

# Sustaining Improved Cassava Production on West African Ferralsols Through Appropriate Varieties and Optimal Potassium Fertilization Schemes

Jean Mianikpo Sogbedji<sup>1</sup>, Lakpo Kokou Agboyi<sup>2</sup>, Kodjovi Sotomè Detchinli<sup>1</sup>, Ruth Atchoglo<sup>1</sup>, Mihikouwe Mazinagou<sup>1</sup>

<sup>1</sup>School of Agronomy, University of Lome, Lome, Togo

<sup>2</sup>Togolese Institute of Agronomic Research, Lome, Togo

## Email address:

mianikpo@yahoo.com (J. M. Sogbedji), agboyikoku@yahoo.fr (L. K. Agboyi), skdetch@gmail.com (K. S. Detchinli),  
ruthatcho@hotmail.fr (R. Atchoglo), mihikmaz@gmail.com (M. Mazinagou)

## To cite this article:

Jean Mianikpo Sogbedji, Lakpo Kokou Agboyi, Kodjovi Sotomè Detchinli, Ruth Atchoglo, Mihikouwe Mazinagou. Sustaining Improved Cassava Production on West African Ferralsols Through Appropriate Varieties and Optimal Potassium Fertilization Schemes. *Journal of Plant Sciences*. Vol. 3, No. 3, 2015, pp. 117-122. doi: 10.11648/j.jps.20150303.12

---

**Abstract:** Improved nutrient use efficiency and use of appropriate crop varieties are required towards producing enough food in a sustainable manner. This study assessed the response of three cassava (*Manihot esculenta* Crantz) varieties to three potassium (K) fertilization rates on West African ferralsols. It aimed at identifying optimal K fertilizer application rates and corresponding appropriate crop varieties for improved and sustainable cassava production. Three K fertilizer rates including 0, 50 and 100 kg K ha<sup>-1</sup> were used together with fertilizers nitrogen (N) and phosphorus (P) each at a fixed rate of 60 kg ha<sup>-1</sup>. The cassava varieties were Gbazeoute (V1), KH (V2) and Moya (V3). Field data including cassava fresh tuber and stover yields, and harvest index (HI) were collected from the 2-yr experiment in which treatments were arranged in a split-plot design, with varieties as main plots and K fertilizer rate as subplots. Mean fresh tuber yield under Gbazeoute (65.5 Mg ha<sup>-1</sup>) increased by 68.4 and 44.3% as compared with KH (38.9 Mg ha<sup>-1</sup>) and Moya (45.4 Mg ha<sup>-1</sup>), respectively, while yield under Moya was superior to that of KH by 16.7%, indicating that tuber yield potential was highest, intermediate and lowest for V1, V3 and V2, respectively. Mean stover yield under Gbazeoute (52.2 Mg ha<sup>-1</sup>) decreased by 12.6 and 18.7% as compared with KH (59.7 Mg ha<sup>-1</sup>) and Moya (64.2 Mg ha<sup>-1</sup>), respectively. Mean harvest index values increased under Gbazeoute (55.7%) by 41 and 34.5 % as compared with KH (39.5%) and Moya (41.4%), respectively, and value under KH was 4.6% lower than that for Moya. The three varieties were responsive to applied fertilizer K rate with the response being highest, intermediate and lowest for the KH, Moya and Gbazeoute, respectively. For the three varieties, the optimum K fertilizer application rate was 50 kg K ha<sup>-1</sup>. Gbazeoute proved superior over KH and Moya in efficiently allocating assimilates to storage roots at the expenses of the stover. The use of 50 kg K ha<sup>-1</sup> together with 60 kg N ha<sup>-1</sup> and 60 kg P ha<sup>-1</sup> (N<sub>60</sub>P<sub>60</sub>K<sub>50</sub> kg ha<sup>-1</sup>) under the Gbazeoute may be a recommended practice towards sustaining improved cassava production on the inherently degraded West African ferralsols.

**Keywords:** Cassava Variety, Ferralsols, Fertilizer Potassium, Yield, Harvest Index

---

## 1. Introduction

Food shortages have become an increasing worldwide concern with the highest severity in Africa where the phenomenon is seriously hampering the development of the continent. In sub-Saharan Africa, food production should increase by 70% by 2050 to meet the necessary caloric requirements [1]. However, producing enough food, in a

sustainable manner, to meet the needs of an increasing global population is one of the greatest challenges we face [2]. The ability to achieve this goal is compounded by the decrease in arable land through environmental degradation and urban encroachment [3, 4], increased cost and potential shortages of fertilizers [3, 5] and climate change. Efforts towards improving agricultural productions to enhancing food security in the region should therefore address major constraints with focus on reversing nutrient depletion from

soils, mitigating the effect of drought spells and erosion, increasing nutrient and water use efficiency and adaptation of improved crop varieties.

Cassava (*Manihot esculenta* Crantz) is one of the staple food crops in tropical countries primarily due to the variability of foods that can be derived from it for human as well as for livestock use. It is a strategic crop for the FAO because of its potential for famine mitigation in many tropical underdeveloped countries and is the third source of calories in the tropics after rice and maize, and, as such constitutes an important staple food crop especially in Sub-Saharan Africa [6, 7]. Furthermore, cassava root and its derivatives are dominant food in Sub-Saharan Africa, being responsible for fifty percent of food intake and about 1000 calories per capita per day [8]. Cassava is also an industrial crop [9]. The crop is grown throughout the tropics, and supports approximately 25 percent of farming households (about 100 million people) and is a major crop on 35 percent of all agricultural land (about 60 million hectares) in Sub-Saharan Africa [10].

The cassava cropping based literature especially the crop nutrient needs and utilization for growth and yield is subject to a highly controversial debate. Several studies described cassava as a low nutrient demanding crop. References [11, 12] indicated that it can grow on poor soils. Cassava is generally grown in marginal soils because of its minimal requirement for land preparation and its ability to produce reasonably good yields even on eroded and degraded soils [13]. The crop can grow on soils that are too impoverished to support other staple crops [14], and farmers do not fertilize cassava, partly because they think that cassava does not require it and partly because they are contented with the minimal yields obtained from using limited inputs or even from their infertile soils [15]. On the other hand, several other studies indicated that cassava cropping requires fertile soils with high levels of nutrients. Reference [9] pointed out that cassava production is limited by soil fertility status and this necessitates application of organic and inorganic fertilizers. Cassava is known as a soil depleting crop because of the large amounts of nutrient it takes up from the soil and farmers need technical support to diagnose and correct soil nutrient deficiencies towards enhancing the crop production [16]. To achieve the yield potential of cassava, good soil fertility and adequate fertilization is essential [15, 17]. The harvested roots in particular contain large amounts of K - the NPK ratio in the roots being 5:1:10 in comparison to the typical ratio of 7:1:7 as in other crops [18].

Despite the controversial debate on the cassava nutrient needs and utilization, it has been unanimously agreed that the crop growth and yield are primarily limited by K. Reference [10] reported that since cassava is a high carbohydrate producer, it requires a large amount of K which has a special role in carbohydrate synthesis and translocation. Although variation in local soil conditions is important, increases in cassava yield can be readily achieved with a strong response to application of K and moderate responses to nitrogen (N) and phosphorus (P) [19], and this can be especially important in the developing world, as access to synthetic fertilizers is often

limited or non-existent [2]. However, several studies [20, 21, 22] demonstrated that cassava response to fertilizer and environment is also a function of the crop genotype. Although the plant is well adapted to low levels of available P, it requires fairly high quantities of K, especially when grown continuously for many years on the same site [23]. Long-term fertility trials have clearly indicated that sooner or later K deficiency becomes the most limiting nutritional constraint if cassava is grown continuously without adequate K fertilization [10]. Efforts towards sustainably improving cassava production should primarily focus on a quantitative determination of optimal K fertilization schemes together with the use of appropriate crop varieties on a site-specific basis.

The objective of this study was to assess the response of three cassava varieties to three K fertilization rates on coastal West African ferralsols. The aim was to identify optimal fertilizer K rates of application and corresponding appropriate crop varieties towards an improved and sustainable cassava production in this agro ecosystem.

## 2. Materials and Methods

### 2.1. Experimental Site

The study was conducted at the University of Lomé Research Station near Lomé, Togo (6°22'N, 1°13'E; altitude = 50 m). The soil type was a rhodic ferralsol locally called "Terres de Barre" that developed from a continental deposit [24]. This soil type covers part of the arable lands in Togo, Bénin, Ghana, and Nigeria and is commonly used for cassava production in coastal Western Africa. The experimental site has a slope of less than 1% and annual precipitation typically ranges from 800 to 1100 mm. At the onset of this experiment, the site, which has usually been used by farmers for unfertilized continuous maize cropping, was under a 2-yr grass fallow.

### 2.2. Crop and Soil Management

A 2-yr period (2010-2011) split-plot experiment was established with three replicates. Three cassava varieties were the main plot effects and three K fertilizer levels were at the subplot level. The site was manually plowed and 9 main plots (15 x 10 m) and 27 subplots (5 x 10 m) were laid out in a spatially-balanced complete block design [25]. Spatially-balanced complete block (SBCB) designs are a model-based approach that guarantees that the experiment is insensitive to trends, spatial correlation, or periodicity in the research domain [26]. It aims to equalize variances among treatment contrasts and allows for conventional statistical analysis methods. The three cassava varieties were: (i) Gbazeoute, V1, (ii) KH, V2 and (iii) Moya, V3. Gbazeoute and Moya are locally popular varieties and KH is a recently created and tested variety by the Laboratoire de Biotechnologie de l'Ecole Supérieure d'Agronomie de l'Université de Lomé. Fertilizer treatments were applied to subplots under each of the three varieties. Three subplots were

treated with three levels of K including 0 kg K ha<sup>-1</sup> (T1), 50 kg K ha<sup>-1</sup> (T2) and 100 kg K ha<sup>-1</sup>. All subplots were fertilized with N and P at a rate of 60 kg ha<sup>-1</sup> each. Fertilizer N, P and K were manually applied by hill placement as urea, P<sub>2</sub>O<sub>5</sub> and KCl, respectively, six weeks after cassava planting at approximately 8 cm depth. Cuttings of the tree varieties were planted slanted, at an angle in April and harvested in February of the subsequent year (approximately 11 months) at a density of 10,000 plants ha<sup>-1</sup> (at a spacing of 1 m x 1 m). The crop was manually weeded three times in each year.

### 2.3. Data Collection

At the onset of the experiment in 2010 (at cassava planting in April), soil properties including total C and N and nitrate-N (NO<sub>3</sub>-N) contents, available P and K, exchangeable bases (Ca<sup>++</sup>, Mg<sup>++</sup>, Na<sup>+</sup> and K<sup>+</sup>), pH, total cation exchange capacity (CEC) and particle size distribution were measured for the first 20 cm soil layer (0-20 cm depth) on the experiment site from twenty four composite soil samples using the standard methods of the International Institute for Tropical Agriculture [27].

Yield data were measured on fresh tuber weight and stover weight from samples of 12 matured plants randomly selected and manually harvested from each subplot after 11 months of growth. Stover was the above-ground parts, made up of cassava stems cut at the soil surface, leaves, and branches. Harvest Index (HI) was also determined by the relationship below and expressed as a percentage:

$$HI = \text{Economic Yield} \times (\text{Biological Yield})^{-1} \quad (1)$$

with, economic yield referring to tuber yield and biological yield referring to total biomass yield. The yield data were analyzed using the general linear mixed model with rep and rep\*variety as random, and fertilizer level and variety as fixed effects. Significant effects were followed by multiple comparisons adjusted with a Bonferoni correction. The MIXED procedure in Statistical Analytical System [28] was used to run the analysis.

## 3. Results and Discussion

### 3.1. Soil Properties

The soil of the experimental site was moderately acidic with a pH of 6.48 and very low total C and N contents of 0.75 and 0.07%, respectively (Table 1). The soil texture results showed that the soil was sandy, with a total sand content of 80% for the top 20 cm soil profile, indicating that the site was a well-drained soil with low and fairly low P and K contents of 10.86 and 76.80 mg kg<sup>-1</sup>, respectively. The CEC was low (2.52 cmol kg<sup>-1</sup>) with exchangeable bases Ca<sup>++</sup>, Mg<sup>+</sup>, Na<sup>+</sup> and K<sup>+</sup> of 30.75, 7.12, 5.0 and 3.38 cmol kg<sup>-1</sup>, respectively (Table 1). Overall, the soil properties indicated that the experimental site was low in inherent fertility as demonstrated earlier by [29] and, therefore, according to [30] will require additional fertilizer for optimum tuber yield. It was thus expected that

cassava crop would respond to fertilizer application on the site.

**Table 1.** Soil properties at the onset of the experiment.

Parameter	Value
pH (H <sub>2</sub> O)	6.48
Total C (%)	0.75
Total N (%)	0.07
NO <sub>3</sub> -N (mg kg <sup>-1</sup> )	3.30
Available P (mg kg <sup>-1</sup> )	10.86
Available K (mg kg <sup>-1</sup> )	76.80
Exchangeable bases (cmol kg <sup>-1</sup> )	
Ca <sup>++</sup>	30.75
Mg <sup>++</sup>	7.12
Na <sup>+</sup>	5.0
K <sup>+</sup>	3.38
Total CEC (cmol kg <sup>-1</sup> )	2.52
Sand content (%)	80.0
Silt content (%)	7.0
Clay content (%)	13.0

### 3.2. Tuber Yield

Fresh tuber yield typically ranged from 23 to 71 Mg ha<sup>-1</sup> (Table 2), which agreed reasonably well with results of 28 to 43, 30 to 45, 38 to 50 and 38 to 77 Mg ha<sup>-1</sup> reported by [31], [22], [32] and [16], respectively. Two-yr mean fresh tuber yield regardless of K fertilization rate increased under Gbazeoute variety (65.5 Mg ha<sup>-1</sup>) by 68.4 and 44.3 % as compared with KH (38.9 Mg ha<sup>-1</sup>) and Moya (45.4 Mg ha<sup>-1</sup>) varieties, respectively, while yield under Moya was superior to that of KH by 16.7% (Table 2). This indicated that yield potential in the agro ecosystem was highest, intermediate and lowest for V1, V3 and V2, respectively.

In the first year of the study and within the three varieties, fresh tuber yield was in general similar for the three fertilizer K application rates (Table 2). The limited yield response to fertilizer K might be explained by the soil nutrient particularly K content (76.8 mg kg<sup>-1</sup>) at the onset of the experiment that presumably masked the K fertilizer effects. In the second year, the effects K fertilizer application rate and its interactions with varieties were significant. Under the Gbazeoute variety, fresh tuber yield increased by 18.2% (from 58.1 to 68.7 Mg ha<sup>-1</sup>) and by 2.9% (from 58.1 to 59.8 Mg ha<sup>-1</sup>) when applied K fertilizer rate was increased from 0 to 50 and 0 to 100 kg ha<sup>-1</sup>, respectively, but decreased by 12.9% when applied K fertilizer was increased from 50 to 100 kg ha<sup>-1</sup>. For the KH variety, fresh tuber yield increased by 48.1 % (from 23.5 to 34.8 Mg ha<sup>-1</sup>) and 28.83% (from 23.5 to 32.3 Mg ha<sup>-1</sup>) when applied K fertilizer rate was increased from 0 to 50 and 0 to 100 kg ha<sup>-1</sup>, respectively, but decreased by 7.2% when applied K fertilizer was increased from 50 to 100 kg ha<sup>-1</sup>. Fresh tuber yield under the Moya variety increased by 25.5% (from 33.7 to 42.3 Mg ha<sup>-1</sup>) and 34.7% (from 33.7 to 45.4 Mg ha<sup>-1</sup>) when applied K fertilizer rate was increased from 0 to 50 and 0 to 100 kg ha<sup>-1</sup>, respectively, and increased by 7.3% (from 42.3 to 45.4 Mg ha<sup>-1</sup>) when applied K fertilizer was increased from 50 to 100 kg ha<sup>-1</sup> (Table 2). These results indicated that the three varieties were responsive to applied fertilizer K rate with the

response being highest, intermediate and lowest for the KH, Moya and Gbazeokute varieties, respectively. However, for all three varieties, the response was clearly significant only for K fertilizer increase from 0 to 50 kg K ha<sup>-1</sup>. Beyond the rate of 50 kg K ha<sup>-1</sup> cassava tuber yield decreased (for the Gbazeokute and the KH varieties) or was similar to yield under the 50 kg K ha<sup>-1</sup> rate (for the Moya variety) (Table 2). Reference [14] studied cassava response to fertilizer K in the forest-savanna transition zone of Ghana and found that addition of 30 kg K ha<sup>-1</sup> made a significant contribution to fresh tuber yields, increasing 28 to 40% over the 0 kg K ha<sup>-1</sup> treatment: their optimal rate of 30 kg K ha<sup>-1</sup> was lower than the 50 kg K ha<sup>-1</sup> from our study but the 28 to 40% corresponding increases are reasonably comparable to values in the range of 18 to 48% from our study. Results of this study corroborated those by [33] who reported from their study in Nigeria the rate of 50 kg K ha<sup>-1</sup> as the optimal K fertilizer application rate for cassava storage root production. Furthermore, findings from our study agreed well with [10] who indicated that K deficiency in cassava can be corrected by the application of 50-100 kg ha<sup>-1</sup> of K as KCl, with rates being dependent on soil fertility status, and [34] who stated that the high rate of fertilizer application had no beneficial effect on cassava yields, but increased the P and K levels in the soil.

### 3.3. Stover Yield

Table 2 shows that stover yield ranged on an overall basis from 45 to 76 Mg ha<sup>-1</sup>, which was reasonably similar to values ranging from 45 to 67 Mg ha<sup>-1</sup> reported by [22]. Two-yr mean stover yield values regardless of K fertilization rate decreased under Gbazeokute variety (52.2 Mg ha<sup>-1</sup>) by 12.6 and 18.7% as compared with KH (59.7 Mg ha<sup>-1</sup>) and Moya (64.2 Mg ha<sup>-1</sup>) varieties, respectively, while yield under KH was 7.0% lower than that for Moya (Table 2). These results indicated that the potential for stover production varied among varieties, being lower for the Gbazeokute variety than that for the two other varieties, and thus corroborate research findings published by [32] and [22]. In the first year of the study and under each of the three varieties, stover yield typically was not responsive to K fertilizer rate of application (Table 2), and this might be in part a result of soil initial conditions in terms of nutrient particularly K content. In year-two of the experiment, the lack of response to K fertilization rate persisted under the Gbazeokute variety, clearly indicating that the variety utilized K fertilizer primarily for tuber production at the expense of the above ground biomass growth. This trend in the variety K utilization systematically differed from research results by [22] who reported luxuriant top at the expense of tuber growth. For

the KH variety, increasing K fertilizer from 0 to 50 kg K ha<sup>-1</sup> resulted in a significant increase in stover yield (of typically 24%) but further addition of K did not result in a significant increase of stover yield (Table 2). A similar stover yield pattern was observed under the Moya variety except that in this case K fertilization rate above 50 kg K ha<sup>-1</sup> decreased stover yield. Reference [14] found that stover yield was responsive to K fertilizer rate of application up to 90 kg K ha<sup>-1</sup>.

### 3.4. Harvest Index

The harvest index values typically ranged from 39 to 60% (Table 2), which agreed well with values ranging from 41 to 55, 53 to 63 and 55 to 67% published by [14], [35] and [36], respectively. Two-yr mean harvest index values increased under Gbazeokute variety (55.7%) by 41 and 34.5 % as compared with KH (39.5%) and Moya (41.4%) varieties, respectively, while value under KH was 4.6% lower than that for Moya (Table 2). These results demonstrated that the Gbazeokute variety was more efficient than the two other varieties in redistributing photosynthate and conversion of assimilates from leaves and stems into the tubers. During the experiment, vegetative growth under the KH and Moya varieties was more vigorous than under Gbazeokute, which according to [35] was a demonstration of the limited capacity of KH and Moya to allocate the assimilates to the storage roots. The fertilization level did not significantly affect the harvest index within each of the three varieties (Table 2), indicating that there was no luxuriant consumption as a result of fertilization rate. However, [14] found that the HI was reduced by fertilizing with K probably due to excessive stover production.

## 4. Conclusions

Increasing cassava tuber and stover yields on West African ferralsols requires the use of K fertilizer. Gbazeokute, KH and Moya were differently responsive to K fertilizer rate of application, but for the three varieties the optimum K fertilizer application rate was 50 kg K ha<sup>-1</sup>, and application at rates beyond was not justified. Gbazeokute provided the highest tuber yield and harvest index and the lowest stover yield, and thus proved superior over KH and Moya in efficiently allocating assimilates to storage roots at the expenses of the stover. The use of 50 kg K ha<sup>-1</sup> together with 60 kg N ha<sup>-1</sup> and 60 kg P ha<sup>-1</sup> (N<sub>60</sub>P<sub>60</sub>K<sub>50</sub> kg ha<sup>-1</sup>) under the Gbazeokute variety may be a recommended practice towards sustaining improved cassava production on the inherently degraded West African ferralsols.

Table 2. Mean cassava yield (Mg ha<sup>-1</sup>) and harvest index.

Treatment	Tuber weight (Mg ha <sup>-1</sup> )			Stover weight (Mg ha <sup>-1</sup> )			Harvest index (%)		
	Year 1	Year 2	Average	Year 1	Year 2	Average	Year 1	Year 2	Average
V1T1	68.0 <sup>a</sup>	58.1 <sup>a</sup>	63.1 <sup>a</sup>	45.3 <sup>a</sup>	58.1 <sup>a</sup>	51.7 <sup>a</sup>	60.0 <sup>a</sup>	50.0 <sup>a</sup>	55.0 <sup>a</sup>
V1T2	71.3	68.7 <sup>b</sup>	70.0 <sup>b</sup>	47.2 <sup>a</sup>	59.2 <sup>a</sup>	53.2 <sup>a</sup>	60.0 <sup>a</sup>	53.7 <sup>a</sup>	56.9 <sup>a</sup>
V1T3	67.1	59.8 <sup>a</sup>	63.4 <sup>a</sup>	47.5 <sup>a</sup>	55.9 <sup>a</sup>	51.7 <sup>a</sup>	58.5 <sup>a</sup>	51.7 <sup>a</sup>	55.1 <sup>a</sup>
Mean	68.8	62.2	65.5	46.7	57.7	52.2	59.6	51.8	55.7
V2T1	49.6 <sup>b</sup>	23.5 <sup>c</sup>	36.6 <sup>c</sup>	64.0 <sup>b</sup>	46.1 <sup>b</sup>	55.0 <sup>a</sup>	43.7 <sup>b</sup>	33.8 <sup>b</sup>	40.0 <sup>b</sup>

Treatment	Tuber weight (Mg ha <sup>-1</sup> )			Stover weight (Mg ha <sup>-1</sup> )			Harvest index (%)		
V2T2	47.2b	34.8d	41.0d	68.4b	57.0a	62.7b	40.8b	37.9b	39.4b
V2T3	46.0b	32.3d	39.2cd	65.7b	56.7a	61.2b	41.2b	36.3b	38.7b
Mean	47.6	30.2	38.9	66.0	53.3	59.7	41.9	36.0	39.5
V3T1	48.5b	33.7d	41.1d	76.8c	55.2a	66.0b	38.7b	37.9b	38.3b
V3T2	56.7c	42.3e	49.5e	72.1c	67.1c	69.6b	44.0b	38.7b	41.6b
V3T3	46.6b	45.4e	45.5d	60.5d	53.5a	57.0a	43.5b	45.4a	44.4b
Mean	50.6	40.1	45.4	69.8	58.6	64.2	42.1	40.6	41.4

¶ Means within the same column not followed by letters or followed by the same letter are not significantly different at  $\alpha = 0.05$ . The comparisons were adjusted by a Bonferroni correction for multiple comparisons.

## References

- [1] H. P. Liniger, R. Mekdaschi Studer, C. Hauert, and M. Gurtner, "La pratique de la gestion durable des terres. directives et bonnes pratiques en Afrique subsaharienne," TerrAfrica, Panorama mondial des approches et technologies de conservation (WOCAT) et Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO). Rome, Italie, 243p, 2011.
- [2] A. Burns, R. Gleadow, J. Cliff, A. Zacarias, T. Cavagnaro T. "Cassava: the drought, war and famine crop in a changing world," Sustainability, Vol. 2, pp. 3572-3607, 2010.
- [3] D. Baulcombe, I. Crute, B. Davies, J. Dunwell, M. Gale, J. Jones, J. Pretty, W. Sutherland, C. Toulmin, N. Green, et al. "Reaping the benefits: science and the sustainable intensification of global agriculture," Roy. Soc. London, 2009.
- [4] A. Challinor, T. Wheeler, C. Garforth, P. Craufurd, A. Kassam, "Assessing the vulnerability of food crop systems in Africa to climate change," Climatic Change, vol. 83, pp. 831-399, 2007.
- [5] D. Cordell, J. O. Drangert, S. White, "The story of phosphorus: global food security and food for thought," Global Environ. Change, vol. 19, pp. 292-305, 2009.
- [6] E. A. Frison, E. Feliu, "FAO/IBPGR Technical Guidelines for the Safe Movement of Cassava Germplasm," Food and Agriculture Organization of the United Nations, Rome/International Board for Plant Genetic Resources, Rome, 48 pp, 1991.
- [7] IFDC, International Fertilizer Development Center, "Mainstreaming pro-poor fertilizer access and innovative practices in West Africa," IFAD Technical Assistance Grant No. 1174 report. Muscle Shoals, Alabama, 2013.
- [8] S. O. Ojeniyi, S. A. Adejoro, O. Ikotun, O. Amusan, "Soil and plant nutrient composition, growth and yield of cassava as influenced by integrated application of NPK fertilizer and poultry manure," New York Sci. J. vol. 9, pp. 62-68, 2012.
- [9] S. O. Ojeniyi, P. O. Ezekiel, D. O. Asawalam, A. O. Awo, S. A. Odedina, J. N. Odedina, "Root growth and NPK status of cassava as influenced by oil palm bunch ash," Afr. J. Biotechnol. Vol. 8, pp. 4407 – 4412, 2009.
- [10] P. Imas, K.S. John, "Potassium nutrition of cassava" International Potash Institute. Research Findings, Baumgärtlistrasse 17, 8810 Horgen, Suisse, pp. 13-18, 2013.
- [11] J. R. Hillocks, J. M. Thresh, C. A. Bellotti, "Cassava: biology, production and utilization," CABI Publishing: Oxon, UK, 2002.
- [12] T. M. Dahniya, "An overview of cassava in Africa," Afr. Crop Sci. J. vol. 2, pp. 337-343, 1994.
- [13] H. R. Howeler, "Cassava mineral nutrition and fertilization," In: Hillocks, R.J., Thresh J.M. and Bellotti, A.C. (eds.) Cassava: biology, production and utilization. CAB International, UK, pp. 115-147, 2002.
- [14] S. Agyenim Boateng, S. Boadi, "Cassava yield response to sources and rates of potassium in the forest-savanna transition zone of Ghana," Afr. J. Root and Tuber Crops, vol. 8, pp. 1-15, 2010.
- [15] O. G. Agbaje, A. T. Akinlosotu, "Influence of NPK fertilizer on tuber yield of early and late planted cassava in a forest alfisol of south-western Nigeria," Afr. J. Biotechnol, Vol. 3, pp. 547–551, 2004
- [16] P. Akanza Kouadjo, A. Yao-Kouame, "Fertilisation organo-minérale du manioc (*Manihot esculenta* Crantz) et diagnostic des carences du sol," J. Appl. Biosci, vol. 46, pp. 3163– 3172, 2011.
- [17] N. R. Issaka, M. M. Buri, D. Asare, K. J. Senayah, A. M. Essien, "Effects of cropping system and mineral fertilizer on root yield of cassava," Agric. Food Sci. J. Ghana, vol. 6, pp. 445-458, 2007.
- [18] B. Vanlauwe, P. Pypers, N. Sanginga, "The potential of integrated soil fertility management to improve the productivity of cassava-based systems," In: Cassava: Meeting of the Challenges of the New Millennium: Proceedings of the First Scientific Meeting of the Global Cassava Partnership 21-25 July 2008, Ghent, Belgium. Institute of Plant Biotechnology for Developing Countries (IPBO), Ghent University, Ghent, Belgium, 2008.
- [19] H. R. Howeler, "Long-term effect of cassava cultivation on soil productivity," Field Crop. Res, vol. 26, pp. 1-18, 1991.
- [20] B. P. Boakye, O. Kwadwo, K. Asante Isaac, Y. E. Parkes, "Performance of nine cassava (*Manihot esculenta* Crantz) clones across three environments. J. Plant Breed. Crop Sci, vol. 5, pp. 48-53, 2013.
- [21] G. Ssemakula, A. Dixon A, "Genotype X environment interaction, stability and agronomic performance of carotenoid-rich cassava clones," Scientific Research and Essay. 2 (9)390-399, 2007.
- [22] Y. E. Parkes, K. F. D. Allotey, E. Lotsu, A. Akuffo, "Yield performance of five cassava genotypes under different fertilizer rates," Intl. J. Agric. Sci, vol. 2, pp. 173-177, 2012.
- [23] IFA, International Fertilizer Agency, IFA World Fertilizer Use Manual. International Fertilizer Industry Association, Paris, 1992.

- [24] H. Saragoni, R. Olivier, R. Poss, "Dynamique et lixiviation des éléments minéraux," *Agron. Trop.*, vol. 45, pp. 259-273, 1991.
- [25] M. H. van Es, C. L. van Es, "Spatial nature of randomization and its effect on the outcome of field experiments," *Agron. J.*, vol. 85, pp. 420-428, 1993.
- [26] M. H. van Es, C. Gomes, M. Sellmann, C. L. van Es, "Spatially-balanced designs for experiments on autocorrelated fields," In: 2004 Proc. Am. Statistical Assoc., Statistics & the Environment Section [CDROM], Alexandria, VA, 2004.
- [27] IITA, International Institute for Tropical Agriculture, "Automated and Semi-automated Methods for soil and plant analysis," IITA, Ibadan, Nigeria, 2014.
- [28] SAS Institute. Base SAS 9.4 Procedures Guide. SAS Institute, Cary, NC, 2014.
- [29] K. B. Tossah, "Influence of soil properties and organic inputs on phosphorus cycling in herbaceous legume-based cropping systems in the West African derived savanna," Ph.D. Thesis No. 428, K.U. Leuven, Belgium, 2000.
- [30] T. B. Kang, E. J. Okeke, "Nitrogen and potassium responses of two cassava varieties grown on an alfisol in southern Nigeria," In: Proceedings, 6<sup>th</sup> symposium of the International Society of Tropical Root Crops, 1984, Lima, Peru, pp. 231-234, 1984.
- [31] D. K. Asare, E. O. Ayeh, G. Amenorpe, "Response of rainfed cassava to methods of application of fertilizer-nitrogen in a coastal savannah environment of Ghana," *World J. Agric. Sci.*, vol. 5, pp. 323-327, 2009.
- [32] P. B. Boakye, O. Kwadwo, K. Asante Isaac, E. Y. Parkes, "Performance of nine cassava (*Manihot esculenta* Crantz) clones across three environments," *J. Plant Breed. Crop Sci.*, Vol. 5, pp. 48-53, 2013.
- [33] D. A. Okpara, U. S. Agoha, M. Iroegbu, "Response of cassava variety TMS/98/0505 to potassium fertilization and time of harvest in South Eastern Nigeria," *Nigeria Agric. J.*, vol. 41, pp. 91-100, 2010.
- [34] H. R. Howeler, L. F. Cadavid, "Short- and long-term fertility trials in Colombia to determine the nutrient requirements of cassava," *Fert. Res.*, vol. 26, pp. 61-80, 1990.
- [35] E. Sagrilo, P. S. V. Filho, M. G. Pequeno, M. C. Gonçalves-Vidigal, M. V. Kvitschal, "Dry matter production and distribution in three Cassava (*Manihot esculenta* Crantz) cultivars during the Second vegetative plant cycle," *Braz. arch. biol. technol.*, vol. 51, pp. 1079-1087, 2008.
- [36] G. C. Daellenbach, P. C. Kerridge, M. S. Wolfe, E. Frossard, M. R. Finckh, "Plant productivity in cassava-based mixed cropping systems in Colombian hillside farms," *Agric. Ecosyst. Environ.*, 105, pp. 595-614, 2005.