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Cassava response to the integrated use of manure and NPK fertilizer in Zambia

Gizachew Kebede Biratu [a,b,c,*], **Eyasu Elias** [a], **Pheneas Ntawuruhunga** [b],
Gudeta W. Sileshi [d,e]

[a] *Center for Environmental Science, College of Natural and Computational Science, Addis Ababa University, PO Box 3131, Addis Ababa, Ethiopia*

[b] *International Institute of Tropical Agriculture (IITA), Plot 1458B Ngwerere Road, PO Box 310142, Chelston, Lusaka, Zambia*

[c] *College of Agriculture and Veterinary Science, Department of Natural Resource Management, Ambo University, PO Box 19, Ambo, Ethiopia*

[d] *Plot 1244 Ibex Hill, Lusaka, Zambia*

[e] *School of Agricultural, Earth and Environmental Sciences, University of Kwazulu-Natal, Pietermaritzburg, South Africa*

[*] Corresponding author.

E-mail address: gizachewk2006@yahoo.com (G.K. Biratu).

Abstract

Cassava is Africa's second most important food source in terms of calories consumed per capita. However, farmers use little or no fertilizer on cassava and scant information is available regarding the cassava yield response to mineral and organic fertilizer inputs in Zambia. This study was undertaken to determine the response of cassava to the integrated use of organic and inorganic nutrient sources in two contrasting agroecological zones of Zambia; Mansa located in Zone III and Kabangwe located in Zone II. The treatments consisted of a factorial combination of four NPK rates (unfertilized control, 50N-11P-41.5K, 100N-22P-83K, and 150N-33P-124.5K kg/ha) with four rates of chicken manure (0, 1.4, 2.8, and 4.2 t/ha). The treatments were laid out in a randomized complete block design with three replications. Cassava height, stem girth, canopy diameter, leaf area index, and chlorophyll index were monitored over time and roots were harvested at 12 months after planting (MAP). Growth parameters and

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yield varied significantly ($p < 0.01$) both with NPK, manure application, and their interaction effects at 12 MAP. The combined application of 4.2 t/ha of chicken manure and 100N-22P-83 K kg/ha of mineral fertilizer resulted in the highest yields of 35.2 t/ha at Kabangwe. But, the highest average yield of 34.4 t/ha was recorded with the application of 2.8 t/ha manure and 100N-22P-83 K kg/ha mineral fertilizer at Mansa. This increased treatment yield by 24 and 29% over the sole NPK fertilizer application at Mansa and Kabangwe sites, respectively. Harvest index (HI) was higher when 2.8 t/ha chicken manure was applied in combination with 50N-11P-41.5K kg/ha at Kabangwe. But, the highest HI at Mansa site was achieved with the combination of 2.8 t/ha manure and 100N-22P-83 K kg/ha. This combination also resulted in the highest agronomic efficiency of N, P and K at both sites. It is concluded that cassava productivity and nutrient use efficiency can be improved through the integrated use of NPK and manure in Zambia.

Keyword: Agriculture

1. Introduction

Cassava is Africa's second most important food source in terms of calories consumed per capita (Bennett, 2015; Roothaert and Magado, 2011). Sub-Saharan Africa (SSA) is also the largest producer of cassava in the world. For example, out of the 277 million tons of cassava produced globally in 2013, 57% (158 million tons) came from Africa (Bennett, 2015). However, cassava is mainly a subsistence crop grown for food by small-scale farmers, and all the cassava produced is consumed domestically. However, there is a growing realization that cassava is important for the future of Africa from several perspectives. It can play a greater role in tackling food insecurity and hunger in the face of climate uncertainty. It can also serve as a source of cash income, a driver of local agro-industry, and a means to reduce the cost of imports through substitution and/or biofuel production (Bennett, 2015). Changes in rural economies, particularly urbanization and new patterns of demand, offer new opportunities for the supply of cassava at a larger scale. The challenge now is to match productivity with market demand (Bennett, 2015).

Cassava is highly adaptable and grown in a wide range of agroecological settings: from Africa's arid Sahel to the cool highlands of Zambia (Delaquis et al., 2018). It is able to grow on poor soils and has the advantage of flexibility in time of harvest, making it the crop of 'last resort' (M.A. El-Sharkawy, 2014). It is also said to be highly resilient in the face of current climatic changes (Jarvis et al., 2012). Cassava crops are often maintained by resource-poor farmers who operate on marginal lands, at the fringes of sensitive biodiverse habitats (Delaquis et al., 2018).

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Its ability to produce fair yields where other crops fail has led many to believe that soil fertility is not important in cassava production. However, research results show that this is a misconception (Fening et al., 2009). When improved varieties were grown without fertilizer, low soil fertility has been shown to be a principal constraint to cassava yields. One way of countering the soil fertility constraint is the use of commercially available fertilizers (Mugwe et al., 2009). However, due to high costs, non-availability at the right time, and poor yield response in dry periods exacerbated by technical and institutional issues, the use of chemical fertilizer by smallholders is negligible or non-existent. For this reason the use of fertilizer alone does not seem to be an attractive option to restore soil fertility for most farmers in SSA (Druilhe and Barreiro-Hurlé, 2012). On the other hand, even though organic inputs are able to increase crop productivity and maintain soil fertility, the limited supply cannot satisfy crop demand and their application requires much effort in terms of labor and time inputs (Pypers et al., 2012). Therefore, integrated soil fertility management (ISFM), combining the use of locally available organic inputs with judicious amounts of chemical fertilizer is the best-bet option for sustainable intensification of smallholder agriculture (Fairhurst, 2012; Sanginga and Woomer, 2009; Vanlauwe et al., 2010). ISFM is a flexible option based on principles, and is site-specific according to crop, farm conditions, landscape position, and seasons (Vanlauwe et al., 2010).

In Zambia, cassava is one of the main food security crops and the second staple food next to maize (Biratu et al., 2018; Ntawuruhunga et al., 2013). Cassava provides 14% of the caloric intake after maize, which supplies 50% of calories. Cassava has received more attention in recent years in Zambia partly because maize is susceptible to drought, and poor harvests caused food shortages in the country (Barratt et al., 2006). Cassava production is mostly done by smallholder farmers without the use of external inputs as they consider that cassava is well-adapted to infertile soils (Pypers et al., 2012). As a result, there is a huge yield gap between actual productivity on farmers' fields and the potential productivity of cassava crops (Ezui et al., 2016). Farm yields throughout Africa average 10 t/ha, which is below potential yields (15−20 t/ha) obtained from on-farm trials in the country (Ntawuruhunga et al., 2013). Pypers et al. (2012) demonstrated that strategic use of ISFM can bridge this yield gap. However, the potential of ISFM in increasing cassava yields has not been systematically studied in Zambia. Therefore, the objective of this study was to evaluate the effect of sole and integrated use of chicken manure and NPK fertilizer on cassava yield in two agroecological zones of Zambia as a key component of ISFM. Chicken manure was chosen as an amendment because it is readily available to smallholder households and has higher N and P content than cattle manure (Sileshi et al., 2017). The main hypothesis being tested is that the integrated use of manure and NPK fertilizer will achieve higher nutrient use efficiency and cassava yields than sole application.

2. Materials and methods

2.1. Description of the study sites

The experiment was conducted in the 2015/2016 growing season at two sites; Mansa research station of the Zambia Agricultural Research Institute (ZARI), in Mansa District, Luapula Province, and the Kabangwe research station of the International Institute of Tropical Agriculture (IITA) located in Chibombo District, Central Province of Zambia. The site in Mansa is located at 28°56′33.4″E and 11°14′30.2″S, while the site in Chibombo is located at 28°18′26.9″E and 15°18′11.6″S. Mansa is located in agroecological zone (AEZ) III, which receives more than 1000 mm of rainfall per annum (Aregheore, 2009), while Kabangwe is located in AEZ II, an area that receives between 800 and 1000 mm rainfall annually. However, during the 2015/2016 cropping season, there was an El Niño event in Zambia that resulted in very low rainfall (422.6 mm) at Kabangwe while Mansa recorded 1245.6 mm between 23/11/2015 and 22/11/2016 (Fig. 1). According to the Köppen climate classification, Zambia is dominated by a humid subtropical climate (Zifan, 2016). As such, both sites experience a humid to sub-humid climate with growing periods varying from 100 to 140 days in AEZ II to 120−150 days in AEZ III (Saasa, 2003). Depending on the onset of the unimodal rainfall, cassava planting dates start either in late November or early December.

The soils at Kabangwe are classified as Acrisols, while those at Mansa are Ferralsols according to the World Reference Base (WRB) (ZEMA, 2013). Acrisols are strongly weathered acid soils with low base saturation at some depth. On the other hand, Ferralsols represent the classical, deeply weathered, red or yellow soils of the humid tropics.

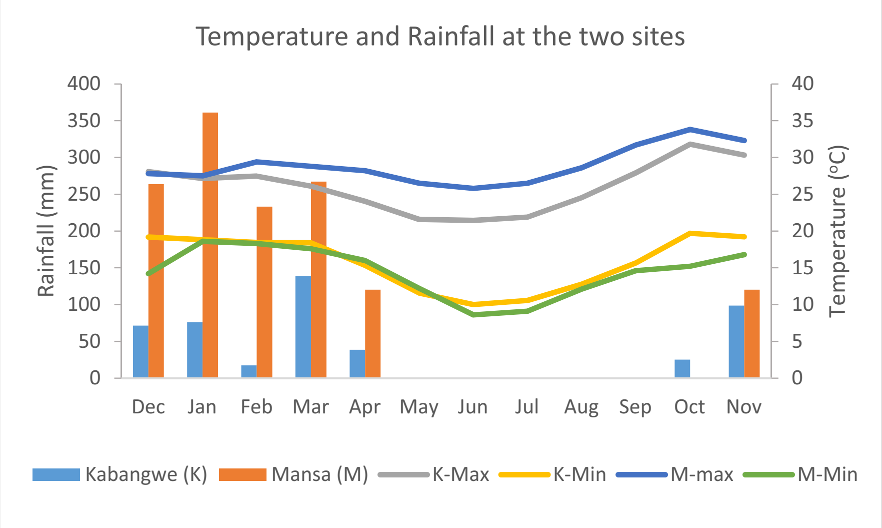

Fig. 1. Mean monthly maximum and minimum temperature with total monthly rainfall during the study period for the two sites. Bar graphs show the total monthly rainfall and the line graphs shows the mean maximum and minimum temperature.

They have great soil depth, good permeability, and stable microstructure. They are also well drained but they usually experience low available water storage capacity. Ferralsols also have poor fertility, low base cations, and experience strong P fixation.

2.2. Experimental design

Four levels of chicken manure (0, 1.4, 2.8, 4.2 t/ha) and four levels of mineral fertilizer rate (0, 50N-11P-41.5K, 100N-22P-83K, 150N-33P-124.5K kg/ha) were arranged in a factorial combination, giving a total of 16 treatments set in a Randomized Complete Block Design (RCBD) with three replications. These factorial combinations resulted in two groups of treatments: (1) substitutive combination where the total nutrient (e.g., N, P, or K) applied from manure + NPK fertilizer was equal to 100N-22P-83 K kg/ha recommended by Howeler et al. (2013) after reviewing many fertilizer research with cassava. For example, 1.4 t/ha manure + 50N-11P-41.5K could give approximately the recommended N, P, and K. (2) Additive combination where the total nutrient (e.g., N) applied from manure + NPK fertilizer might exceed the recommended nutrient. For example, 4.2 t/ha manure + 150N-33P-124.5K could give over 300 kg/ha N and 50 kg/ha P. This recommended mineral fertilizer rate (100N-22P-83 K kg/ha) has been also tried by Fermont et al. (2010) in East Africa. The other two levels were 50% above and 50% below this recommended rate. While setting these rates, care was also given for the additive effect of the combined application of manure and NPK fertilizer that can result in environmental problems. Even the higher level combinations were not that far from the recommend rate for cassava. The rates of 200−300 kg/ha N may be needed when cassava is grown for multiple harvests of forage (Lebot, 2009), but this is too high when cassava is grown for roots, and 200−400 kg/ha P_2O_5 may be needed in some highly P-fixing soils in the first year. It is also way too high in subsequent years as cassava removes only about 11−12 kg/ha P in roots and 20−25 kg/ha P in the whole plant with a fresh root harvest of 30 t/ha. Even with annual applications of 22 kg P/ha, P tend to accumulate in the soil after several years of cassava production (Howeler, 2014). The manure rates were calculated based on the N equivalent of the recommended fertilizer level. Chicken manure (pure feces of chicken with no mixture of bedding material and feed) was freshly collected from caged, commercial layer farms, then properly dried and mixed to reach a homogenized mixture before application. After being properly mixed, a manure sample was also collected to determine its nutrient content for NPK and micronutrients. The nutrient content of the manure has been summarized in Table 1.

Plot size was 5 m × 5 m giving a total plant population of 25 plants per plot. Land preparation was done by ploughing using disc plows mounted on a tractor, and then harrowed. Mature, improved cassava variety "*Mweru*" cuttings of 25−30 cm in length were obtained from the Zambia Agricultural Research Institute (ZARI)

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Table 1. Selected physicochemical properties of topsoil (0−20 cm depth) of the two experimental sites and manure.

Parameters	**Soil analyses**		**Manure analyses**[c]	**Low level requirement**[b]
	Mansa	**Kabangwe**		
pH (water)	4.9	5.28	7.48	3.5−4.5 (in H_20 1:1)
Organic matter (%)	1.8	2.0	44.7	1−2
Organic C (%)	1.07	1.19	26	
Total nitrogen (%)	0.048	0.061	3.6	
C/N	22.34	19.39	7.2	
Available P (mg/kg)	20.51	3.78	1.32[a]	2−4
Exchangeable acidity (c mol (+)/kg)	0.26	0.14	−	
CEC (cmol (+)/kg)	2.97	4.56	22.01	
Exchangeable bases (c mol (+)/kg)				
Ca	1.22	2.57	8.6[a]	0.25−1
Mg	0.29	1.2	0.62[a]	0.2−0.4
K	0.12	0.09	1.99[a]	0.1−0.15
Na	0.044	0.045	7.75	
Total exchangeable bases	1.674	3.905		
Micronutrients (mg/kg)				
Zn	0.74	0.41	142.8	0.5−1
Cu	6.18	1.31	10.39	0.1−0.3
Mn	57	107	182	5−10
Fe	78	59	95	1−10
Particle size (%)				
Sand	77.53	53.67		
Silt	6.64	20.57		
Clay	15.83	25.76		
Textural class	Sandy loam	Sandy clay loam		

[a] Results are expressed in percent (%).

[b] Low level cassava requirement as stated in (Howeler, 2014).

[c] The nutrient contents of manure are total nutrient contents, not necessarily available.

research station at Mansa. These were planted at 1 m × 1 m standard inter- and intrarow spacing vertically. "*Mweru*" was selected because it is disease resistant, highly adaptable, and establishes well even when rainfall is erratic.

The NPK fertilizers were band applied next to each plant in the form of urea, triple superphosphate, and potassium sulfate, respectively. Chicken manure was applied and properly incorporated into the soil during planting; while the N and K were divided into two equal parts and applied at one and three MAP, respectively. However, P was applied all at once at 1 MAP. The trials were kept weed free by hand weeding whenever necessary.

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2.3. Soil sampling and analytical procedures

To determine the nutrient content of the soil before planting, composite soil samples were collected (0–20 cm depth) using the Edelman auger crisscrossing experimental sites. One composite sample was collected for each of the experimental sites. Samples were air-dried and ground to pass through a 2-mm sieve to get the fine earth fraction (<2 mm separates). Soil samples were sent to the IITA soil laboratory in Cameroon and the results are presented in (Table 1). Particle size distribution (sand, silt, and clay separates) were determined by the hydrometer method as outlined by Bouyoucos (1951) and Day (1953). Soil pH was determined in a 1:2.5 (w/v) soil: water solution using a pH meter as outlined by McLean (1982). Organic carbon (OC) was determined by chromic acid digestion and spectrophotometric analysis as described by Heanes (1984). Total N was determined from a wet acid digestion (Buondonno et al., 1995) and analyzed by colorimetric analysis (Anderson and Ingram, 1993). Exchangeable cations (Ca, Mg, K and Na), available micronutrients (Cu, Zn, Mn, Fe), and available phosphorus (AvP) were extracted using the Mehlich-3 procedure (Mehlich, 1984). The contents in the extracts were determined by flame photometry and atomic absorption spectrophotometry (AAS). Exchangeable acidity was extracted with 1M KCl and quantified by titration. CEC was extracted using the ammonium acetate method in which the content was determined colorimetrically.

The physical and chemical properties of the soils in the study areas have been summarized in Table 1. The soil texture at Mansa is sandy, while at Kabangwe it is sandy loam. The soil reaction at both sites was slightly acidic. A pH below 5.6 may limit the growth of some crops, but not cassava. For optimum growth of cassava soil pH should be in the range of 4.5–7.0. Therefore, the soil pH level was within the critical level for cassava at both sites. Soil organic matter and total nitrogen were very low at both sites. The available P value was below the critical level of 11 mg/kg at Kabangwe, but at Mansa P levels were adequate. Potassium status of both sites was near critical values.

2.4. Agronomic data collected

Plant height was measured from the base of the first branch to the newly emerging leaf of the tallest plant using a tape measure. Canopy diameter was measured twice (perpendicular and parallel to the ridge) for each plant using the tape measure and the average record was considered. Stem girth was measured on the biggest stem using a digital Vernier caliper.

Leaf Area Index (LAI) was indirectly measured under the canopy using the SunScan Canopy Analysis System (Delta-T device, Cambridge, UK). Four readings of leaf chlorophyll (two from either side of the midrib) were measured from the central

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lobe of the first fully expanded leaf using a chlorophyll meter (SPAD 502, Konica Minolta, Tokyo, Japan) under the shadow of the reader. For all the plant growth parameters, plot readings were taken from five plants following an ‘X’ pattern in the plot and an average of the five readings was considered as a plot reading. Readings were taken every two months and finally averaged over time.

Harvesting was done at 12 MAP from the nine plants in the 3 m × 3 m net plots. After uprooting, the plant parts were separated into root, leaf, and stem; the fresh weight was recorded right in the field with a digital balance. After weighing, 500 g samples of the roots and stems; and 300 g of leaves were collected for determination of the dry weight. The samples were oven dried at 70 °C until the weight became constant (Hauser et al., Unpublished). Finally dry matter content was calculated as the ratio of sample dry weight to sample fresh weight (Sánchez et al., 2006).

Next, the HI was computed on a dry weight basis. Root to shoot allocation in plants is influenced by stress factors, and plants growing under water or nutrient stress are known to show higher root to shoot ratios. Shifting growth patterns allow plants to compensate for resource limitations by increasing allocation to organs or functions most closely related to acquisition of the limiting resource (Mooney and Winner, 1991).

To determine the variation in nutrient use efficiency, the agronomic efficiency of N (AE-N), P (AE-P) and K (AE-K) fertilizer was calculated. In ISFM, the primary objective is to improve the agronomic efficiency of the applied nutrient inputs (Vanlauwe et al., 2011). The AE is an integrated index of two nutrient efficiency indices; recovery efficiency and physiological efficiency (Ladha et al., 2005). For example AE-N is the bases for both economic and environmental efficiencies (Montemurro and Diacono, 2016). Therefore, we calculated AE-N, AE-P, and AE-K using the equation below as in Ladha et al. (2005).

$$AE\left(kg\,kg^{-1}\right) = \frac{RY_f - RY_u}{N_a} \tag{1}$$

where RY_f is the dry root yield from a fertilized or manured plot, RY_u is the dry root yield from an unfertilized plot, and N_a is the amount of nutrient (N, P or K) applied both in the form of chicken manure and NPK fertilizer.

2.5. Data analysis

The agronomic data were subjected to statistical analysis of variance (ANOVA) using the linear model (*lm*) of R statistical software of version 3.4.2 (R Core Team, 2016). The total variability was then detected using the following model for the two sites separately:

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$$T_{ijkl} = \mu + R_i + O_j + M_k + (OM)_{jk} + \varepsilon_{ijk} \tag{2}$$

where: - T_{ijk} is the total variation for a given yield component, μ is the overall mean, R_i is the i^{th} replication, O_j is the j^{th} manure treatment effect, M_k is k^{th} NPK fertilizer treatment effect, $(OM)_{jk}$ is the interaction between manure and fertilizer, and ε_{ijk} is the variation due to random error.

The significance of the treatments was tested using the *agricolae* package of R (de Mendiburu, 2016) and the means were compared using the *lsmean* package of R (Lenth, 2016) with Tukey's honest significant difference (HSD) at a 5% level of significance.

3. Results

3.1. Variation in cassava growth with treatments

Cassava plant height, canopy diameter, stem girth, LAI, and chlorophyll index significantly ($P < 0.05$) varied with mineral fertilizer (NPK) and manure application at both Mansa and Kabangwe sites. The combined applications of manure and NPK also had a significant effect on most variables except stem girth. All plant growth variables were lower in the control plots and increased with increasing rates of application of NPK and manure for both sites (Table 2). However, canopy diameter and LAI did not significantly differ with the different levels of mineral fertilizers at the Mansa site. Compared to manure application, mineral fertilizer application resulted in higher mean cassava height (163.9 cm), stem girth (23.2 mm), LAI (2.5), and chlorophyll index (44.9) with 150N-33P-124.5K application at the Mansa site (Table 2). Similarly, height (153.8 cm), canopy diameter (119.3 cm), stem girth (24.2 mm), LAI (2.7), and chlorophyll index (44.2) were highest for the highest level of mineral fertilizer at the Kabangwe site. Combining manure with NPK fertilizer further improved cassava growth variables. Plant height of 183.0 cm and LAI of 2.7 were recorded when 1.4 t/ha manure was applied with 150N-33P-124.5K at Mansa. This combination resulted in an even higher mean LAI (3.0) at Kabangwe, but the highest mean plant height of 168.7 cm was recorded from 2.8 t/ha manure combined with 150N-33P-124.5K.

3.2. Variation in cassava root yield with treatments

Fresh root yields significantly differed ($p < 0.05$) with the rate of chicken manure, NPK fertilizer, and their combination at both sites. Root yield was lower in the control plot under both manure and mineral fertilizer application for both sites. However, no significant difference was observed between the two lower levels and the two higher levels of manure and fertilizer application at Mansa site. At Kabangwe, the increase in manure application rate significantly increased cassava fresh root yield.

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Table 2. Variation of cassava growth in height, canopy diameter, stem girth, leaf area index (LAI), and chlorophyll index at 12 MAP ($\alpha = 0.05$) with application of organic and inorganic fertilizer at Mansa and Kabangwe sites.

Treatments	Mansa					Kabangwe				
	Height (cm)	Canopy (cm)	Girth (mm)	LAI	Chlorophyll Index	Height (cm)	Canopy (cm)	Girth (mm)	LAI	Chlorophyll Index
Manure (t/ha)										
0	133.3 b	102.0 b	19.8 b	2.0 b	44.0 a	120.4 b	101.0 b	20.3 b	2.1 b	43.0 b
1.4 (O1)	144.8 ab	108.1 ab	20.9 ab	2.2 ab	42.8 b	145.9 a	116.0 a	23.2 a	2.5 a	43.2 ab
2.8 (O2)	148.6 ab	110.6 ab	21.8 ab	2.3 ab	44.2 a	156.3 a	116.8 a	24.4 a	2.6 a	43.6 ab
4.2 (O3)	157.4 a	116.9 a	22.8 a	2.4 a	43.9 a	144.3 a	111.3 a	23.5 a	2.6 a	44.1 a
P value	0.044	0.004	0.031	0.05	<0.001	<0.001	<0.001	<.001	<0.001	0.017
Sig.	*	**	*	*	***	***	***	***	***	*
Fertilizer (kg/ha)										
0	135.2 b	107.1 a	20.3 b	2.1 a	43.2 b	127.2 b	104.9 b	21.1 b	2.3 b	42.4 b
50N + 11P + 41.5K (F1)	139.6 b	108.6 a	21.1 ab	2.3 a	43.3 b	143.2 a	111.4 ab	23.0 a	2.4 b	43.4 ab
100N + 22P + 83K (F2)	145.4 ab	108.0 a	20.8 ab	2.1 a	43.5 b	142.6 a	109.6 b	23.1 a	2.5 b	43.9 a
150N + 33P + 124.5K(F3)	163.9 a	113.7 a	23.2 a	2.5 a	44.9 a	153.8 a	119.3 a	24.2 a	2.7 a	44.2 a
P value	0.007	0.321	0.030	0.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sig.	**	ns	*	ns	***	***	***	***	***	***

(*continued on next page*)

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Table 2. (*Continued*)

Treatments	**Mansa**					**Kabangwe**				
	Height (cm)	**Canopy (cm)**	**Girth (mm)**	**LAI**	**Chlorophyll Index**	**Height (cm)**	**Canopy (cm)**	**Girth (mm)**	**LAI**	**Chlorophyll Index**
Interaction										
O1 + F1	146.0 ab	110.0 ab	21.9 ab	2.3 ab	42.4 d	156.4 a	119.6 a	24.9 a	2.7 abc	42.7 b
O1 + F2	122.2 b	96.4 ab	18.0 ab	1.9 ab	42.2 d	136.6 a	109.6 a	22.0 a	2.4 c	43.6 a
O1 + F3	183.0 a	122.2 a	24.0 ab	2.7 a	44.1 abcd	163.1 a	129.0 a	24.4 a	3.0 a	44.5 a
O2 + F1	156.7 ab	116.0 ab	22.6 ab	2.4 ab	44.1 abcd	157.8 a	117.9 a	25.4 a	2.6 abc	43.4 a
O2 + F2	140.6 ab	106.2 ab	20.9 ab	2.0 ab	43.4 bcd	161.6 a	114.8 a	24.7 a	2.5 abc	43.5 a
O2 + F3	153.0 ab	106.9 ab	22.1 ab	2.4 ab	45.1 ab	168.7 a	126.1 a	25.2 a	2.9 ab	43.8 a
O3 + F1	139.0 ab	109.9 ab	21.3 ab	2.2 ab	43.5 bcd	140.9 a	107.8 a	22.3 a	2.4 bc	44.4 a
O3 + F2	169.4 ab	120.7 a	22.6 ab	2.4 ab	43.6 bcd	143.9 a	110.3 a	23.8 a	2.8 abc	44.3 a
O3 + F3	162.1 ab	114.5 ab	24.6 a	2.3 ab	44.1 abcd	147.2 a	116.3 a	25.2 a	2.5 bc	44.2 a
P value	0.044	0.015	0.238	0.033	0.00	0.099	0.356	0.108	<0.001	0.016
Sig.	*	*	ns	*	**	ns	ns	ns	***	*

Means followed by the same letters in a column are not significantly different from each other according to Tukey's HSD. O = Organic input (chicken manure), F = mineral fertilizer. <0.05 (*), <0.01 (**), <0.001 (***).

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Table 3. Variation of cassava fresh biomass yield (t/ha), dry biomass yield, and HI at 12 MAP ($\alpha = 0.05$) with application of organic and inorganic fertilizer at Mansa and Kabangwe.

Treatments	Mansa							Kabangwe						
	Fresh root	Fresh stem	Fresh leaf	Dry root	Dry stem	Dry leaf	HI	Fresh root	Fresh stem	Fresh leaf	Dry root	Dry stem	Dry leaf	HI
Manure (t/ha)														
0	19.8 b	14.0 b	3.4 b	6.7 b	4.4 b	0.9 b	0.60 ab	20.4 d	14.9 d	4.1 c	7.0 c	3.7 d	1.0 c	0.62 a
1.4 (O1)	22.1 b	16.4 b	3.9 b	7.4 b	4.9 b	1.0 b	0.62 a	22.9 c	18.1 c	4.8 b	7.8 c	4.8 c	1.2 b	0.58 a
2.8 (O2)	27.1 a	24.2 a	5.1 a	9.0 a	7.1 a	1.2 a	0.62 a	27.0 b	22.4 b	5.5 a	9.3 b	5.8 b	1.4 a	0.64 a
4.2 (O3)	28.5 a	25.7 a	5.4 a	9.6 a	7.4 a	1.3 a	0.57 b	30.2 a	24.6 a	5.5 a	10.6 a	6.4 a	1.4 a	0.63 a
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.591
Sig.	***	***	***	***	***	***	*	***	***	***	***	***	***	ns
Fertilizer (kg/ha)														
0	21.3 a	15.4 b	3.7 b	7.2 b	4.7 b	0.9 b	0.62 a	21.5 c	15.8 c	4.3 c	7.4 c	4.1 c	1.1 c	0.53 b
50N + 11P + 41.5K (F1)	21.3 a	17.1 b	3.9 b	7.2 b	5.3 b	1.0 b	0.62 a	23.9 b	18.6 b	4.8 cb	8.4 b	4.8 b	1.2 cb	0.62 ab
100N + 22P + 83K (F2)	27.2 b	23.1 a	5.0 a	9.0 a	6.8 a	1.2 a	0.57 b	27.8 a	23.2 a	5.6 ba	9.6 a	5.9 a	1.4 a	0.66 a
150N + 33P + 124.5K(F3)	27.8 b	24.8 a	5.1 a	9.3 a	7.0 a	1.3 a	0.60 ab	27.3 a	22.5 a	5.2 a	9.4 a	5.8 a	1.3 ba	0.64 a
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.049	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.05
Sig.	***	***	***	***	***	***	*	***	***	***	***	***	***	*
Interaction														
O1 + F1	20.2 c	16.5 c	3.8 c	6.4 bc	5.1 c	1.0 c	0.65 ab	22.6 d	16.9 e	4.4 c	7.5 d	4.6 e	1.1 b	0.59 bcde
O1 + F2	21.1 bc	14.5 c	3.6 c	7.0 abc	4.6 c	0.9 c	0.61 abc	22.7 d	17.7 de	5.4 abc	8.1 cd	4.8 de	1.3 ab	0.57 cde

(*continued on next page*)

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Table 3. (*Continued*)

Treatments	Mansa							Kabangwe						
	Fresh root	**Fresh stem**	**Fresh leaf**	**Dry root**	**Dry stem**	**Dry leaf**	**HI**	**Fresh root**	**Fresh stem**	**Fresh leaf**	**Dry root**	**Dry stem**	**Dry leaf**	**HI**
O1 + F3	27.1 abc	21.7 bc	4.6 bc	9.2 ab	6.0 bc	1.2 abc	0.62 abc	26.3 bcd	22.6 bcd	5.2 abc	8.9 bcd	5.8 bcde	1.3 ab	0.61 abcde
O2 + F1	22.5 bc	17.3 c	4.0 c	8.0 abc	5.4 c	1.0 c	0.66 a	25.1 bcd	20.5 cde	5.2 abc	8.8 bcd	5.0 cde	1.4 ab	0.49 e
O2 + F2	34.4 a	34.0 a	6.6 a	10.4a	9.4 a	1.5 a	0.59 abc	31.2 ab	28.0 ab	6.2 ab	11.0 ab	7.1 ab	1.6 a	0.80 a
O2 + F3	29.1 abc	29.0 ab	5.9 ab	9.7 ab	8.2 ab	1.5 ab	0.58 bc	29.0 abcd	24.2 bc	5.7 abc	9.9 abcd	6.4 abc	1.4 ab	0.76 abc
O3 + F1	27.7 abc	23.1 bc	4.9 abc	9.3 ab	6.9 bc	1.2 abc	0.57 cd	28.3 bcd	23.1 bcd	5.6 abc	10.1 abcd	6.2 bcde	1.4 ab	0.77 ab
O3 + F2	30.1 ab	29.2 ab	6.2 ab	10.3 a	8.3 ab	1.4 ab	0.50 d	35.2 a	30.9 a	6.5 a	12.1 a	7.8 a	1.7 a	0.72 abcd
O3 + F3	29.6 abc	27.8 ab	5.3 abc	9.7 ab	7.9 ab	1.3 abc	0.60 abc	29.5 abc	23.5 bc	4.9 bc	10.6 abc	6.4 abcd	1.3 ab	0.55 de
P value	0.044	<0.001	0.006	0.005	0.004	0.011	0.041	0.019	<0.001	0.031	0.002	0.006	0.045	0.022
Sig.	*	***	**	**	**	*	*	*	***	*	**	**	*	*

Means followed by the same letters in a column are not significantly different from each other according to Tukey's HSD. O = Organic input (chicken manure), F = mineral fertilizer. <0.05 (*), <0.01 (**), <0.001 (***).

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Table 4. Variations in the agronomic efficiencies of nitrogen (AE-N) phosphorous (AE-P) and potassium (AE-K) with treatments at Mansa and Kabangwe sites.

	AE-N		**AE-P**		**AE-K**	
	Mansa	**Kabangwe**	**Mansa**	**Kabangwe**	**Mansa**	**Kabangwe**
Manure (t/ha)						
1.4 (O1)	15.0	18.8	55.4	68.5	63.9 b	81.2 a
2.8 (O2)	21.2	22.8	71.2	76.5	94.0 a	97.3 a
4.2 (O3)	19.1	22.6	60.9	72.3	80.4 ab	97.1 a
P value	0.157 ns	0.300 ns	0.343 ns	0.706 ns	0.026*	0.221 ns
Fertilizer (kg/ha)						
50 N + 11 P + 41.5 K	17.3	22.5	54.5	71.3	78.2 a	103.3 a
100 N + 22 P + 83 K	19.9	24.2	67.6	82.5	87.4 a	100.4 a
150 N + 33 P + 124.5 K	18.0	17.5	65.4	63.5	72.6 a	72.1 b
P value	0.695 ns	0.075 ns	0.435 ns	0.164 ns	0.350 ns	0.013*
Interaction						
O1 + F1	12.3	21.3	41.7	72.3	66.3 b	104.9 ab
O1 + F2	12.2	17.8	45.1	65.8	46.8 b	66.5 c
O1 + F3	20.4	17.4	79.4	67.4	75.5 ab	72.2 bc
O2 + F1	18.9	22.6	59.1	70.8	71.5 b	101.0 abc
O2 + F2	26.3	28.0	89.2	94.8	135.6 a	119.0 a
O2 + F3	18.3	17.9	65.3	64.0	74.8. ab	75.9 bc
O3 + F1	20.9	23.6	62.8	71.0	96.8 ab	104.1 ab
O3 + F2	21.2	27.0	68.5	87.0	76.8 ab	115.5 a
O3 + F3	15.2	17.4	51.6	59.0	67.6 b	68.3 bc
P value	0.200 ns	0.577 ns	0.174 ns	0.591 ns	0.007**	0.014*

O = Organic input (chicken manure), F = mineral fertilizer (kg/ha). <0.05 (*), <0.01 (**).

But no significant difference was noted between the two higher rates of NPK application (Table 3). The highest mean root yield (28.5 t/ha) was achieved with 4.2 t/ha manure followed by 27.8 t/ha achieved with 150N-33P-124.5K kg/ha at Mansa. This gave 44 and 30% yield advantage over the control, respectively. The highest mean root yield at Kabangwe (30.2 t/ha) was achieved with 4.2 t/ha manure followed by 27.3 t/ha achieved with 150N-33P-124.5K kg/ha. This constitutes 48 and 27% yield advantages over the control, respectively. The highest cassava root yield from the combined application was 34.4 t/ha from 2.8 t/ha manure applied together with 100N-22P-83K kg/ha followed by 30.1 t/ha from 4.2 t/ha manure applied with 100N-22P-83K kg/ha at Mansa. Similarly, at Kabangwe the highest root yield was 35.2 t/ha from the 4.2 t/ha manure combined with 100N-22P-83K kg/ha followed by 31.2 t/ha from 2.8 t/ha manure with 100N-22P-83K kg/ha. The highest yield from the combined application gave 67 and 68% yield advantage over the control plot at Mansa and Kabangwe sites, respectively. The number of storage roots also varied with the application of both mineral and organic fertilizer, and their combined application. Manure application significantly affected storage root number per plant at both sites. But neither the mineral fertilizer, nor the combined application showed significant variation in the number of storage roots per plant. However, at Mansa the highest number (15.3) was recorded from the combined application of manure and mineral fertilizer.

The HI significantly varied with manure rate, NPK fertilizer, and their combined application at both sites, with the only exception of that under manure application at Kabangwe site. The HI varied from 0.50 to 0.66 at Mansa, while it varied from 0.49 to 0.80 at the Kabangwe site (Table 3). At Mansa, the lowest HI (0.57) for manure treatment was achieved with 4.2 t/ha manure and with 100N-22P-83K kg/ha for fertilizer at Mansa site. However, at Kabangwe, the lowest HI for manure treatments was recorded with a 1.4 t/ha manure level and the control plots for the NPK fertilizer treatments. At Mansa, the highest HI (0.66) was achieved with 2.8 t/ha manure combined with 50N-11P-41.5K kg/ha treatments. But the lowest HI was achieved with 4.2 t/ha manure combined with 100N-22P-83K kg/ha fertilizer. At Kabangwe, the highest HI (0.8) was achieved with 2.8 t/ha manure combined with 100N-22P-83K kg/ha, while the lowest (0.49) was achieved with 2.8 t/ha manure combined with 50N-11P-42.5K kg/ha fertilizer (Table 3).

3.3. Agronomic efficiency of N, P, and K

There was a clear variation between the different levels of manure, mineral fertilizer, and their combined application in relation to N, P, and K agronomic efficiencies (Table 4).

3.4. Agronomic efficiency of nitrogen

Application of mineral fertilizer at the rate of 100N-22P-83K kg/ha resulted in the highest mean AE-N at both sites. But AE-N with 50N-11P-41.5K and 100N-22P-83K kg/ha were higher at Kabangwe compared to the Mansa site. The difference between the two sites was not statistically significant for the highest level of NPK fertilizer. With manure application rates, mean AE-N was higher with 2.8 t/ha manure compared to 1.4 and 4.2 t/ha at both sites and higher values were recorded at Kabangwe compared to Mansa. Mean AE-N was highest (24.2 kg/kg) for NPK fertilizer at Kabangwe and low (15 kg/kg) for manure treatments at Mansa. With the combined application of manure and NPK, the highest (28 kg/kg) AE-N was recorded when 2.8 t/ha manure was combined with 100N-22P-83K kg/ha, while the lowest (17.4 kg/kg) was recorded where 1.4 t/ha manure was combined with 150N-33P-124.5K kg/ha at Kabangwe site. At both sites, the highest AE-N was

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recorded where the combination of 2.8 t/ha manure and 100N-22P-83K kg/ha was applied (Table 4).

3.5. Agronomic efficiency of phosphorous

Application of mineral fertilizer at a rate of 100N-22P-83K kg/ha resulted in the highest AE-P at both sites. Except for the highest level of NPK, mean AE-P was higher for Kabangwe compared to the Mansa site. The highest AE-P (82.5 kg/kg) was achieved with 100N-22P-83K kg/ha at Kabangwe and the lowest (54.5 kg/kg) with 50N-11P-41.5K kg/kg treatments at Mansa. For the combined application at Mansa, the highest mean AE-P was 89.2 kg/kg achieved with 2.8 t/ha combined with 100N-22P-83K kg/ha, while the lowest (41.7 kg/kg) was achieved with 1.4 t/ha manure and 50N-11P-41.5K kg/ha. At both Mansa and Kabangwe sites, the highest AE-P was achieved with 2.8 t/ha manure combined with 100N-22P-83K kg/ha mineral fertilizer (Table 4).

3.6. Agronomic efficiency of potassium

As in N and P, application of 2.8 t/ha manure resulted in the highest mean AE-K compared to the rest of the manure treatments at both Mansa and Kabangwe sites. However, the response of mineral fertilizer was different at different sites. At Mansa site, the 100N-22P-83K kg/ha treatment resulted in the highest mean AE-K (87.4 kg/kg). But the highest mean AE-K (103.3 kg/kg) was recorded in the plots treated with the lowest level of mineral fertilizer. For the combined application, plots treated with 2.8 t/ha manure and 100N-22P-83K kg/ha resulted in the highest mean AE-K. While the highest AE-K was 135.6 kg/kg for Mansa site, it was 119.0 kg/kg for Kabangwe site. Except for very few treatments, AE-K was higher at Kabangwe compared to Mansa site (Table 4).

4. Discussion

The combined application of manure and NPK significantly increased cassava growth variables including plant height, canopy diameter, stem girth, and LAI compared to the sole application of either manure or NPK. Overall, the greatest improvement of these variables was recorded with the combined application of 1.4 t/ha manure and 150N-33P-124.5K at both sites. These variables are good indicators of cassava growth. For example, a stem diameter (girth in Table 2) between 2 and 8 cm and plant height of 1.2−3.7 m are considered agronomically good cassava growth indicators (Alves, 2002). With the combined application of manure and NPK, the desirable stem diameter and plant height were achieved. Full canopy closure is also another indicator and in our case it ranged between 102 and 122 cm at Mansa and between 101 and 129 cm at Kabangwe, fully closing the inter- and intra-spacing of 100 cm. Large canopy diameter in cassava stands increases solar

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interception and photosynthesis, because it ensures larger surface exposure (Lebot, 2009). LAI is another parameter to rate cassava root and biomass yield. A LAI between 2.5−3.5 was considered ideal for root production (M. A. El-Sharkawy, 2004); while large LAI (>4), mostly from high nitrogen fertilizer application, can lead to more vegetative growth by partitioning less assimilates for the growth of storage roots (Howeler, 2002). In this regard, the only treatment that achieved this desirable LAI (2.7) at Mansa was the combined application of 1.4 t/ha manure + 150 N + 33 P + 124.5 K.

It is often thought that fertilization of cassava produces little response, but this is mainly the case in newly opened land with still adequate inherent soil fertility. When the crop is grown on land that has been previously cultivated with no or inadequate fertilization, the crop responds well to the application of adequate and well-balanced fertilizer applications (Howeler, 2002). This study provides evidence that cassava fertilization either with chicken manure or with NPK fertilizer can significantly improve root yields in the two tested locations in Zambia. The results are consistent with other studies that show a significant improvement in cassava root yield due to the application of mineral NPK fertilizer (Chaisri et al., 2013; Fermont et al., 2010; Mathias and Kabambe, 2015) and chicken manure (Akanza and Yao-Kouame, 2011; Mathias and Kabambe, 2015). The underlying reason could be because manure contains not only NPK but also other plant nutrients and improves the soil condition that can increase nutrient uptake compared to mineral fertilizers alone (Adekiya and Agbede, 2016; Amanullah et al., 2007).

The interactions between organic and mineral fertilizers were also significant for fresh cassava root at both sites. However, research findings are still highly varied emphasizing the need for site specificity in the application of ISFM. For instance, in Nigeria, Ayoola and Adeniyan (2006) found no difference in cassava yield under sole NPK application and NPK combined with chicken manure. On the other hand, Joy Odedina et al. (2012) found high cassava yield and improved soil condition under the combined application of NPK and organic amendment. Our results confirmed that combining chicken manure with NPK fertilizer further improves cassava root and biomass yield.

Dry matter partitioning between the root and shoot is another important parameter that has attracted the attention of cassava researchers. According to Alves (2002), dry matter in cassava is mainly translocated to the stems and storage roots, and the distribution to the most economically important part is measured by the HI, i.e. the root yield divided by the yield of roots + tops (total biomass, either on a dry or fresh weight basis). Earlier research reported in Alves (2002) indicated that HI values between 0.49 and 0.77 are expected when cassava is harvested between 10 and 12 MAP. Generally, HI > 0.5 is considered acceptable for cassava (Howeler, 2002), and in this study HI values for most of the treatments fell within

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the acceptable range. However, HI was highest with the combined application of 2.8 t/ha manure and 100N-22P-83K at the P-deficient Kabangwe site. On the Mansa site where P was adequate, the highest HI (0.66) was recorded with a lower nutrient input.

Nitrogen, phosphorous, and potassium fertilizer are the three nutrients most important for cassava tuberization (Odedina et al., 2015). Chemical fertilizers usually have 10−20 times higher concentrations of these three nutrients but manures also contain many secondary- and micro-nutrients, which may contribute to higher yields (Howeler, 2014). However, the nutrient uptake is highly related to plant growth rate, varietal differences, soil fertility status, and the prevailing climatic conditions (Howeler, 2002). Therefore, it is very important to look at the nutrient use efficiency because over use of fertilizer in crop production has a significant impact on the environment that includes soil acidification, fresh water contamination, and greenhouse gas emission (Howeler et al., 2013); especially when the additive effect from the applied fertilizer is factored in. In this study, though not statistically significant for all the nutrients, the application of manure increased agronomic efficiencies with increased application of manure at a lower rate of NPK. Maximum AE-N, AE-P and AE-K was attained when a medium level of manure was combined with a medium application of NPK, and increased manure application rate resulted in declining N, P, and K use efficiencies at a higher rate of NPK. The variation was clear at Mansa site where the pre-planting soil nutrient status was far below the critical requirement for cassava. This is in line with what was previously observed for cereals; that mixing organic with mineral fertilizer increases agronomic efficacy, while excess fertilizer application results in low agronomic efficiency, especially for AE-N (Vanlauwe et al., 2011). Agronomic efficacies were generally higher for NPK than for chicken manure in this study. This may be because the soil organic matter and N content on both sites were below the critical requirement of most crops. In addition, nutrients from mineral fertilizer are readily available to crops and are released faster than nutrients from organic sources.

5. Conclusion

This study examined the effect of the integrated application of organic and mineral fertilizer on cassava growth, root biomass yield, and agronomic use efficiency of N and P. We concluded that cassava responds more to the combined application of organic and inorganic fertilizer than their sole application. Combined application of fertilizers also resulted in higher agronomic efficiency. Thus, we recommend the use of 2.4 t/ha chicken manure in combination with 100N-22P-83K kg/ha NPK for yield increment in areas similar to Mansa and Kabangwe in Zambia.

Declarations

Author contribution statement

Gizachew Kebede Biratu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Pheneas Ntawuruhunga: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Eyasu Elias, Gudeta W. Sileshi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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