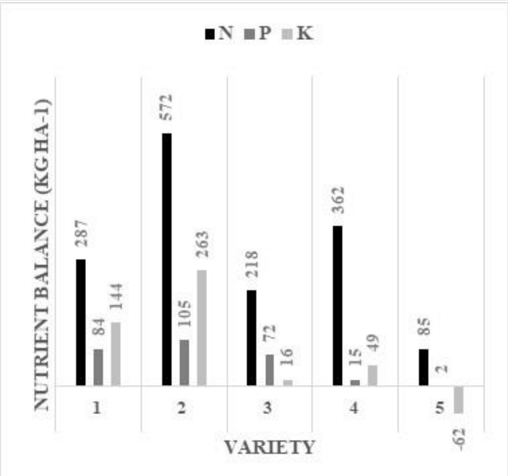


Fig 1. N, P, and K nutrients balance in the cassava field; (1) = Farmer's Harvest Method - all plant parts biomass transported from the field; (2) = Harvest Method Intoduced - all tubers and 60% stem of biomass transported from the field). Variety: 1 = Uk1 Agritan, 2 = Malang 4, 3 = Barokah, 4 = UJ-5, 5 = Mangu.

This difference is related to genetics or varieties, as shown in Table 8. The growth of shoot and tuber of cassava differed among genetics and locations (Adetoro et al., 2021). Genetics affect the performance of leaves and biomass (Phosaengsri et al., 2018). All growth variables of shoot and roots were significant differences among cassava varieties (de Oliveira et al., 2016). Cassava varieties had a significant effect on tuber yield (Umeh et al., 2015). Omondi et al. (2018) reported that types of cassava plants resulted in differences in harvest index. The harvest index of the 3 varieties tested ranged from 0.35 to 0.70. The Nalumino variety was the lowest (0.35), in NPK fertilization of 200-30-220 mg L^{-1}. The value is similar to the harvest index of the UJ-5 (0.37), while others (UK 1 Agritan, Malang 4, Barokah, and Mangu) have a harvest index range from 0.53 to 0.64. The harvest index of cassava at several doses of N fertilizers ranged from 0.48 to 0.59 (Sangakkara and Wijesinghe, 2014). The number and weight of tubers that determine the harvest index was significantly affected by cassava varieties (Giménez et al., 2019).

Nutrient content of N, P, and K (% w/w) was highest in the leaves (Table 3) for all varieties. Similarly, Hamano et al. (2011) found differences in nutrient allocation to plant organs. In cassava leaves, there is a higher total-N and soluble protein than in the roots (Cruz et al., 2004). Cassava has higher shoot growth at increased phosphorus availability (Pereira et al., 2012). Nutrient content of N, P, and K (% w/w) was highest in the leaves (Table 3) for all varieties. Similarly, Hamano et al. (2011) found differences in nutrient allocation to plant organs. Cassava leaves contain a higher total-N and soluble protein than tubers (Cruz et al., 2004). The shoot of cassava grows faster at increased phosphorus availability (Pereira et al., 2012). Potassium content in the cassava leaves increases with the availability of potassium increase in the soil (Umeh

Table 2. Allocation of fresh weight biomass to the plant parts and harvest index of five cassava varieties

Varietas	Fresh weight biomass (g plant^{-1})					Harvest index
	Stem	Leaves	Petiole	Tuber	Total	
UK 1 Agritan	4,847^{a}	397	359^{a}	7,680^{a}	13,283^{a}	0.58
Malang 4	3,900^{ab}	314	230^{b}	5,850^{ab}	10,294^{ab}	0.57
Barokah	3,510^{ab}	295	196^{b}	4,440^{bc}	8,441^{b}	0.53
UJ 5	3,030^{b}	355	218^{b}	2,130^{c}	5,733^{b}	0.37
Mangu	2,760^{b}	286	197^{b}	5,790^{ab}	9,790^{b}	0.64

Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%

Table 3. N, P, and K nutrient content in the plant parts of five cassava varieties

Varieties	N (% w/w)			
	Stem	Leaves	Petiole	Tubers
UK 1 Agritan	0.81	4.68	1.51	0.50
Malang 4	0.97	4.63	1.06	0.46
Barokah	0.80	4.41	1.22	0.33
UJ 5	0.77	4.02	0.90	0.47
Mangu	0.67	4.15	0.88	0.54
Varieties	**P (% w/w)**			
	Stem	Leaves	Petiole	Tubers
UK 1 Agritan	0.10	0.28	0.14	0.08
Malang 4	0.09	0.30	0.09	0.07
Barokah	0.08	0.28	0.12	0.07
UJ 5	0.11	0.26	0.10	0.08
Mangu	0.10	0.30	0.11	0.07
Varieties	**K (% w/w)**			
	Stem	Leaves	Petiole	Tubers
UK 1 Agritan	0.79	1.58	1.15	0.64
Malang 4	0.53	1.15	0.39	0.49
Barokah	0.93	1.29	1.35	0.52
UJ 5	0.87	1.85	1.14	0.94
Mangu	0.64	1.60	1.49	0.90

Source: Testing laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University.

et al., 2015). Table 3 shows a little different N, P, and K nutrient content in the plant parts among the cassava varieties. Cassava yield and N accumulation were determined by genotypes (Kang et al., 2020).

Table 4 shows the highest amount of N and P in cassava plants (g plant^{-1}) were in leaves, and K was highest in tubers. The amount of nutrients in cassava plant parts depends on their biomass weight. The fresh weight of tubers biomass (g plant^{-1}) was higher than the weight of leaves biomass for all varieties (Table 1). The biomass weight of plant parts determined the number of nutrients transported at harvest from the cassava field. As a result, the amount of K nutrients transported ranged from 72 - 160 kg ha^{-1}, it was more than N nutrient (44 - 80 kg ha^{-1}) and P nutrients (8 - 12 kg ha^{-1}) for a yield of 40 ton ha^{-1} fresh tubers (Table 6). Howeler (2018) reported that 35.5 tons ha^{-1} of tubers removed 55 kg N, 13.2 kg P, and 112 kg K from the field.

Harvesting method (1) resulted in a negative nutrient balance (Fig. 1(1)) for N and K nutrients (with an average of -222 kg N ha^{-1} and -103 kg K ha^{-1}) and a positive nutrient balance for P (48 kg P ha^{-1}). Similarly, Sopheap *et al.* (2012) reported a negative nutrient balance for N and K nutrients (with an average of -64.45 kg N ha^{-1} and -52.83 kg K ha^{-1}) in the cassava field cultivated by small-scale farmers in Cambodia. Harvesting method (2) resulted in positive nutrient balances (Fig. 1(2)) for N, P, and K nutrients (with an average of 305 kg N ha^{-1}, 56 kg P ha^{-1}, and 82 kg K ha^{-1}).

The retention of crop residues in the field is a part of the sustainability of intensive agriculture (Nango et al., 2022) for improving soil fertility (Otieno et al., 2021). The biomass of 40% of stems and all the biomass of

Table 4. The amount of N, P, and K nutrients in the plant parts biomass of five cassava varieties.

Varieties	N (g plant^{-1})				
	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	14.80^{a}	33.00	5.53^{a}	13.77^{a}	67.13^{a}
Malang 4	13.37^{ab}	28.60	2.97^{b}	11.40^{a}	56.33^{ab}
Barokah	12.33^{abc}	22.97	1.77^{bc}	4.93^{b}	42.00^{b}
UJ 5	8.03^{bc}	26.70	2.53^{bc}	4.63^{b}	41.87^{b}
Mangu	7.10^{c}	22.30	1.43^{c}	11.80^{a}	42.60^{b}
Varieties	**P (g plant^{-1})**				
	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	1.83^{a}	1.97	0.51^{a}	2.20^{a}	6.53^{a}
Malang 4	1.23^{b}	1.87	0.27^{b}	1.73^{ab}	5.10^{ab}
Barokah	1.23^{b}	1.77	0.20^{b}	1.07^{bc}	4.13^{b}
UJ 5	1.17^{b}	1.70	0.30^{b}	0.80^{c}	3.90^{b}
Mangu	1.07^{b}	1.60	0.23^{b}	1.57^{abc}	4.40^{b}
Varieties	**K (g plant^{-1})**				
	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	14.47^{a}	11.17	4.20^{a}	17.73^{a}	47.57^{a}
Malang 4	7.30^{b}	7.10	1.10^{b}	12.07^{ab}	27.53^{b}
Barokah	14.37^{a}	8.87	3.00^{a}	7.80^{b}	34.03^{ab}
UJ 5	9.10^{b}	7.80	3.17^{a}	9.23^{b}	29.33^{b}
Mangu	6.73^{b}	8.60	1.37^{b}	19.60^{a}	36.33^{ab}

Means in the same column and the same variable followed by the same superscript letter are not significantly different by DMRT 5%.

Table 5. The amount of N, P, and K nutrients in the plant parts for producing one ton of cassava fresh tubers.

Varieties	N (kg ton^{-1} fresh tubers)				
	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	2.23^{a}	4.33^{b}	0.82^{a}	1.80^{a}	9,17^{b}
Malang 4	1.97^{ab}	4.97^{b}	0.44^{b}	2.00^{a}	9,34^{b}
Barokah	1.83^{abc}	5.00^{b}	0.26^{bc}	1.10^{b}	8.51^{b}
UJ 5	1.20^{bc}	11.97^{a}	0.37^{bc}	2.00^{a}	15.20^{a}
Mangu	1.07^{c}	4.10^{b}	0.21^{c}	2.00^{a}	6.25^{b}
	P (kg ton^{-1} fresh tubers)				
Varieties	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	0.27	0,27^{b}	0.07^{a}	0.30^{a}	0.90^{b}
Malang 4	0.17	0,33^{b}	0.04^{b}	0.30^{a}	0.84^{b}
Barokah	0.17	0,37^{b}	0.03^{b}	0.20^{b}	0.84^{b}
UJ 5	0.20	0,73^{a}	0.04^{b}	0.30^{a}	1.26^{a}
Mangu	0.17	0,30^{b}	0.03^{b}	0.30^{a}	0.59^{b}
	K (kg ton^{-1} fresh tubers)				
Varieties	Stem	Leaves	Petiole	Tubers	Total
UK 1 Agritan	2.13^{a}	1.47^{b}	0.62^{a}	2.30^{b}	6.55^{ab}
Malang 4	1.10^{b}	1.23^{b}	0.16^{b}	2.10^{b}	4.53^{b}
Barokah	2.13^{a}	1.93^{b}	0.44^{a}	1.80^{b}	6.63^{ab}
UJ 5	1.33^{b}	3.50^{a}	0.47^{a}	4.00^{a}	8.55^{a}
Mangu	1.00^{b}	1.60^{b}	0.20^{b}	3.40^{a}	4.59^{b}

Means in the same column and the same variable followed by the same superscript letter are not significantly different by DMRT 5%.

Table 6. The amount of N, P, and K transported through tubers at harvest of a 40-ton fresh tuber yield per hectare.

Varieties	Nutrients transported (kg ha^{-1})		
	N	P	K
UK 1 Agritan	72^{a}	12^{a}	92^{b}
Malang 4	80^{a}	12^{a}	84^{b}
Barokah	44^{b}	8^{b}	72^{b}
UJ 5	80^{a}	12^{a}	160^{a}
Mangu	80^{a}	12^{b}	136^{a}

Means in the same column followed by the same superscript letter are not significantly different by DMRT 5%.

Table 7. The amount of N, P, and K nutrients transported from the cassava field for a yield of 40 tons per hectare of two harvesting methods.

Varieties	Farmer's Harvest Method (FHM) (kg ha^{-1})			Harvest Method Introduced (HMI) (kg ha-1)			Nutrients not transported by HMI (kg ha-1)		
	N	P	K	N	P	K	N	P	K
UK 1 Agritan	367.2^{b}	36.0^{b}	262.0^{b}	124.6^{a}	18.1^{a}	144.0^{b}	242.6	17.9	118.0
Malang 4	373.2^{b}	33.6^{b}	181.2^{c}	125.3^{a}	16.3^{a}	108.3^{c}	247.9	17.3	72.9
Barokah	336.0^{b}	31.6^{b}	233.6^{b}	88.1^{b}	13.9^{b}	121.1^{c}	247.9	17.7	112.5
UJ-5	579.2^{a}	50.4^{a}	432.8^{a}	108.6^{b}	17.7^{a}	192.0^{a}	470.6	32.7	240.8
Mangu	298.4^{b}	30.0^{b}	257.6^{b}	106.8^{a}	14.2^{b}	159.6^{b}	191.6	15.8	98.0

Means in the same column and the same variable followed by the same superscript letter are not significantly. different by DMRT 5%.

petiole and leaves at harvest method (2) is left in the field as cassava plant residue. The cassava plant residue contained a high nutrient range of 191.6-470.6 kg N ha^{-1}, 15.8-32.7 kg P ha^{-1}, and 72.9-240.8 kg K ha^{-1} (Table 7). The left nutrients in the field changed from a negative nutrient balance of N and K (Fig.1(1)) in the FHM to be a positive nutrient balance of N, P, and K (Fig.1 (2)) in the HMI for all varieties. The residue of leaves biomass containing the highest nutrients (Table 2), 40% of stem biomass, and all petiole left in the field contributed to the N, P, and K balances that are surplus in the HMI. It indicates that the HMI can be applied to maintain soil fertility and sustainability high of cassava productivity.

The cassava varieties showed differences in the number of nutrients transported from the field through harvested tubers (Table 6) and other plant parts (Table 7) and nutrient balances of N, P, and K (Fig. 1(1) and Fig. 1(2)) for a yield of 40 tons ha^{-1}. Therefore, it is necessary to determine the right and efficient fertilizer dosage for each variety to maintain soil fertility and sustain high productivity in the cassava field.

Materials and methods

Field experiment

The experiment was conducted at the Jonggol Experimental Station, IPB University, from March to December 2021. It is located in Bogor Regency, West Java, Indonesia, at 6º18'0"– 6º47'10" South Latitude and 106º23'45"–107º13'30" East Longitude. Rainfall during the study ranged from humid to wet months, from 64 to 350 mm/month, and the relative humidity was above 80% (Figure 2). The climatic conditions are suitable for cassava. The soil type was Ultisol. The soil chemical properties were pH (4.39), total-N (0.24%), total P (9.07 ppm), K (0.35 cmol+ kg-1), and cation exchange capacity (26.23 cmol^{+} kg^{-1}) and soil organic carbon (1.52%). The pH and total N were categorized as low, total P was moderate, and K was high for cassava (Howeler 2018). The physical properties of the soil were a soil water content of 43.21%, a soil density of 1.12 g cm3, and a soil porosity of 57.66%.

The experiment used varieties as a single factor in a completely randomized design. Three varieties of bitter cassava (Malang 4, Barokah, UJ-5) and two varieties of non-bitter cassava (UK 1 Agritan and Mangu) with descriptions as shown in Table 8 were grown in three replications rows. Each row was 20 meters long. On the row were planted 20 cassava cuttings 1 m apart. The distance between rows was 1 meter, so the cassava spacing was 1 m x 1 m. The plant was fertilizers at a dose of 300 kg Urea (45% N), 200 kg SP36 (36%P2O5), 200 kg KCl (60% K2O), and 200 kg NPK (17-6-25) per hectare. The fertilizers contained 169 kg N, 84 kg P, and 170 kg K per hectare. The fertilizer was applied in grooves around the plant at a distance of 10-15 cm. Weeds, pests, and diseases were controlled as needed. Two harvesting methods are applied; namely the farmer's harvest method (FHM) and the harvest method introduced (HMI). In the FHM all tubers and other plant parts biomass are transported from the cassava field, and in the HMI all

Table 8. Description of the five varieties of cassava for the experiment.

Varieties	Superiority	Harvest age (months)	Plant height	Canopy diameter	Productivity (ton ha^{-1})	Tuber taste	Main uses
UK 1 Agritan[1)]	National	7 - 9	>2.5m	>1m	41.8	Non-bitter	Fresh tuber
Malang 4[1)]	National	9	>2.0m	>1m	39.7	Bitter	Tapioca
Barokah[2)]	Local	8 - 10	2 – 3 m	1.0 – 1.5 m	35 - 40	Bitter	Tapioca
UJ-5[1)]	National	9 - 10	>2.5m	>1m	25 – 38	Bitter	Tapioca
Mangu[2)]	Local	8 - 10	2 – 3m	0.75 – 1.0m	35 – 40	Non-bitter	Fresh tuber

[1)] ILETRI (2016); [2)] Author observation (2021).

tubers and 60% of stem biomass are transported from the cassava field.

Plant part biomass

One cassava plant was taken randomly as a sample plant from each replication at harvest 9 months after planting. The sample plants were separated into stems, leaves, petioles, and tubers and weighed to obtain the fresh weight of biomass (g $plant^{-1}$). Then, each of the plant parts biomass was dried in an oven at $60^{o}C$ for 48 hours and weighed to obtain the dry weight of the biomass.

NPK Analysis

The dry weight biomass of 86.7 g stems, 73.8 g leaves, 48.3 g petiole, and 115.9 g tubers were taken to analyze their N, P, and K content. The N content was determined by the Kjeldahl Titrimetry, P by the Visible Spectrophotometer, and K by the Atomic Absorbance Spectrometer method (Yee-Jin et al., 2017). This analysis resulted in the nutrient content of N, P, and K in each part of the plant (% w/w).

NPK nutrient in biomass

The amount of N, P, and K nutrients in plant parts biomass was calculated by multiplying the dry weight of stem, leaf, petiole, and tuber biomass by the nutrient content of those plant parts (Sopeaph et al., 2012). The dry weight of the plant part biomass was then converted to the wet weight of the biomass to obtain the amount of N, P, and K nutrients in the fresh biomass of each plant part. The amount of N, P, and K nutrients to produce one ton of tubers (kg ton^{-1}) is the sum of the amount of N, P, and K nutrients in fresh tuber biomass and the number of nutrients in fresh biomass of stem, petiole, and leaves.

NPK nutrient transported

The amount of N, P, and K nutrients transported at harvest was the number of nutrients in the fresh biomass of plant parts (stems, leaves, petioles, and tubers) transported from the cassava field to produce tubers by 40 tons per hectare. The nutrients transported were calculated for two harvesting

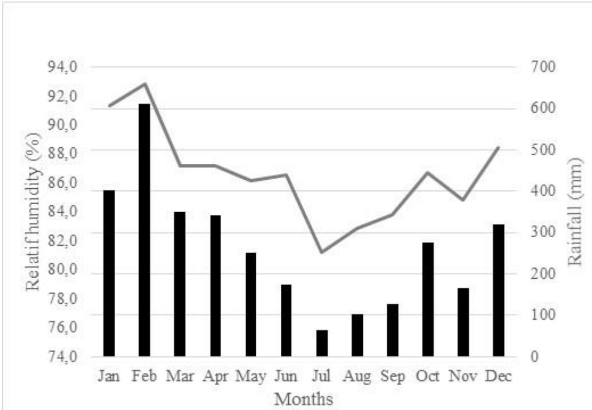


Fig 2. Rainfall and humidity during the study in 2021.

methods: (1) farmer's harvest method (FHM)-all plant parts biomass transported from the field, and (2) harvest method introduced (HMI)-all tuber biomass and 60% stem biomass transported from the cassava field.

NPK Nutrient balance

Nutrient balance was determined by the nutrient content and the biomass weight of each plant part (Sopheap et al., 2012). This value was then used to calculate the number of nutrients transported from the cassava field.

The N, P, and K nutrient balances were determined from the difference in the amount of N, P, and K nutrients in the applied fertilizer (169 kg N, 84 kg P, 170 kg K per hectare) and from plant biomass residues in the field, by the amount of the nutrients transported at harvest of 40 tons of fresh tubers per hectare. The formula used: Nu_bal = NuUpt_fert + Nu_res – Nu_trans; Nu_bal: nutrient balance (N, P, and K) in the soil of cassava field at harvest; NuUpt_fert: the nutrient (N, P, and K) uptake, namely 67.0%, 64.5%, and 52% of the applied fertilizer, respectively (Adiele et al.,2021); Nu_res: the number of nutrients (N, P, and K) in the biomass not transported from the field at harvest; Nu-trans: the number of nutrients (N, P, and K) in the biomass transported from at harvest. If the N, P, and K nutrients balance > 0 kg ha^{-1}, cassava cultivation could be sustainable for high productivity (40 tons ha^{-1} fresh tubers).

Data analysis

Analysis of variance (Larson, 2008) was used to determine the effect of varieties on the NPK nutrient content of each plant part and nutrients transported from the field. Duncan's Multiple Range Test (DMRT) was used to compare the differences in the variables mean of the varieties.

Conclusion

There were differences in growth, biomass production, the nutrient content of N, P, and K, and the amount of nutrients N, P, and K among varieties and plant parts of cassava. It resulted in a different amount of nutrients transported from the cassava field and the nutrient balance at harvest. For maintaining soil fertility and cassava productivity in Ultisol soils, the harvest method introduced (HMI)-that transported all tuber biomass as an economic yield and a maximum of 60% stem biomass from the cassava field, is recommended for all varieties, and the Barokah variety is the best.

Acknowledgments

Gratitude is expressed to the Rector and RISPRO Team of IPB University for facilitating this research at Jonggol Experimental Station and the Head of the Department of Agronomy and Horticulture for facilitating the laboratory for nutrient testing of cassava biomass.

Funding

Funding was provided by a grant from the LPDP, Ministry of Finance, Indonesia.

References

Adiele JG, Schut AGT, Ezui KS, Pypers P, Giller KE (2021) Dynamics of N-P-K demand and uptake in cassava. Agronomy for Sustainable Development. 41(1).

Adetoro NA, Oworu OO, Nassir AL, Bello A, Parkes E, Ogunbayo SA, Akinwale MG, Aina OO, Afolabi A, Iluebbey P, Sanni LO, Maziya-Dixon B, Dixon A, Kulakow P (2021) Evaluation of improved cassava genotypes for yield and related traits for a better breeding strategy under different agroecologies in Nigeria. Euphytica. 217:73-92.

Akongo GO, Godfrey A.O, Laban FT, Anton B, Alfred K, Obong S (2021) Effects of Improved Cassava Varieties on Farmers' Income in Northern Agro-ecological Zone, Uganda. Sustainable Agriculture Research. 10(2): 65–73. https://doi.org/10.5539/sar.v10n2p65

Cruz JL, Mosquim PR, Palacani CR, Araujo WL, DeMatta FM (2004) Effects of Nitrate Nutrition on Nitrogen Metabolism in Cassava. Biologia Plantarum. 48: 67-72.

de Oliveira EJ, dos Santos PEF, Pires AJV, Tolentino DC, da Silva SV (2016) Selection of cassava varieties for biomass and protein production in semiarid areas from bahia. Biosci J. 32(3):661-669.

ILETRI [Indonesian Legumes and Tuber Crops Research Institut] (2016) Description of Superior Varieties of Cassava 1978-2016. Available at: https://balitkabi.litbang.pertanian.go.id/wp-content/ uploads/2016 /09/ubikayu.pdf. Last accessed 22.04.2022.

Kang L, Liang Q, Jing Q, Yao Y, Dong M, He B, Gu M (2020) Screening of diverse cassava genotypes based on nitrogen uptake efficiency and yield. Journal of Integrative Agriculture. 19(4):665-974. https://doi.org/10.1016/S2095-3119(1)62746-2.

Ministry of Agriculture Republic of Indonesia (2018) Cassava Productivity by Province 2014 – 2017. Available at: https://www.pertanian.go.id/Data5tahun/TPATAP-2017(pdf)/37-ProdtvUbikayu.pdf. Last accessed 22.04.2022.

Fukuda WMG, Guevara CL, Kawuki R, Ferguson ME (2010) Selected morphological and agronomic descriptors for the characterization of cassava. International Institute of Tropical Agriculture (IITA).

Hamano H, Saito N, Tanaka Y, Kato S, Tahara K, Takahashi N, Yamada K, Kojima T (2011) Factors Affecting the Allocation of Nutrients in the Tree Organs of Eucalyptus camaldulensis in the Arid Lands of Western Australia. Journal of Chemical Engineering of Japan. 44(9): 653-661. https://doi.org/10.1252/jcej.10we237

Howeler (2018) Strategic Environmental Assessment: An Assessment of the Impact of Smallholder Cassava Production and Processing Practices on the Environment. Conference Paper. CIAT, Columbia. January, 18, 2018.

Larson MG (2008) Analysis of Variance. Circulation. 177(1):115-121.

Omondi JO, Lazarovitch N, Rachmilevitch S, Boahen S, Ntawuruhunga P, Sokolowski E, Yermiyahu U (2018) Nutrient use efficiency and harvest index of cassava decline as fertigation solution concentration increases. J Plant Nutr Soil Sci. 1–11. https://doi.org/10.1002/jpln.201700455.

Omondi JO, Lazarovitch N, Rachmilevitch S, Yermiyah U (2019) Phosphorus affects storage root yield of cassava through root numbers. Journal of Plant Nutrition. 42(17):2070-2079.

Otieno EO, Ngetich FK, Kiboi MN, Muriuki A, Adamtey NN (2021) Tillage system and integrated soil fertility inputs improve smallholder farmers' soil fertility and maize productivity in the Central Highlands of Kenya. Journal of Agriculture and Rural Development in the Tropics and Subtropics. 122(2):159-171.

Pereira GAM, Lemos VT, dos Santos JB, Ferreira EA, Silva DV, de Oliveira MC, de Menezes CWG (2012) Growth of cassava and weed in response to phosphate fertilizer. Rev Ceres Viçosa. 59(5):716-722.

Phosaengsri W, Banterng P, Vorasoot N, Jogloy S, Theerakulpisut P (2019) Leaf performances of cassava genotypes in different seasons and its relationship with biomass. Turk J Field Crops. 24(1):54-64.

Prasetyo BH, Suharta N, Subagyo H, Hikmatullah (2001) Chemical and mineralogical properties of ultisols of Sasamba area, East kalimantan. Indonesian Journal of Agricultural Science. 2(2): 37-47.

Sangakkara UR, Wijesinghe DB (2014) Nitrogen fertilizer affects growth, yield, and N recovery in cassava (*Manihot esculenta* L. Crantz). Communications in Soil Science and Plant Analysis. 45(11):1446-1452.

Sange N (2021) List of World's Largest cassava Producing Countries. Available at: https://www.nyongesasande.com/list-of-worlds-largest-cassava-producing-countries/. Last accessed 22.04.2022.

Sopheap U, Patanothai A, Aye TM (2012) Nutrient balances for cassava cultivation in Kampong Cham province in Northeast Cambodia. International Journal of Plant Production 6(1): 37-58.

Sok S, Malik I, Newby J, Fahrney K (2017) Effect of fertilizer on growth and yield of cassava (*Manihot esculenta* crantz). International Conference on Root and Tuber Crops for Food Sustainability. International Center for Tropical Agriculture (CIAT).

Suwarto, Asih R (2021) Growth of legume cover crops under cassava and its effect on soil properties. Legume Research. 4(9):1077-1081.

Umeh SI, Onyeonagu CC, Umeh B (2015). Potassium Nutrition and Translocation in Cassava (*Manihot esculenta* Crantz) Intercropped with Soybean. American Journal of Experimental Agriculture. 5(4):281-286.

Yuniwati ED, Utomo WH, Howeler RH (2015) Farmers' based technology development for sustainable cassava production system. International Journal of Agricultural Research. 10 (2):54-64.

Yee-Jin, L, Jwa-Kyung S, Seul-Bi L, Jung-Eun L, Yo-Sung S, Deog-Bae L, Suk-Young H (2017) Plant Analysis Methods for Evaluating Mineral Nutrient. Korean J Soil Sci Fert. 50(2):93-99.