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Effect of Chicken Manure Application on Cassava Biomass and Root Yields in Two Agro-Ecologies of Zambia

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Abstract: Fertilizer application is known to increase crop yields and mitigate net soil nutrient mining due to continuous removal. However, smallholder farmers rarely apply adequate fertilizers because of high cost, limited availability and lack of awareness. An experiment was conducted to evaluate the effect of chicken manure on cassava root and biomass yield at Kabangwe and Mansa, two locations representing agroecological zones II and III, respectively, in Zambia. With the aim of exploring alternative soil fertility management for smallholder farmers, the effect of sole chicken manure and mineral fertilizers was evaluated on cassava. The treatments were four levels of chicken manure (0, 1.4, 2.8, 4.2 ton/ha) and a single level of mineral NPK applied at 100N-22P-83K kg/ha as recommended. The design was a Randomized Complete Block (RCBD), with three replications using the improved cassava variety "*Mweru*" during the 2015/2016 growing season. The results showed significant ($p < 0.05$) treatment effects on cassava root yields and yield components (fresh and dry root, leaf, stem, and total biomass) at both sites. The highest mean fresh (27.66 ton/ha) and dry root yield (9.55 ton/ha), and total fresh biomass (53.68 ton/ha) and dry biomass (16.12 ton/ha) production were achieved with the application of 4.2 ton/ha of chicken manure. This treatment showed 71% and 81% fresh root yield advantage over the control at Mansa and Kabangwe, respectively. While the marginal rate of return (MRR) was negative for the mineral fertilizer, it was positive for all the chicken manure treatments with the maximum (315%) achieved from the application of 4.2 ton/ha. The study concludes that application of chicken manure significantly increases the yield and biomass production of cassava and is economically efficient.

Keywords: cassava root; economic analysis; leaf area index; NPK fertilizer; organic amendment

1. Introduction

Cassava is the third most important tropical food crop after rice and maize, which contribute directly to feeding the growing population under very challenging environmental conditions [1]. In Zambia, the crop is one of the main food security crops, dominating the smallholder farming systems [2,3]. The importance of the crop emanates from its adaptation to wider agroecology, its ability to grow on poor soils, its ability to tolerate drought, pest and disease, and the production of high dry matter per given area [4]. In recent years, cassava production has increased in sub-Saharan Africa (SSA) as a result of a food shortage to feed the rapidly growing population and increasingly degrading environmental conditions [5]. However, Vanlauwe, et al. [6] emphasized that the production increase was a result of area expansion rather than an increase in yield per unit area. Available information also indicates that input use in cassava fields is very limited or absent among smallholder farms in SSA [7–10].

Soil fertility is dynamic, changing based on processes such as accumulation or depletion, which are governed by the interplay between physical, chemical, biological and anthropogenic processes [11]. Without applying a significant quantity of ameliorants such as manure or mineral fertilizer to replenish the soil, anthropogenic process in SSA have led to the removal of huge amounts of soil nutrients [12]. As a result, deteriorating soil fertility is considered a fundamental biophysical factor responsible for declining per-capita food production in SSA [13]. Cassava suffers the most in these scenarios because the majority of farmers in the region assume cassava production does not require external nutrient input [14,15]. For example, the average Zambian farmer does not apply manure or mineral fertilizer to his/her cassava field. As a result, cassava yield in 2014 was 44.5% and 92.8% lower than the African and global average cassava yields, respectively [16].

So far, application of mineral fertilizers is the main soil fertility management strategy used by many, but if not handled properly, can cause environmental problems such as soil acidity and eutrophication [17]. It is also unaffordable for most African farmers [18]. On the other hand, intensive farming produces a significant amount of manure [19], and poultry manure is among the most easily available resource for poor farm households. In addition to the supply of plant nutrients and organic carbon, the use of organic manure improves soil physical properties and enhances its water holding ability [20]. Poultry manure is the best quality animal manure in terms of nutrient content and availability [20,21]. However, no significant guidelines have been developed for application rates for cassava.

In Zambia, maize receives much of the priority attention in terms of external nutrient application because it is a major food staple and the most preferable dietary source of carbohydrates in the country. Despite its food security importance, cassava does not receive soil fertility inputs or the attention it deserves. The importance of cassava has become more prominent in recent years due to the growing population and drought susceptibility of maize in the face of climate change [22]. In response to the striking relation between drought occurrences and high vulnerability of maize to adverse weather conditions, Zambia has begun introducing new and improved cassava varieties. Additionally, the country is focusing on the traditional cassava growing areas, i.e., CopperBelt, Luapula, Northern and Muchinga provinces and new non-cassava growing areas such as the Central, Eastern and Southern Provinces of the country [23]. As of yet, no soil fertility management regime has been developed for cassava production in Zambia. Given the financial constraints and availability problems with mineral fertilizer, the promotion of organic inputs is the most feasible option. However, it requires derivation of optimum rates of manure application to attain acceptable levels of cassava yields for resource-poor households. Against this background and with the objective of deriving optimum rates of chicken manure application, a study was conducted to evaluate the effect of chicken manure compared to recommended mineral fertilizer (NPK) application on cassava yield and biomass in two agroecologies of Zambia as an option for integrated soil fertility management.

2. Materials and Methods

2.1. Description of the Study Sites

The experiment was conducted at two sites: Zambian Agricultural Research Institute (ZARI) Mansa Station in the Mansa district of Luapula province and the Kabangwe Station of the International Institute of Tropical Agriculture (IITA) Southern Africa Research and Administrative Hub (SARAH), which is located at the outskirt of Lusaka in Chibombo district central province of Zambia (Figure 1). A brief summary of the characteristics of these two sites is given in Table 1.

Table 1. Characteristics of the study sites [24–27].

Characterisics	**Sites**	
	Mansa	**Kabangwe**
Province	Luapula	Central
Districts	Mansa	Chibombo
Longitude	28°56′33.4″ E	28°18′26.9″ E
Latitude	11°14′30.2″ S	15°18′11.6″ S
Elevation	1246	1204
Agroecology	III	II
Growing days	120–150	100–120
Rainfall type	Unimodal	Unimodal
Soils	Gleysols associated with Acrisols	Acrisol and Luvisol Vertisols in some areas
Vegetation	Wet miombo woodland	Dry miombo woodland

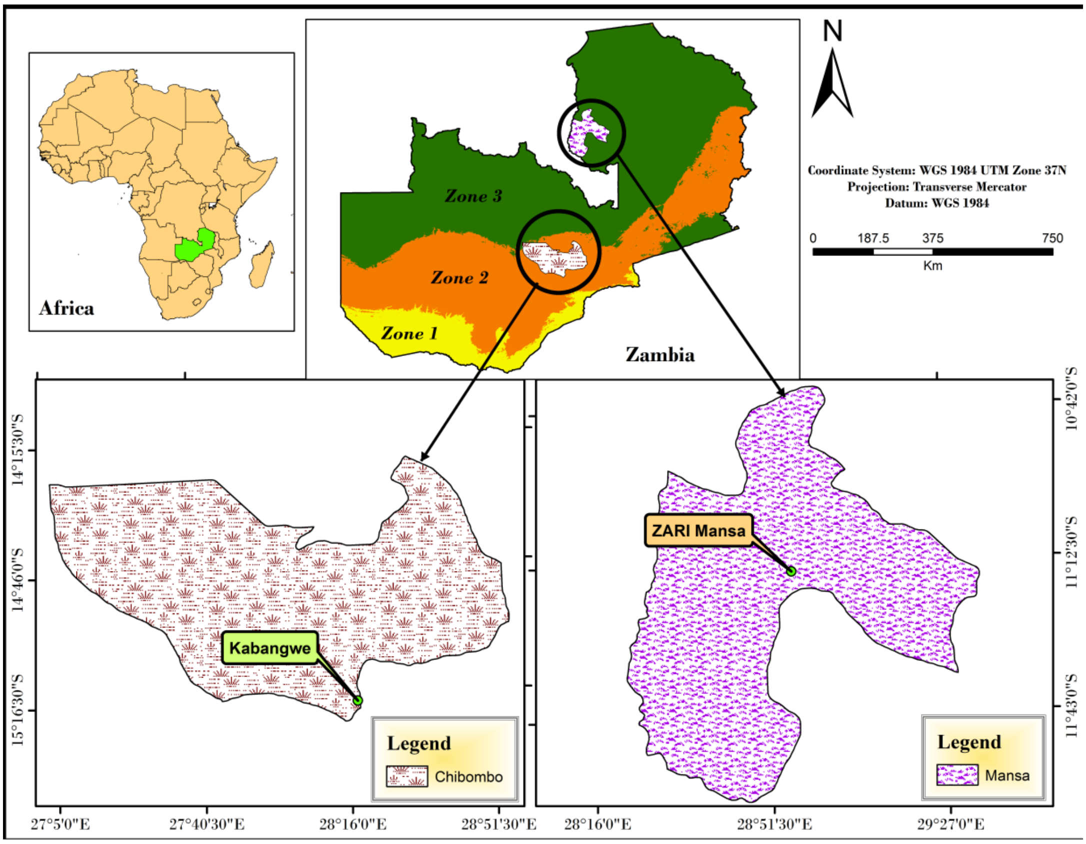

Figure 1. Map of the study sites and their respective districts on a map of the Republic of Zambia.

Zambia is divided into three major agroecologies based on rainfall. Zone II is an area that receives an annual rainfall of between 800 and 1000 mm per annum, but zone III is a high rainfall area receiving more than 1000 mm per annum [24]. However, the 2015/2016 cropping season was an El Niño season in Zambia. This brought minimal rainfall to the central and southern parts of the country while the northern region received an appreciable amount of rain. As a result, from 23 November 2015 to 22 November 2016, the Kabangwe site recorded 422.9 mm of rain, while Mansa recorded 1245.6 mm.

2.2. Experimental Design

Four levels of chicken manure (0, 1.4, 2.8, 4.2 ton/ha) were evaluated against 100N-22P-83K kg/ha, a fertilizer rate generally recommended by Howeler, et al. [8] for cassava and tried by Fermont, et al. [9]

in East Africa. This is to help fill the need for a blanket fertilizer recommendation for cassava in Zambia. The experiment was set using a Randomized Complete Block Design (RCBD) with three replications at both sites. The plot sizes were 5 m × 5 m, giving a total plant population of 25 per plot. Each plot was set 1.5 m apart with ditches running parallel and perpendicular to the plots to prevent runoff crossing during heavy rain. Fresh chicken manure was collected from one egg layers' farm, properly dried and mixed to reach a homogenized mixture before application. The properly mixed manure was sampled to determine the macronutrient (N, P, K) and micronutrient contents in it. Land ploughing was done using disc plows mounted on tractors and then harrowed. Matured improved cassava variety "*Mweru*" cuttings of 25–30 cm in length, collected from ZARI in Mansa, were planted at 1 m × 1 m standard inter and intra spacing. Extra cuttings were planted at the edge of the plots and later transplanted to substitute cuttings that did not sprout or those affected by termites within 1 month after planting (MAP). The optimum dose of mineral fertilizer was band applied in the form of urea, triple superphosphate and potassium sulfate. To enhance nutrient release from chicken manure and to reduce nutrient loss from the mineral fertilizer, manure was applied and properly incorporated to the soil during planting while the conventional practice of a split application of N and K was followed to apply the mineral fertilizer twice, at one and three MAP. However, all of the P was applied at once, i.e., at one MAP. The trial plots were kept weed free by hand weeding as needed.

2.3. Agronomic Data Collection

Harvesting was conducted at 12 MAP, and plant growth parameters such as plant height, canopy diameter, stem girth, Leaf Area Index (LAI)—the leaf area per unit ground [28], and chlorophyll index were recorded. Plant height was measured from the base of the first branch to the newly emerging leaf of the tallest plant using a measuring tape. Similarly, the average of two measurements (made perpendicular and parallel to the ridge) was recorded for the canopy diameter of each plant. Stem girth was measured on the largest stem using digital Vernier calipers. LAI was indirectly measured under the canopy using a 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 lobe of the first fully expanded leaf using a chlorophyll meter (SPAD 502, Konica Minolta, Tokyo, Japan). To avoid the effect of direct sunlight [29], chlorophyll readings were taken under the shadow of the reader. For all plant growth parameters, plot readings were taken from five plants following an 'X' pattern in the plot, and the average of the five readings was recorded. The harvest was conducted on 9 plants in the 3 m × 3 m net plot areas. After uprooting, the plants were separated into root, leaf, and stem. Fresh weight was recorded in the field with a digital balance. After the fresh weight was recorded, a 500 g sample from the root and stem and a 300 g sample from the leaf were taken to determine the dry weight. The samples were oven dried at 70 °C to constant weight to determine the dry weight of the biomass [30].

2.4. Soil Sampling and Analysis

Surface soil samples were collected (0–20 cm) using an Edelman auger at every 5 m crossing the fields in an X-like pattern and bulked together and properly homogenized to obtain one composite sample for each of the experimental sites. Samples were air-dried, ground, and passed through a 2-mm sieve to obtain the fine earth fraction (<2 mm separates). Soil samples were analyzed at the IITA soil laboratory in Cameroon. Particle size distribution (sand, silt, clay) was determined by the hydrometer method as outlined by Bouyoucos [31] and Day [32]. Soil pH-H_2O (1:2.5 solution) was determined in a 1:2.5 (*w/v*) soil to water solution using a pH meter as outlined by McLean [33]. Organic carbon (Org. C) was determined by chromic acid digestion and spectrophotometric analysis as described by Heanes [34]. Total nitrogen (TN) was determined from a wet acid digest [35] and analyzed by colorimetric analysis [36]. Exchangeable cations (Ca, Mg, K and Na), as well as available micronutrients (Cu, Zn, Mn, Fe) and available phosphorus (AvP), were extracted using the Mehlich-3 procedure [37], whereby the contents in the extracts were determined by flame photometry and atomic absorption spectrophotometry (AAS). CEC was extracted using the ammonium acetate method [38] in which the content was determined colorimetrically.

2.5. Data Analysis

The agronomic data were subjected to statistical analysis of variance using a generalized linear model (GLM) in R statistical software version 3.3.2 [39]. The total variability was then detected using the following model:

$$T_{ij} = \mu + \beta_i + \gamma_j + \varepsilon_{ij} \quad (1)$$

where T_{ij} is the total observation, μ is the overall mean, β_i is the ith replication, γ_j is the jth treatment effect and ε_{ij} is the variation due to random error.

Significance of the treatments was tested using the agricolae package of R [40]. The means were compared using the lsmean package of R [41] with the least significant difference (LSD) set at a 5% level of significance. Single degree of freedom orthogonal contrast of the control against the manure and fertilizer treatments was performed to evaluate treatment effects on crop performance.

2.6. Economic Analysis

To evaluate the economic feasibility of the different organic fertilizer treatments, economic cost and benefit analysis was done based on the partial budget techniques detailed in [42]. For the economic analysis, the prevailing market price for inputs during planting time and prevailing market price for outputs (the cassava roots in particular) during harvesting time was considered. The mean cassava root yield for each treatment was averaged over the two sites. All the costs and benefits were calculated on a hectare (ha) basis using Zambian Kwacha (ZMW) as a common denominator. The partial budget concepts used during the economic analysis were the following:

- Mean cassava root yield is the average root yield (ton/ha) of each treatment for the two locations minus 10% of the yield (to estimate what can be expected for a farmers' field);
- Field price of cassava is the farm gate price (from the local market at harvest) of cassava root per kg minus the cost of harvesting and packing;
- Gross field benefit (GFB) per ha is the product of the field price of cassava and mean cassava root yield of each treatment;
- Field price of manure is the retail price of chicken manure per kg and its transportation to the field;
- Field price of NPK fertilizer is the retail price of fertilizer per kilogram and its transportation to the field;
- Field cost of manure per ha is the product of the quantity of manure applied per ha in each treatment and the field price of manure;
- Field cost of NPK fertilizer is the product of the quantity of fertilizer required per ha by each treatment and the field price of the fertilizers;
- Fertilizer application cost is the product of labor hours used to apply both organic and mineral fertilizers and the wage rate per-day;
- Total variable cost (TVC) is the sum of all costs;
- The net benefit (NB) per ha for each treatment is GFB minus TVC.

Once the TVC and NB were calculated, potentially promising treatments were selected for further marginal rate of return (MRR) analysis by the dominant analysis procedure explained in [42]. After discarding the dominant treatments (any treatment with NB less than or equal to those treatment costs that vary when the treatments are listed in increasing TVC), the remaining treatments were ranked again from the lowest to highest TVC for % MRR analysis between pairs of treatments. The MRR between two treatments (say 1 & 2) was calculated as follows:

$$MRR = \frac{Change\ in\ NB(NB_2\ - NB_1)}{Change\ in\ TVC(TVC_2 - TVC_1)} \times 100 \quad (2)$$

Therefore, 100% MRR indicates that for every one Kwacha invested in fertilizer application, there is one Kwacha return on investment.

3. Results and Discussion

3.1. Soil Fertility Status and Manure Quality

Table 2 presents the results of the soil analysis for the two research stations. In terms of physical properties, sandy texture dominates the soil particle size distribution (54–77%), with low levels of silt (7–20%) and clay (16–26%) at Mansa and Kabangwe stations, respectively. The sandy loam texture class at Mansa indicates alluvial and transported parent materials of the study site soils. The soil reaction of the two sites was 4.9 and 5.28, and the pH of manure was 7.48. Based on the rating of Hazelton and Murphy [43], the soil reaction is rated as very strongly acidic for Mansa and strongly acidic for Kabangwe, while the manure was slightly alkaline. In terms of nutrient supply capacity, the soils are very low in the contents of soil Org. C (1.0–1.2%) and TN (0.05–0.06%), and extremely low in CEC (3–4 cmol (+)/kg) and basic cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}). The soil at Kabangwe is particularly deficient in terms of AvP (3.78 mg/kg), whereas that of Mansa has excess levels of AvP (20.51 mg/kg). This may indicate natural variation and/or differences in previous land use that resulted in residual phosphate accumulation in Mansa and depletion at Kabangwe. The low levels of nutrients and CEC are consistent with the low levels of clay and therefore limited surface area for nutrient and cation retention as result of the sandy nature of the soils [44,45]. The implication of this is that application of organic fertilizers and leaf litter is essential to retain nutrients and enhance the soil organic matter content. In light of this, the chicken manure can contribute favorable qualities, including high contents of Org. C (26%) and organic matter (45%), high levels of nutrients including TN (3.6%) and CEC (26 cmol (+)/kg), cations such as Ca (9 cmol (+)/kg) and K (2 cmol (+)/kg), and most micronutrients (Fe, Mn, Zn, Cu). The result therefore shows the potential of chicken manure as a soil amendment to address the low levels of nutrients and organic matter in the soils. However, low levels of AvP (1.3%) and high levels of Na (8 cmol (+)/kg) are the sources of concern, suggesting the need for combining chicken manure with phosphate fertilizer to avoid salinity increases from large quantities of manure application.

Table 2. Selected physicochemical properties of topsoil (0–20 cm depth) of the two experimental sites and manure.

Parameters	Mansa	Kabangwe	Manure	Requirement **
Particle size (%)				
Sand	77	54		
Silt	7	20		
Clay	16	26		
Textural class	Sandy loam	Sandy clay loam		
pH (water)	4.9	5.28	7.48	3.5–4.5 (in H_2O 1:1)
Org. C (%)	1.07	1.19	26	1–2 (Walkley & Black)
TN (%)	0.05	0.06	3.6	
C/N	22.34	19.39	7.86	
AvP (mg/kg)	20.51	3.78	13200	2–4
CEC (cmol (+)/kg)	2.97	4.56	22.01	
Exchangeable bases (cmol (+)/kg)				
Ca	1.22	2.57	8.6 *	0.25–1
Mg	0.29	1.2	0.62 *	0.2–0.4
K	0.12	0.09	1.99 *	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

* Results are expressed in percent (%), ** low level cassava requirement as stated in Howeler [46].

3.2. Effect of Chicken Manure on Growth Parameters of Cassava

Table 3 presents the result of plant growth parameters for different rates of chicken manure and fertilizer application. The results show that chicken manure application significantly ($p < 0.05$) affected plant height, canopy diameter, and leaf area index (LAI) at Mansa but not stem girth or chlorophyll index. At Kabangwe, plant height, canopy diameter, stem girth, leaf area index and chlorophyll index were significantly ($p < 0.001$) improved by chicken manure application. Plant growth parameters increased at both sites following the application of manure and the NPK fertilizer. Mean plant height, canopy diameter, and stem girth were higher at Mansa (207.6 cm, 140.33 cm, and 28.21 mm, respectively) compared to (205.33 cm, 123.9 cm and 25.81 mm, respectively) at Kabangwe site. On the other hand, LAI and the chlorophyll index (3.57 and 44.43, respectively) were higher at Kabangwe site compared to Mansa (Table 4). The 1.4 ton/ha chicken manure application rate resulted in a higher mean value for all plant growth parameters compared to the control, but the differences were not statistically significant. On the other hand, plant growth parameters were significantly higher ($p < 0.05$) for the 1.4 ton/ha rate of manure compared to the control at Kabangwe. The 4.2 ton/ha chicken manure (O_3) and recommended 100N-22P-83K kg/ha (R_F) treatments resulted in greater effects compared to the other treatments. However, these two treatments were not significantly different from each other for all traits except LAI, which was significantly ($p < 0.05$) higher at Mansa than at Kabangwe, with values of 3.57 and 3.37, respectively. Generally, LAI, the leaf area per unit ground area, increases slowly during the first 1 to 2 months of the growth period and then follows a rapid increase and a decline after 6 months [47]. It was reported that clones that gave high yields have the ability to retain a large number of leaves and have a large leaf area and a large green stem area. Cassava genotypes with relatively high LAI and long Leaf Area Duration (LAD) have high root yields [28]. The LAI of cassava ranges from 1 to 7 while optimum LAI ranges from 3 to 4 in the tropics. The current results from the chicken manure treatments fall in the range of high yielding clones.

Table 3. Overall mean values of growth parameters and cassava yield as affected by fertilizer treatments in Zambia.

Parameter	Mansa			Kabangwe		
	Mean [1]	Sig.	CV	Mean	Sig.	CV
Plant height (cm)	182.91	*	9.01	177.13	***	7.02
Canopy diameter (cm)	123.59	*	8.72	117.94	**	3.86
Stem girth (mm)	25.25	NS	10.87	23.96	**	4.77
Leaf area index	2.82	*	6.70	3.13	*	9.27
Chlorophyll index	41.56	NS	3.94	42.64	**	3.10
Fresh root weight (ton/ha)	21.64	*	13.53	21.59	**	11.12
Fresh leaf weight (ton/ha)	3.70	***	11.79	4.28	***	6.82
Fresh stem weight (ton/ha)	15.28	***	14.44	15.85	***	5.56
Total fresh biomass weight (ton/ha)	40.62	***	8.16	41.71	***	7.25
Dry root weight (ton/ha)	7.37	*	13.95	7.32	*	13.62
Dry leaf weight (ton/ha)	0.94	**	13.02	1.05	**	9.95
Dry stem weight (ton/ha)	4.68	**	15.16	4.05	***	8.57
Total dry biomass (ton/ha)	13.00	***	8.32	12.43	**	10.33

[1] the overall mean, Sig. = significance, <0.05 (*), <0.01 (**), <0.001 (***); NS = non-significant, CV = coefficient of variation.

Table 4. Means of the effect of treatments on cassava growth parameters at the two sites.

Treatments	Parameters				
	Height (cm)	**Canopy (cm)**	**Girth (mm)**	**LAI**	**Chlorophyll**
Mansa					
O_0	151.27 ^{c}	101.60 ^{c}	21.49 ^{a}	2.40 ^{c}	39.95 ^{a}
O_1	169.93 ^{bc}	116.67 ^{bc}	24.11 ^{a}	2.63 ^{bc}	40.98 ^{a}
O_2	188.07 ^{ab}	127.40 ^{ab}	25.51 ^{a}	2.83 ^{b}	42.89 ^{a}
O_3	207.60 ^{a}	140.13 ^{a}	28.21 ^{a}	3.37 ^{a}	41.25 ^{a}
R_F	197.67 ^{ab}	132.17 ^{ab}	26.91 ^{a}	2.87 ^{b}	42.74 ^{a}
Mean	182.91	123.60	25.25	2.82	41.56
LSD	31.04	20.29	5.17	0.36	3.08
Trt. vs. contr	**	**	*	*	.
Kabangwe					
O_0	129.67 ^{c}	101.70 ^{b}	20.68 ^{b}	2.50 ^{c}	38.75 ^{b}
O_1	176.00 ^{b}	118.87 ^{a}	24.00 ^{a}	2.97 ^{bc}	42.19 ^{a}
O_2	190.20 ^{ab}	123.90 ^{a}	24.69 ^{a}	3.40 ^{ab}	43.89 ^{a}
O_3	205.33 ^{a}	123.50 ^{a}	25.81 ^{a}	3.57 ^{a}	43.91 ^{a}
R_F	184.47 ^{ab}	121.73 ^{a}	24.60 ^{a}	3.20 ^{ab}	44.43 ^{a}
Mean	177.13	117.94	23.96	3.16	42.63
LSD	23.42	8.56	2.15	2.42	2.48
Trt. Vs. contr	***	***	***	**	***

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$. O_0 = control, O_1 = 1.4 ton/ha manure, O_2 = 2.8 ton/ha manure, O_3 = 4.2 ton/ha manure, R_F = recommended mineral fertilizer (100N-22P-83K), Significance = < 0.05 (*), < 0.01 (**), < 0.001 (***).

The 4.2 ton/ha manure treatment resulted in the highest values for all growth parameters at both locations, but the mean difference was not statistically different between O_2 and R_F except for LAI at Mansa. The treatments vs control mean group comparison showed a significant difference at least at the $p < 0.05$ level at both sites, except for the chlorophyll index at Mansa station, which was non-significant. A recent study revealed that canopy characteristics of cassava are affected by different fertilization regimes [48]. In addition, organic manure and NPK fertilizer application significantly increased cassava height, stem girth, number of leaves, and internode length [49], and our present results are in line with these findings.

3.3. Fresh and Dry Cassava Root and Biomass Yield

Fresh and dry cassava root weight was significantly ($p < 0.05$) influenced by the application of fertilizers at both Mansa and Kabangwe sites (Table 3). All the manure rates and fertilizer applied led to significantly high fresh and dry cassava root yield compared to the control at both sites, except the root yield with the rate of 1.4 ton/ha manure that gave a higher, but statistically non-significant result at Mansa. While 4.2 ton/ha outperformed the 1.4 ton/ha manure treatment in terms of fresh root yield, no significant difference was observed between the 1.4 and 2.8 ton/ha and between the 2.8 and 4.2 ton/ha manure treatments at the Mansa site. At Kabangwe, the 4.2 ton/ha treatment resulted in significantly higher fresh root yield compared to other fertilizer treatments, but no significant difference was observed between the other manure levels and the mineral fertilizer treatments (Table 5). With the exception of the 1.4 ton/ha manure treatment, all the treatments resulted in significantly higher dry root yield with no significant difference among themselves at the Mansa site. At Kabangwe, the 4.2 ton/ha manure application significantly increased dry cassava root yield compared to the other treatments. While the 2.8 ton/ha treatment significantly increased dry root yield compared to the control, no significant difference was observed between the other treatments at Kabangwe (Table 6). The highest fresh root yield of 26.59 ton/ha at Mansa and 27.66 ton/ha at Kabangwe, and the highest dry root weight of 8.99 ton/ha at Mansa and 9.55 ton/ha at Kabangwe were obtained at the rate of 4.2 ton/ha chicken manure (Tables 5 and 6). This is because chicken manure is the best in terms of quality and can supply both macro- and micronutrients to the plant compared to the NPK fertilizer treatments [20,21,46]. Organic amendments also buffer acidity problems and increase P availability in acid soils [50]. As a result, soils treated with manure have this advantage and can respond better to crop production.

Table 5. Means of the effect of treatments on fresh cassava yield and biomass.

Treatments	Parameters			
	Root (ton/ha)	**Leaf (ton/ha)**	**Stem (ton/ha)**	**Total Biomass (ton/ha)**
Mansa				
O_0	15.56 ^{c}	2.41 ^{c}	9.31 ^{c}	27.29 ^{d}
O_1	20.24 ^{bc}	3.47 ^{b}	12.83 ^{bc}	36.54 ^{c}
O_2	22.64 ^{ab}	3.77 ^{b}	16.61 ^{b}	43.02 ^{b}
O_3	26.59 ^{a}	5.12 ^{a}	22.82 ^{a}	54.54 ^{a}
R_F	23.20 ^{ab}	3.72 ^{b}	14.80 ^{b}	41.72 ^{bc}
Mean	21.65	3.70	15.27	40.62
LSD	5.52	0.82	4.15	6.24
Trt. Vs. contr	**	***	***	***
Kabangwe				
O_0	15.27 ^{c}	3.20 ^{c}	10.35 ^{d}	28.82 ^{c}
O_1	20.08 ^{b}	4.14 ^{b}	15.04 ^{c}	39.26 ^{b}
O_2	22.76 ^{b}	4.80 ^{a}	16.84 ^{b}	44.40 ^{b}
O_3	27.66 ^{a}	5.05 ^{a}	20.97 ^{a}	53.68 ^{a}
R_F	22.18 ^{b}	4.19 ^{b}	16.04 ^{bc}	42.41 ^{b}
Mean	21.29	4.28	15.85	41.71
LSD	4.52	0.55	1.66	5.69
Trt. Vs. contr	***	***	***	***

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$. O_0 = control, O_1 = 1.4 ton/ha manure, O_2 = 2.8 ton/ha manure, O_3 = 4.2 ton/ha manure, R_F = recommended mineral fertilizer (100N-22P-83K), Significance = < 0.05 (*), < 0.01 (**), < 0.001 (***).

The organic amendment and fertilizer treatment also consistently and significantly increased the cassava fresh and dry leaf, stem and total biomass yield at both sites compared to the control. The only exception is the mean fresh stem yield for the rate of 1.4 ton/ha manure that showed higher but statistically non-significant effects at Mansa. Mean fresh leaf, stem and total biomasses were significantly higher for the 4.2 ton/ha chicken manure treatment at both sites. However, there was no significant difference between the mean fresh leaf of the two highest manure levels at Kabangwe (Tables 3 and 5). Except for the dry stem mass at Mansa and dry leaf mass at Kabangwe, a similar trend was observed for the dry biomass yield.

The application of dry chicken manure at a rate of 1.4, 2.8, 4.2 ton/ha and the NPK fertilizer resulted in 32%, 49%, 80%, and 45% increases, respectively, in fresh cassava root yield compared with the control at Kabangwe. The respective increases at Mansa were 30%, 46%, 71% and 49%. However, the biomass yield advantage over the control was much higher for fresh cassava stem (145% at Mansa and 103% at Kabangwe site), while it was 100% for fresh total biomass at Mansa; all at the rate of 4.2 ton/ha manure. Similarly, the dry cassava root yield advantage was 37%, 49%, 74%, and 54%, respectively at Mansa, while it was 27%, 41%, 76% and 33%, respectively at Kabangwe. The highest biomass gain was 112% for dry stem biomass at Mansa, followed by 101% for dry stem biomass at Kabangwe and 95% for dry leaf biomass at Mansa site in response to O_3.

Table 6. Table of means of the different treatment effects on dry cassava yield and biomass.

Treatments	Parameters			
	Root(ton/ha)	**Leaf(ton/ha)**	**Stem(ton/ha)**	**Total(ton/ha)**
Mansa				
O_0	5.16 ^{b}	0.64 ^{c}	3.09 ^{d}	8.88 ^{d}
O_1	7.06 ^{ab}	0.92 ^{b}	3.78 ^{cd}	11.76 ^{c}
O_2	7.71 ^{a}	0.92 ^{b}	5.34 ^{ab}	13.97 ^{b}
O_3	8.99 ^{a}	1.25 ^{a}	6.54 ^{a}	16.78 ^{a}
R_F	7.95 ^{a}	0.97 ^{b}	4.68 ^{bc}	13.59 ^{bc}
Mean	7.37	0.94	4.69	13.00
LSD	1.94	0.23	1.34	2.04
Trt. Vs. contr	**	***	**	***
Kabangwe				
O_0	5.40 ^{c}	0.77 ^{c}	2.63 ^{d}	8.80 ^{c}
O_1	6.85 ^{bc}	1.05 ^{b}	3.96 ^{bc}	11.86 ^{b}
O_2	7.64 ^{b}	1.18 ^{ab}	4.53 ^{b}	13.34 ^{b}
O_3	9.55 ^{a}	1.28 ^{a}	5.29 ^{a}	16.12 ^{a}
R_F	7.16 ^{bc}	0.99 ^{b}	3.87 ^{c}	12.02 ^{b}
Mean	7.32	1.05	4.06	12.43
LSD	1.88	0.20	0.65	2.42
Trt. Vs. contr	**	***	***	***

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$. O_0 = control, O_1 = 1.4 ton/ha manure, O_2 = 2.8 ton/ha manure, O_3 = 4.2 ton/ha manure, R_F = recommended mineral fertilizer (100N-22P-83K), Significance = < 0.05 (*), < 0.01 (**), < 0.001 (***).

Even though yield advantage over the control was higher at Mansa, cassava response to the applied treatments was more pronounced at Kabangwe than Mansa. This can be evidenced from the 4.2 ton/ha chicken manure treatment that was significantly higher than other treatments at Kabangwe but was not significant at Mansa. This could be explained by other factors that can limit soil productivity such as the soil pH. Mansa is situated in the rain belt of Zambia, closer to the Congo basin, where high rainfall has resulted in higher acidity compared with Kabangwe. This was corroborated by the initial soil analysis result and the P availability in the soil (Table 2). AvP was high enough in Mansa soils, but can be fixed because of the extremely acidic nature of the soil. As explained by Vanlauwe, et al. [6] soils do not always respond to applied nutrients due to constraints by other factors such as soil depth, acidity or alkalinity. Climatic factors and soil conditions can also interact, leading to a limited response to input use. According to Howeler [46], cassava grows best on well drained soils with an appreciable clay content. The clay content of our study soil was higher at Kabangwe, while the rainfall was higher at Mansa.

The response to external inputs from cassava genotypes is variable, ranging from a high response to no response at all. Our result has shown that "*Mweru*" responds favorably to fertility inputs. The results also showed that application of chicken manure and NPK fertilizer resulted in better cassava yield and growth performance. In line with this, different researchers reported that chicken manure application, either in combination or as a sole application, increases cassava yield [51,52]. They also found that, in addition to a cassava yield increase, chicken manure application improved the physico-chemical properties of the soil. Not only did cassava yield respond to the fertility inputs, chicken manure application also significantly improved plant height, LAI, root and shoot weight, and grain yield of sorghum in Nigeria [53]. In Zambia, where farmers do not use input for cassava production, cassava yield has been limited to 4.6 ton/ha [16], and thus the use of external input should be recommended to increase yield and sustain land productivity. The use of 1.4, 2.8, 4.2 ton/ha chicken manure and 100N-22P-83K fertilizer resulted in 3-, 4-, 5- and 4-fold increases in fresh cassava root yield, respectively, compared to the 4.6 ton/ha country average. Our results confirmed that the use of fertilizer (organic or mineral) increases cassava yield. The yield gap between the farmers' and researchers' fields was extremely high [18], confirming that the use of fertilizer by Zambian farmers is either minimal or nonexistent.

The reason why farmers use little or no external input at their farm could be due to fertilizer price or affordability by resource-poor farmers [54,55]. Because farmers can obtain roots for their subsistence from cassava planted on very marginal fields [56–58], a low-to-no input farming system is preferred compared to an input-intensive farming system for cassava. The slash and burn system that is still practiced by some Zambian farmers, especially in the Northern part of the country [59], could also explain the observed low fertilizer use in Zambia. However, as evidenced in West and East African countries [56,58,60], a low input production system cannot support the high crop yield required to meet the needs of a growing population and can also cause environmental degradation, through deforestation and carbon dioxide emissions. Therefore, these conditions necessitate the use of fertilizer, either organic or mineral sources, to sustain cassava farming in the long run and meet the growing cassava demand in the country.

3.4. Economic Analysis

Table 7 shows the partial budget analysis result of the different treatments used in the experiment. The result revealed that the treatment with fertilizer application excluded from the marginal rate of return comparison because it was the dominant treatment (treatment with lower benefit compared to the resources invested in it). However, the 1.4 ton/ha chicken manure treatment has a 138.5% MRR or a return of 1 Kwacha 39 Ngwe relative to one Kwacha investment. A further increase of chicken manure from 1.4 to 2.8 ton/ha (treatment O_2) resulted in 138% MRR or another additional 1 Kwacha 38 Ngwe return on 1 Kwacha investment. The 4.2 ton/ha chicken manure treatment had the highest MRR (315%) compared with the other treatments.

Table 7. Comparison of marginal rate of return between the treatments.

Treatments	O_0	O_1	O_2	O_3	R_F
Mean cassava root yield (ton/ha)	**15.42**	**20.16**	**22.7**	**27.13**	**22.69**
Adjusted yield (10% reduction)	13.878	18.144	20.43	24.417	20.421
Gross field benefit (GFB) per ha	**9714.6**	**12700.8**	**14301**	**17091.9**	**14294.7**
Field price of manure per kg	0.48	0.48	0.48	0.48	0.48
Field cost of manure	0	672	1344	2016	0
Field price of Urea per kg	6.3	6.3	6.3	6.3	6.3
Field cost of Urea per ha	0	0	0	0	1367.1
Field price of TSP per kg	11.4	11.4	11.4	11.4	11.4
Field cost of TSP per ha	0	0	0	0	1242.6
Field price of SOP per kg	10.65	10.65	10.65	10.65	10.65
Field cos of SOP per ha	0	0	0	0	2130
Manure application cost (29/Man day)	0	580	580	580	
Fertilizer application cost (29/man day)	0	0	0	0	870
Total variable cost (TVC)	**0**	**1252**	**1924**	**2596**	**5609.7**
The net benefit (NB)	9714.6	11448.8	12377	14495.9	8685
MRR		**1.385144**	**1.38125**	**3.153125**	**−1.92816** [D]
Sensitivity analysis					
GFB decreased by 15%	8257.41	10795.68	12155.85	14528.12	12150.5
TVC increased by 15%	0	1439.8	2212.6	2985.4	6451.16
NB	8257.41	9355.88	9943.25	11542.72	5699.34
MRR		**0.7629**	**0.76**	**2.0697**	**−1.686**

[D] The recommended fertilizer treatment (R_F) became the dominant treatment in the analysis.

Researchers began questioning long ago how resource-poor farmers can adopt new technology, especially in developing countries [61]. For example, there is an argument that most African farmers cannot afford fertilizer and thus do not apply the required amount to reach the economic return on fertilizer investments [62]. A cassava adoption study conducted in southern Zambia revealed that farmers were reluctant to adopt cassava cultivation because of its economic return on investment compared to an already existing maize system [23]. Therefore, economic analysis of the profitability of investment on fertilizer application is important in order to make better recommendations for input-based cassava farming. Partial budget analysis of profitability of the different treatments showed that the use of all the different levels of chicken manure was economically profitable, and the highest MRR (315%) was attained at the rate of 4.2 ton/ha of chicken manure. On the other hand, despite the yield increase as a result of NPK fertilizer use at both sites, there was no economic benefit. This is basically because of two things: one is as a result of the high fertilizer price and the other is because of the low fresh cassava root price at the farm gate that could reduce the MRR. A study on the cassava sector in Zambia revealed that the major constraints to the sector were that producers themselves are disaggregated with poor transportation and marketing infrastructure, which result in high cost and less competitive price [63]. Even today, it seems that the cassava price is low, and this was shown by the low MRR of NPK compared to manure application. In this changing world, if the inflation in the country is considered to be 15%, benefit reduction and cost inflation by the same amount do not switch the order or the effect of the treatments. The O_3 treatment remains the most profitable investment, with 206.97% MRR, as the benefit dropped by 15% and the price of input, such as fertilizer and manure, increased by the same amount.

4. Conclusions

Our results confirmed that the use of both organic and mineral fertilizer increases cassava yield, but higher yields were observed in response to chicken manure compared to the NPK fertilizer treatment. The 4.2 ton/ha chicken manure treatment resulted in the highest cassava root and biomass yield at both locations. This means that where actual and potential cassava yields are different, the use of either organic or mineral soil amendments can improve cassava productivity in the short run and contribute to sustainable intensification in the long run. The economic analysis indicated that the MRR was all positive for chicken manure application and increased with an increased rate of application. However, with the current condition, either because of the low price of cassava root or because of the high fertilizer cost, the use of an organic source (chicken manure) is economically more viable than the use of mineral fertilizer in Zambia.

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