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Assessment of Soil Nutrient Balances in Organic Based Cassava (*Manihot esculenta* Crantz) and Sorghum (*Sorghum bicolor* (L.) Moench) Cropping Systems of Yatta Subcounty, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NLN and RNO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CMO, GNK and VMK managed the analyses of the study. Authors NLN and RNO managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Long-term food production in developing countries is under threat due to soil nutrient mining resulting from unsustainable production practices. In this study, the sustainability of various cropping systems and organic input combinations were assessed through monitoring nutrient flows and balances at crop production level. The study was conducted in Katangi and Ikombe divisions of Kitui sub-county between October 2010 and August 2012. A randomised complete block design with a split plot arrangement was used. The main plots were three cropping systems: (i) Intercropping (Dolichos [Lablab

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purpureus]/Cassava, Dolichos/Sorghum, Pigeon pea [*Cajanus cajan* (L.) Millsp.]/Sorghum, Pigeon pea/Cassava); (ii) Rotation (Dolichos-Cassava, Dolichos-Sorghum, Pigeon pea-Cassava, Pigeon pea-Sorghum); (iii) Monocrop (pure cassava and sorghum). The split plots were; farm yard manure (FYM), compost and control. All crops had above ground biomass incorporated after harvest in the same plot they were harvested from. Nutrient flows; nitrogen (N), phosphorus (P) and potassium (K), were monitored for four seasons; short rain season (SRS) of 2010, long rain season (LRS) of 2011, SRS of 2011 and LRS of 2012 using NUTMON toolbox. There were no significant differences in nutrient balances between the four seasons except in sorghum based cropping systems where N and P balances were significantly lower in the second year. Losses across the seasons occurred mainly through harvested products in both sorghum and cassava cropping systems while addition mainly occurred through biological N fixation and incorporation of crop residue. Negative NPK balances were found in cassava than sorghum-based cropping systems regardless of legumes used in both sites. Dolichos rotation with sorghum and compost applied resulted in positive N balances. Dolichos-cassava rotation with compost also had reduced N losses compared to when pigeon pea was used. P losses were less negative under pigeon pea-sorghum and pigeon pea-cassava rotation with FYM applied. Pigeon pea rotation with sorghum and FYM applied resulted in reduced K losses while with cassava the same cropping system was superior but with application of compost. The choice of legume and organic input for use would depend on environment farmer operates in. In N, P and K limited environments; dolichos rotation with compost application, pigeon pea rotation plus FYM and, pigeon pea-sorghum rotation plus FYM and pigeon pea-cassava rotation with compost applied would, respectively, be recommended as farming practices.

Keywords: Agroecological intensification; compost; farm yard manure; intercropping; NUTMON toolbox; organic inputs; rotation.

1. INTRODUCTION

Per capita agricultural production in sub-Saharan Africa (SSA) continues to decline thus presenting a serious challenge to food security. Rapid population growth and the need to integrate into the monetary economy has forced farmers to increase production of staple food and cash crops which are heavily reliant on external inorganic inputs [1]. However, these inorganic inputs are either not used at all or applied in suboptimal quantities due to their unavailability and high cost [2]. As a result, most of the income in subsistence-oriented farms is based on nutrient mining putting in danger long-term sustainability of the agricultural production system [3].

To achieve sustainability, it is necessary that farming should make maximum use of nature's goods and services without destroying them [4]. This implies the use of agro-ecological intensification techniques, which call for promotion of biological diversity; use of locally available resources; non-use of synthetic inputs and incorporation of natural process into agricultural production [5,6]. In addition crop varieties produced should be adapted to harsh conditions that prevail in SSA specifically low soil fertility (especially N and P deficiency) and low and erratic rainfall [7,8]. Sorghum and Cassava are some of the recommended crops due to their adaptability to drought, ability to grow in low soil fertility and minimum input requirement. Cassava can also be particularly attractive to small-scale farmers due to its harvest flexibility [9,10,11]. Dual-purpose drought resistant legumes such as dolichos and pigeon pea when in rotation or intercropped with main crops can improve the physical, chemical and biological properties of soils. Organic fertilizers could also be used to improve the soil properties. This would go a long way into increasing food availability and incomes for small-scale farmers and hence improve sustainability of the agricultural system [12,13,14,15].

Sustainability of agricultural production systems and its accurate assessment is crucial for continued food availability in the future [16]. Quantification of nutrient balances can be used as quantifiable indicators of agricultural sustainability [17]. NUTrient MONitoring (NUTMON) is widely considered as a particularly useful tool in this regard as it can be used to assess the effects of various nutrient management strategies on nutrient balances as it employs relatively easy to quantify data to estimate flows [18]. NUTMON has been applied at various levels to study ecological sustainability of various nutrient management strategies in different environments [19,20,21,3,22]. However, limited studies under experimental conditions have been done to determine the combined effects of various cropping systems and organic inputs on nutrient balances at crop activity levels. The current study aimed at monitoring nutrient balances in organic based cassava and sorghum cropping systems as a basis for determining their sustainability.

2. MATERIALS AND METHODS

2.1 Study Site

On-farm trials were conducted in Katangi and Ikombe divisions of Yatta Sub-county of Machakos County, which lies in agroclimatic zone IV classified as semi-arid [23]. The study was conducted for 2 years (from October 2010 to August 2012) which constituted four seasons of experimentation. The two seasons in a year are the short (SRS) occurring from October to December and Long rain season (LRS) from march/April to May (Fig. 1).

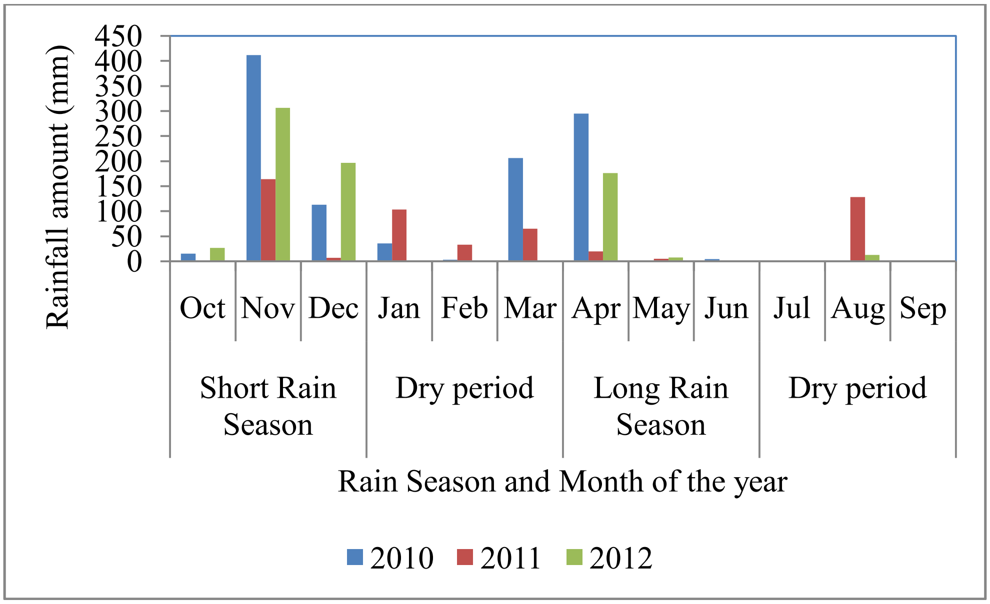

Fig. 1. Total rainfall received during the experimental period
Dry period - Season usually classified as dry period but (with intermittent rainfall) this is no longer the case due to climate change

The first year of experimentation was the SRS of 2010 and LRS of 2011 while the second year was SRS of 2011 and LRS of 2012. Cumulative rainfall received during the SRS of 2010 (season 1) was 539.4 mm; LRS of 2011 (season 2) 501.7 mm; SRS of 2011 (season 3) 171.3 and LRS of 2012 (season 4) 90.6 mm.

Soils of the study area mainly consist of Ferric Luvisols, Lithisols and Rhodic Ferralsols [23; 24] with nitrogen, phosphorous and organic matter being the main limiting nutrients [25]. Soil properties prior to experimental set-up in Katangi were: of clay texture, moderate bulk density [26], moderate organic C, Low nitrogen, high potassium and moderate phosphorus (Table 1). For Ikombe, the initial soil properties were: sandy clay loam texture, low bulk density (Hazelton and Murphy, 2007), low OC, low nitrogen, high phosphorous and moderate potassium (Table 1) according to Landon and Brown [27].

Table 1. Initial physical and chemical soil properties at the experimental sites

Soil properties	Katangi	Ikombe
Bulk density	1.36	1.11
Sand (%)	40	58
Silt (%)	17	19
Clay (%)	43	23
Textural class	Clay	Sandy clay loam
pH (H_2O)	6.31	6.49
pH ($CaCl_2$)	5.67	5.89
EC (dsm^{-1})	0.2	0.2
C (%)	1.17	0.74
N (%)	0.18	0.09
Na (cmol/kg)	0.38	0.38
K (cmol/kg)	0.98	0.75
CEC (cmol/kg)	20.1	8.1
P (ppm)	5.25	26.25

2.2 Treatments and Experimental Design

The treatments consisted of three cropping systems and two organic inputs with a control. The cropping systems; were monocropping, intercropping and rotation of a test crop with either dolichos or pigeon pea. The test crops (TC) were sorghum and cassava. Organic inputs used were compost and Farmyard manure (FYM). This resulted in fifteen treatment combinations for each TC (Table 2). All crops had above ground biomass incorporated after harvest in the same plot they were harvested from.

The experimental setup was a Randomized Complete Block Design with a split plot arrangement replicated three times. The main plots (10m x 10m) were cropping systems while split-plots (3m x 10m) were organic inputs each applied at the rate of 5 tha-1 (Fig. 2).

2.3 Field Practices

Primary land preparation was done using oxen plough and thereafter hand hoes were used during secondary cultivation. Fifteen kilograms of FYM and compost per split plot (translating into a rate of 5t ha^{-1}) were applied (Table 3) and thoroughly mixed with soil.

Table 2. Treatments used in the trial fields

	Sorghum cropping systems		
	Treatment no.	**Cropping system**	**Organic input (5t ha^{-1})**
Monocrop	1	TC	FYM
	2	TC	Compost
	3	TC	Control
Rotation	4	Pigeon pea-TC rotation	FYM
	5	Pigeon pea-TC rotation	Compost
	6	Pigeon pea-TC rotation	Control
	7	Dolichos-TC rotation	FYM
	8	Dolichos-TC rotation	Compost
	9	Dolichos-TC rotation	Control
Intercropping	10	TC pigeon pea intercrop	FYM
	11	TC pigeon pea intercrop	Compost
	12	TC pigeon pea intercrop	Control
	13	TC Dolichos intercrop	FYM
	14	TC Dolichos intercrop	Compost
	15	TC Dolichos intercrop	Control

TC = Test crop (Sorghum and Cassava)

			2010		2011	2012
Cropping system	Description	Crops	SRS	LRS	SRS	LRS
Monocrop	Sorghum monocrop	Sorghum	▨	▨	▨	▨
	Cassava monocrop	Cassava	▨	▨	▨	▨
Rotation	Dolichos-sorghum rotation	Dolichos	▨		▨	
		Sorghum		▨		▨
	Pigeon pea-sorghum rotation	Pigeon pea	▨		▨	
		Sorghum		▨		▨
	Dolichos-cassava rotation	Dolichos	▨			▨
		Cassava		▨	▨	
	Pigeon pea- cassava rotation	Pigeon pea	▨			▨
		Cassava		▨	▨	
Intercropping	Legume sorghum intercrop	Dolichos/sorghum	▨	▨	▨	▨
		Pigeon pea/sorghum	▨	▨	▨	▨
	Legume cassava intercrop	Dolichos/cassava	▨	▨	▨	▨
		Pigeon pea/sorghum	▨	▨	▨	▨

Fig. 2. Cropping sequence during the four seasons experimental period

Table 3. Chemical characteristics of compost and FYM

Organic input property	**FYM**	**Compost**
N (%)	2.71	2.55
P (%)	1.01	0.74
K (%)	3.9	1.81
OC (%)	35	35.60
pH(H_2O)	8.6	9.26
C:N Ratio	12.92	13.96

Planting of crops was done manually by direct placement of seeds/cuttings into planting holes. Cassava variety Muceliceli, sorghum variety Gandam, pigeon pea variety KAT 60/8, and dolichos black variety were planted with sole crops spaced at 1m x 1m (cassava), 0.75 x 0.25 (sorghum), 0.75 by 0.3 m (dolichos) and 0.75 x 0.50 m (pigeon pea). All the crops for intercrop (pigeon pea or dolichos) were sown in rows between sorghum and cassava at the same inter-plant spacing as in pure stands. Weeding was regularly done using hand hoes.

During the subsequent planting seasons, land preparation was done using hand hoes. This was done to avoid mixing of organic inputs from one plot to another. Immediately after harvesting, above ground biomass of crops was weighed, chopped into small pieces and incorporated in the same plots.

2.4 Mapping Nutrient Flows in and Out of the Farm

Resource flow monitoring for quantification of nutrient balances, was monitored for four seasons at plot level (October 2010 to July 2012) using the farm-NUTMON approach [3]. Under this methodology, the farm is conceptualized as a set of dynamic units which form the destination and/or source of nutrient flows depending on the type of management adopted. The farm units distinguished under this methodology are [3].

2.4.1 Farm section units (FSUs)

Areas within the farm with relatively homogenous properties Primary Production Units (PPUs)/Crop activities. Piece of land with different possible activities such as crops, pasture, a fallow. Usually a PPU is located in one or more FSUs.

Secondary production Units (SPUs)/Livestock activities: Group of animals within the farms that are under the same type of management.

2.4.2 Redistribution unit (RUs)

These are nutrient storage locations within the farm from which nutrient gather and later on redistributed.

2.4.3 House hold (HH)

Group of people who usually live in the same house and share food regularly.

2.4.4 Stock

These are the amount of crop products and chemical fertilizers stored for later use.

2.4.5 Outside (EXT)

The external nutrient pool which are the source and destination of nutrient but is itself never monitored. It includes markets, other families and neighbours.

Under this approach, side boundaries of the farm are its physical borders with the upper boundary being the atmosphere-soil interface, the lower boundary is considered to be 30 cm below the soil surface. Calculation of nutrient balances takes into account a set of five inflows: IN1-mineral fertilizer, IN2-organic inputs, IN3-atmospheric deposition, IN4-biological nitrogen fixation and IN5-sedimantation and six outflows. Inflows; OUT1-farm products, OUT2-other organic inputs, OUT3-leaching, OUT4-volatization, OUT 5-erosion and OUT6-human execrate.

Since the current study considered nutrient balances at only crop activity level under experimental conditions, the farm NUTMON approach needed to be customised. The external boundaries were the experimental area, whereas the Farm Section Units (FSUs) were the replicates/blocks, the primary production units (PPUs) were the plots (i.e. the fifteen cropping systems and organic input combinations).

In order to customize the study, certain elements of the concept by de Jager et al. [1] such as nutrient inputs through mineral fertilizer (IN 1) were ignored since the experiment did not involve use of any inorganic materials. De Jagger, [1] also envisions inputs of nutrient into a system through sedimentation (IN 5) can only occur under irrigation. The amount of nutrient supplied through subsoil exploitation (IN 6) is usually ignored due to difficulties in its determination and its relatively smaller contribution to the total nutrient balances. Since the experiment took place under rainfed conditions, IN 5 was similarly ignored. Nutrient flows into PPUs were identified as organic fertilizers (IN 2), atmospheric deposition (IN 3) and biological nitrogen fixation (IN 4) and returned plant residue (OUT 2). For cassava however, no plant residues were returned which represented the common practices of removing stems from the field after harvest and preserving them for the next planting, use as firewood or sold. Nutrient output flows were identified as crop harvest (OUT 1), leaching (OUT 3), volatization (OUT 4) and soil erosion (OUT 5) (Fig. 3).

2.5 Calculation of Nutrient Balances

For the quantification of nutrient flows for calculation of balances, methods utilized included (i) sampling and analysis of product flows for N, P and K, (ii) use of transfer functions and (iii) other approaches using sub-models and assumptions [28].

2.6 Soil Sampling and Analysis

Soil samples for quantification of stocks were randomly sampled at 0-30 cm depth and mixed thoroughly to make composite sample. The soil chemical parameters analyzed were total N, available phosphorous, soil organic carbon and exchangeable potassium. Physical properties analysed included bulk density and texture. Soil analysis was done according to the methods described in Okalebo et al. [29].

2.7 Plant Sampling and Analysis

Sampling and analysis of crop products was used to quantify flows such as IN 2, OUT 1 and OUT 2. Sorghum, pigeon pea and dolichos were harvested three months after planting while cassava was harvested eleven months after planting. Sampling for sorghum, pigeon pea and dolichos was done from the middle rows of each subplot while cassava was sampled from a quadrant area of $4m^2$. Plants from net plot area within inner rows were harvested by cutting the stem immediately above ground. They were then heaped and left for drying. The dried plants were threshed to separate seeds from pods. For cassava, harvesting required digging around the base of individual plants within the net plot area using hand tools and then uprooting the whole plant. Thereafter, the stem was separated from the tuber. The grain, stover and tuber yields were then weighed. Product flows were quantified by extrapolating the recorded yield to $kgha^{-1}$. Absolute amounts of nitrogen, potassium and phosphorous in the product flows were calculated using the nutrient contents of the organic inputs, tubers and seeds of sorghum, dolichos and pigeon pea. The sampled grain and tubers were oven dried at 600C to a constant weight. Nutrient concentrations in seeds and tuber samples were determined by wet oxidation procedure [30] based on a Kjeldahl digestion using H_2SO_4 and H_2O_2. The N and P were determined colorimetrically, while K was measured by flame photometry.

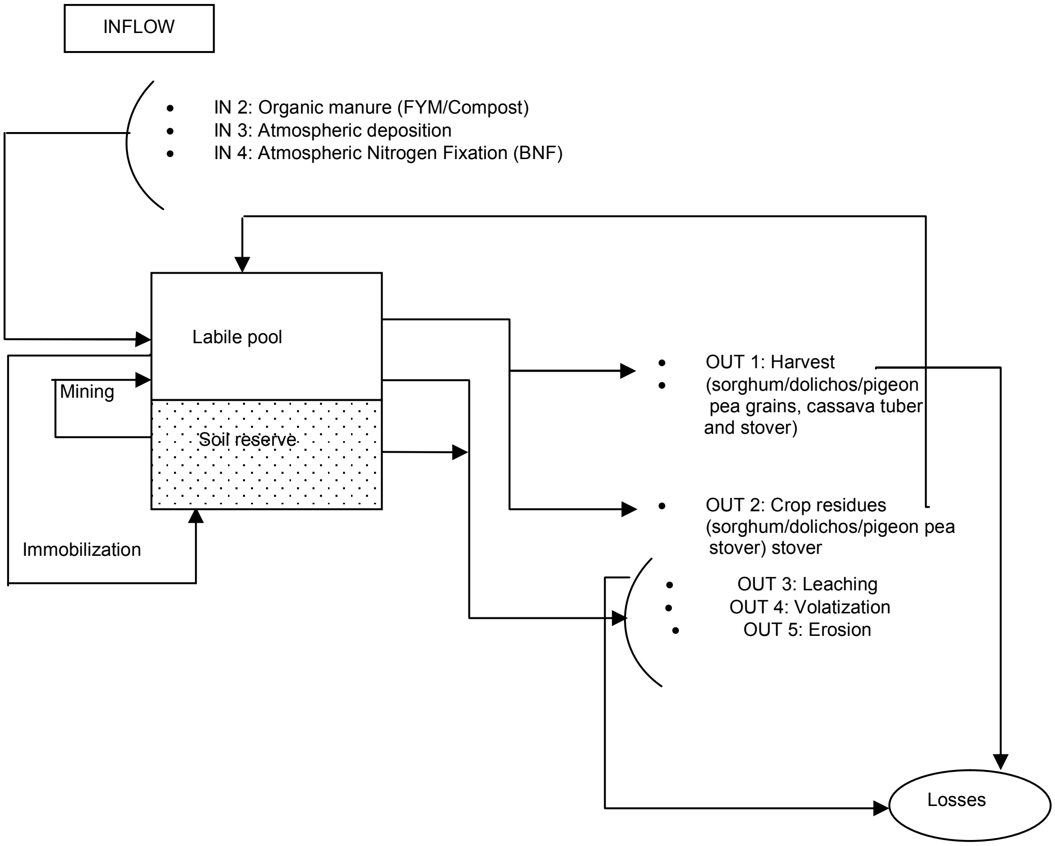

Fig. 3. Modified Concept of on farm nutrient management (modified from Surendran and Mugurapan, 2010)

2.8 Use of Transfer Functions and Assumptions

Transfer functions are used in estimating those flows which cannot be obtained by simple measurements namely IN 3, IN 4, OUT 3, OUT 4 and OUT 5. Transfer functions explain variables which are difficult to obtain as a function of parameters which are easy to obtain [31,17].

NUTMON-toolbox calculated nutrient balances by subtracting sum of nutrient outputs from sum of nutrient inputs and presents then in Kg ha^{-1}

$$Nutrient\ balance_{(N,P,K)} = \left[\sum Inputs(2,3,4)\right] - \left[\sum Outputs(1,2,3,4,5)\right]$$

Where:

Inputs 2-4 are nutrient contained in: In 2- Organic inputs, IN 3-Atmospheric deposition, IN 4- Biological nitrogen fixation.

Outputs 1-5 are nutrients contained in: OUT 1-Harvested products, OUT 2- Removed crop residues, OUT 3-Leaching, OUT 4-Volatization, OUT 5-Runoff/erosion.

Positive balances indicated that nutrients were accumulating in the soil and negative balances indicate that the soil is being mined off nutrients [32].

2.9 Statistical Analysis

NPK balances for various PPUs generated by NUTMON-toolbox were exported to Genstat for further analysis. Analysis of variance for NPK balances at plot level was done and treatment means separated using the Fisher's Protected Least Significant Difference (P = 0.05).

3. RESULTS AND DISCUSSIONS

3.1 Nitrogen Balances

Comparison between cassava based cropping systems and sorghum based cropping systems revealed significantly higher N losses in the former cropping system (Tables 4 and 5).

Losses of N in cassava based cropping systems occurred mainly through tuber and stem removal. This observations indicate that amount of N added to the systems through organic inputs and legumes BNF could not compensate for losses that occur through stover and tuber export. In fact, whenever legumes residual effects seemed to benefit the cassava crop, for example when intercropped, the increased tuber yield led to more extraction of N from soil. This observation is supported by Fermont et al. [33] who demonstrated that cassava tends to heavily mine nutrients from the soil especially when the variety used is improved and both the stem and tuber harvested. Leaching was also noted to be a major contributor to the strong N losses in cassava based cropping system. This view is supported by Howeler [34] who opined that wider crop spacing and slow initial development of cassava tends to leave most of the soil surface exposed. There were no significant differences in N balances between the two sites in both cassava and sorghum based cropping systems. Sorghum and cassava monocrop under the control experiment yielded significantly higher N losses compared to inclusion of legumes (Tables 4 and 5). The same observation was made even when organic inputs were applied though the differences under FYM were not all significant. This was due to N supplied to the systems through BNF and residue decomposition by the inclusion of legumes. Several authors have also reported that root N in legumes may significantly augment the N balance since they contain N derived from the soil as well as the atmosphere [35,36].

Dolichos-sorghum rotation with FYM (46.70) and Dolichos-sorghum rotation with compost (61.00) had significantly higher N balances compared to pigeon pea–sorghum rotation with FYM (0.53) and compost (20.71) applied in Katangi. In the second year, similar observations were made although the differences were not significant. This pattern was also repeated in

Ikombe. This observation indicated that, dolichos fixes N in quantities that can have longer lasting effects on soil compared to pigeon pea. Comparison between the intercrops under the different organic inputs also revealed that sorghum/ dolichos intercrop had significantly higher N balances compared to sorghum/pigeon pea intercrop under both FYM and compost application (Tables 4). In fact, inclusion of dolichos under FYM or compost consistently resulted in positive balances.

In cassava cropping systems, N losses under dolichos based cropping systems for any given organic inputs were also significantly lower compared to those under pigeon pea based systems (Tables 5). This was attributed to differences in amount of fixed N and N input through residues. Dolichos had higher N inputs into the systems through these avenues than pigeon pea. It has previously been reported that nitrogen fixing ability and quality and quantity of litter differ with the species of legume used [37,12,38]. Ayoub [39] also found total N yield and biologically fixed N were higher with dolichos compared to pigeon pea. He also observed that dolichos contributed more to total N budget than pigeon pea noting that pigeon pea gave highest amount of non-recoverable N (lost to the atmosphere or not readily decomposable).

Sorghum/dolichos intercrop and sorghum/pigeon pea intercrop with either compost or FYM added led to significantly lower N balances compared to their respective rotations with either of the two organic inputs added. Cassava systems had similar observations though the differences were not significant. This indicated that intercropping led to lower N balances compared to rotation regardless of the organic input used. These losses were attributed to export of N through the combined harvest of component crops in intercrop. Fermont et al. [33] and Bagayoko et al. [40] obtained similar results noting that nutrient removal from the system through harvest of the intercrops could still be higher than monocrop. Rusinamhodzi et al. [41] also observed that sole cowpea had a more positive N balances compared to when cowpea was intercropped with cotton.

The result also show that application of compost regardless of cropping system used resulted in significantly ($p \leq 0.05$) higher N balances compared to FYM and control respectively (Tables 4 and 5). For example, monocrop sorghum with compost (-1 in katangi and -2.60 in Ikombe) had resulted in reduced N losses than monocrop with FYM (-25.90 in Katangi and -27.33 in Ikombe) and monocrop sorghum control (-37.50 -37.10). This indicates that N losses were higher when FYM was applied than compost though this may not be more than when no input is applied. Higher N balances application of FYM and compost have been observed by Thai Phien and Nguyen Cong Vinh [42] who found that organic inputs could result in higher nutrient balances although this would not necessarily lead to positive balances. FYM had more negative N balances compared to compost due to it slow release of N over a long time [43] which would have stimulated higher crop yields hence more N removal through harvested products. De Jager et al. [3] also observed that higher plant productivity can enhance extraction of considerable quantities of nutrients from the soil. N balances in the second season were significantly lower only in the sorghum cropping systems. In the cassava based system, N balances were also lower in the second year though not significant. No robust explanation could be found other than the unfavourable climatic conditions that reduced BNF as well as reduced the amount of residues which were returned to the soil for decomposition [44,12,45].

3.2 Phosphorus Balances

P losses were significantly higher in the cassava than sorghum based cropping systems (Tables 6 and 7). More P losses under cassava based cropping systems was attributed to export of P through harvesting of tubers and stems.

Only during the first year in Ikombe under sorghum based cropping systems and year 1 in Katangi under the cassava based cropping systems had significant interaction effects between cropping systems and organic inputs. Under the sorghum cropping systems only pigeon-pea sorghum rotation had significantly higher P balances than monocropping (Table 6). In the cassava cropping systems at Ikombe, monocropping with cassava had significantly higher P balances than intercropping with pigeon pea and dolichos in the second year. In the first year, though not significant, monocropping had the highest P balances (Table 7).

Higher P losses in the cropping systems involving legumes could be attributed to higher uptake of P by legume crops which mostly depend on BNF for their N supply [46]. Legumes have also been shown to increase the uptake of P for the subsequent crop in rotation or the associated crop in intercropping systems [47,48]. Increased crop yields under legume rotation could have equally played a part in increased mining of P [20]. Integration of pigeon pea into the cropping systems resulted in higher P balances compared to dolichos. The data revealed that more P was lost through crop uptake under dolichos based cropping system than pigeon pea and this could be attributed to differences in acquisition efficiency of these elements by various legumes [49,50,51]. Another reason could have been that differing residual benefits between the two legumes might have resulted in increased cassava and sorghum yield hence differing levels of P. Differences in yields of the subsequent crop depending on legume used was demonstrated by Cheruiyot et al. [14] who observed the greatest increase in biomass and grain yield of maize following dolichos. Furthermore, rotation with pigeon pea resulted in higher P balances compared to intercropping. Dolichos used in rotation had less P losses compared to intercropping. Intercropping resulted in stronger P losses than rotation in both cassava and sorghum based cropping systems (Tables 6 and 7) mainly due to nutrient removal from the system through harvest of the intercrops.

Pigeon pea-sorghum rotation with FYM application at Ikombe in year 2 resulted in significantly ($p \leq 0.05$) higher P balances than sorghum-pigeon pea rotation with compost (Table 6). At Katangi, FYM application also significantly reduced P losses relative to compost and control in sorghum based cropping systems. Similar observations were made at Ikombe in year 2 (Table 6). This was due to higher P input through FYM as well as higher biomass production, which could have led to more P release upon decomposition. Mpairwe et al. [52] had also noted an increased biomass production due to application of manure. In cassava systems however, application of compost at Ikombe in season 1 and in season 2 at katangi resulted in less P losses than FYM (Table 7). Further, pigeon pea-cassava rotation with compost application had higher P balances than pigeon pea-cassava with FYM. It was observed that the main contributing factor was the uptake of P through biomass which was removed at harvest. Losses of P in second year were significantly ($p \leq 0.05$) higher under sorghum based cropping systems in the first year probably due to reduced productivity of the crops hence low amount of residue available for decomposition. Bauer and Black [53] similarly observed that plant productivity was closely linked to organic matter available for decomposition hence affecting the quantity of P released.

3.3 Potassium Balances

K balances were negative across organic inputs except when monocropping or pigeon pea was used in rotation and/or intercrop and FYM applied. In cassava cropping systems very high K losses were observed across all the cropping systems and organic inputs (Tables 8 and 9).

The high K losses in both cassava and sorghum based cropping systems occurred mainly through harvesting of crop products. This confirms observation by Murugappan et al. [54] that mining of soil K always occurred regardless of whether K is added or not due to luxury consumption of K by most crops. Comparison between the cassava based cropping systems and sorghum based cropping systems revealed K losses were significantly higher in cassava compared to sorghum based cropping systems. Increased losses in the cassava based cropping systems mainly occurred due to tuber and stover harvest. This observation concurs with Howeler [55] who noted that cassava is highly responsive to K hence mines the soil of very high quantities of K when tubers are harvested. Increased K losses through biomass have also been reported by Smalling [56] who found that most K losses occurred due to export of harvested residue. In Katangi, sorghum monocrop with FYM (16.63) had significantly lower K losses than either sorghum/pigeon pea intercrop with FYM (4.67) applied or sorghum/dolichos intercrop with FYM (-26.63) application. Monocropping with compost applied still yielded significant K losses (-40.37) than pigeon pea-sorghum rotation with FYM sorghum/pigeon pea intercrop (-12.37) and sorghum/dolichos intercrop (-40.17). Although not significantly different, comparison between rotation and monocropping under a given organic input equally resulted in lower K balances in the monocrop (Table 8). This observation indicates that monocropping depleted the soil off K compared to legume rotation mainly due increased yields of the subsequent crop which increased amount of K released through decomposition of residues. Similarly, cassava monocrop resulted in lower K losses compared to legume-based systems though the difference was not significant under pigeon pea-sorghum rotation.

Intercropping with a legume under a given organic inputs also resulted in lower K balances compared to the equivalent rotation. For instance, sorghum/pigeon pea intercrop with FYM had significantly lower (4.67) K balances than pigeon pea-sorghum rotation with FYM (13.60). Similarly under the cassava plots, the main effects of cassava/pigeon pea intercrop resulted in significantly lower K balances than pigeon pea-cassava rotation. Inclusion of legumes into the cropping systems especially in rotation could have increased crop yields for the following cassava and sorghum crop which played a part in increased mining of K from the soil through harvested crop products [20]. Intercropping systems registered increased nutrient losses due to harvest of combined products at the same time [33]. It was also noted that inclusion of dolichos under a given organic input yielded significantly lower K balances than pigeon pea inclusion probably due to increased losses through removal of harvested crop products.

Application of FYM resulted in reduced K losses than application of compost under a given cropping system (Tables 8 and 9).Sorghum monocrop with FYM (16.63) applied had significantly higher K balances compared to sorghum monocrop with compost (-0.6). This was attributed to increased losses in harvested tubers and stems due to increase in yield caused by FYM application. Salami and Sangoyomi [57] had also reported increasing levels of K mining with the increase adoption and increasing yield of cassava. Fermont et al. [33] similarly noted a triple fold increase in the amount of K mining per hectare as the amount of yield of tubers tripled.

Table 4. N balances (kgha^{-1}yr^{-1}) as influenced by cropping systems and organic inputs in the sorghum based c ropping systems

	KATANGI						**MEAN**
	Year 1 (SR 2010/LR 2011)			**Year 2 (SR 2011/LR 2012)**			
	FYM	**COMP**	**CTRL**	**FYM**	**COMP**	**CTRL**	
Sorghum monocrop	-25.90 mn	-1.00 i	-37.50 o	-35.77 efg	-1.20 abcdef	-36.77 efgh	
Sorghum/Dolichos intercrop	22.90 de	40.93 c	-4.70 k	6.40 abcde	29.9 a	-10.20 bcdef	
Sorghum/Pigeon pea intercop	-4.10 jk	12.67 f	-26.23 n	-1.43 ebcdef	21.83 abc	-16.83 bdef	
Dolichos-Sorghum rotation	46.70 b	61.00 a	7.07 g	4.37 abcdef	25.03 ab	-20.2 def	
Pigeon pea-Sorghum rotation	0.53 h	20.17 e	-20.23 l	-0.40 abcdefg	24.43 ab	-12.57 bcdef	
LSD $^{0.05}$	Cropping systems (c)						
	Organic inputs (o)						
	(c xo)		2.74			36.88	
CV%			26.10			289.90	
	IKOMBE						
	FYM	**COMP**	**CTRL**	**FYM**	**COMP**	**CTRL**	
Sorghum monocrop	-27.33 mn	-2.60 hj	-37.10 o	-36.73	-4.53	-48.17	-29.81 c
Sorghum/Dolichos intercrop	22.17 d	41.2 bc	1.57 h	8.87	21.3	-23.67	-8.92 bc
Sorghum/Pigeon pea intercrop	-4.40 kj	10.20 f	-22.9 m	-9.37	9.67	-27.07	1.59 bc
Dolichos-Sorghum rotation	47.50 b	61.87 a	8.90 fg	2.37	23.3	-16.07	2.17 b
Pigeon pea-Sorghum rotation	0.33 hi	21.33 de	-15.23 l	1.17	22.37	-18.77	3.20 a
MEAN				-6.74 c	14.42 a	-26.75 b	
LSD $^{0.05}$	Cropping systems (c)					11.09	
	Organic inputs (o)					4.061	
	(c xo)		5.5				
CV%			30.40			83.90	

Table 5. N balances (kg $ha^{-1}yr^{-1}$) as influenced by cropping systems and organic inputs in the cassava based cropping systems

	KATANGI							MEAN
	Year 1 (SR 2010/LR 2011)			**MEAN**	**Year 2 (SR 2011/LR 2012)**			
	FYM	**COMP**	**CTRL**		**FYM**	**COMP**	**CTRL**	
Cassava monocrop	-71.70 fghi	-60.10 efghi	-57.10 defghi		-81.10	-60.60	-50.40	-64.01bb
Cassava/dolichos intercrop	-21.10 bcd	-15.00 ab	-15.5 bc		-11.60	2.00	-1.80	-3.82 a
Cassava/pigeon pea intercrop	-72.40 fghij	-52.30 cdefghi	-71.90 fghij		-76.10	-59.70	-91.30	-75.72b
Dolichos-Cassava rotation	-0.60 ab	21.00 a	-4.20 ab					
Pigeon pea-Cassava rotation	-66.70 efghi	-30.30 bcde	-66.90 efghi					
LSD $^{0.05}$	Cropping systems (c)						20.74	
	Organic inputs (o)							
	(c xo)		38.17					
	CV%		20.1				26.9	
			IKOMBE					
	FYM	**COMP**	**CTRL**					
Cassava monocrop	-58.9	-35.6	-42.6	-45.70 b	-106.70	-85.60	-53.10	-81.80 a
Cassava/dolichos intercrop	-12.8	-1.8	-1.4	-5.37 a	-110.50	-77.50	-51.90	-80.00 a
Cassava/pigeon pea intercrop	-66.3	-59.5	-65.2	-63.68 b	-120.90	-108.50	-98.10	-109.2 a
Dolichos-Cassava rotation	-20.1	14.9	-41.5	-15.56 a				
Pigeon pea-Cassava rotation	-70	-39.1	-63.8	-57.63 b				
MEAN	-45.64 a	24.22 b	42.90 a		-90.50 b	-67.70c	-112.70a	
LSD $^{0.05}$	Cropping systems (c)		24.72					
	Organic inputs (o)		11.36				22.88	
	(c xo)							
	CV%		39.7				24.7	

Table 6. P balances (kgha^{-1}yr^{-1}) as affected by cropping systems and organic inputs in sorghum based cropping systems

	KATANGI							MEAN
	Year 1 (SR 2010/LR 2011)			MEAN	Year 2 (SR 2011/LR 2012)			
	FYM	COMP	CTRL		FYM	COMP	CTRL	MEAN
Sorghum monocrop	-4.03	-4.77	-9.5	-6.10 b	-10.87	-8.67	-11.6	-10.38 b
Sorghum/Dolichos intercrop	-10.2	-11.2	-15.03	-12.14 d	-21.77	-21.17	-23.17	-22.04 c
Sorghum/Pigeon pea intercrop	-6.23	-8.67	-12.23	-9.04 c	-11.57	-10.63	-13.03	-11.74 b
Dolichos-Sorghum rotation	-3.47	-5.53	-8.17	-5.72 b	-2.73	-5.2	-8.67	-5.5.3 ab
Pigeon pea-Sorghum rotation	0.13	-1.57	-6.23	-2.56 a	-2.00	-3	-5.87	-3.62 a
MEAN	-4.76 a	-6.35 b	-10.23 c		-9.79 a	-9.73 a	-12.47 b	
LSD $^{0.05}$	Cropping systems (o)		0.78				6.41	
	Organic inputs (o)		0.49				1.08	
	(c xo)							
CV%			9				13.2	
	IKOMBE							MEAN
	FYM	COMP	CTRL		FYM	COMP	CTRL	
Sorghum monocrop	-4.67 d	-5.37 e	-9.53 j		-10.53	-9.1	-15.43	-6.52 c
Sorghum/Dolichos intercrop	-11.13 k	-12.10 l	-15.03 m		-14.10	-13.77	-18	-12.76 e
Sorghum/Pigeon pea intercrop	-7.30 g	-8.03 i	-10.70 k		-9.23	-11.03	-14.07	-8.68 d
Dolichos-Sorghum rotation	-3.63 c	-6.00 f	-7.77 h		-0.83	-2.73	-6.37	-5.8 b
Pigeon pea-Sorghum rotation	-0.067 a	-1.50 b	-5.37 e		-0.63	-3.33	-8.4	-2.31 a
MEAN					-7.07 a	7.99 b	-12.45 b	
LSD $^{0.05}$	Cropping systems (c)						2.62	
	Organic inputs (o)						1.36	
	(c xo)		0.5				3.4	
CV%			3.5				19.5	

Table 7. P balances ($kgha^{-1}yr^{-1}$) as affected by cropping systems and organic inputs in cassava based cropping systems

	KATANGI							**MEAN**
	Year 1 (SR 2010/LR 2011)			**MEAN**	**Year 2 (SR 2011/LR 2012)**			
	FYM	**COMP**	**CTRL**		**FYM**	**COMP**	**CTRL**	**MEAN**
Cassava monocrop	-12.10 abcd	-12.9 abcdef	-9.30 abc		-17.83	-14	-9.7	-13.84 b
Cassava/Dolichos intercrop	-21.33 i	-19.57 ghi	-17.00 efghi		-10.70	-8.47	-7.93	-9.03 a
Cassava/Pigeon pea intercop	-19.13 fghi	-16.90 defgh	-19.87 hi		-23.7	-19.9	-23.07	-22.22 c
Dolichos-Cassava rotation	-12.17 abcd	-13.7 cdefg	-13.30 bcdefg					
Pigeon pea-Cassava rotation	-8.40 ab	-7.5 a	-12.70 abcde					
MEAN					-17.41 a	-14.12 a	-13.57 a	
LSD $^{0.05}$	Cropping systems (o)						2.84	
	Organic inputs (o)						3.43	
	(c xo)		6.91					
CV%			13.3				22.2	
	IKOMBE							**MEAN**
	FYM	**COMP**	**CTRL**		**FYM**	**COMP**	**CTRL**	
Cassava monocrop	-21.60	-20.4	-18.2	4.14 a	-22	-18.4	-10.2	-16.86 a
Cassava/Dolichos intercrop	-30	-27.1	-24.5	-10.22 a	-35.80	-25.9	-18	-26.57 b
Cassava/Pigeon pea intercop	-23.5	-19	-14.7	-12.82 a	-32.60	-30.6	-26.5	-29.87 b
Dolichos-Cassava rotation	-24.9	-23.6	-19.8	-11.01 a				
Pigeon pea-Cassava rotation	-24.1	-18.2	-21.9	-7.93 a				
MEAN	-8.96 a	-8.88 a	-9.84 a		-30.19 c	-25.00 b	-18.2 a	
LSD $^{0.05}$	Cropping systems (o)						9.18	
	Organic inputs (o)						5.83	
	(c xo)		0.5				10.81	
CV%			3.5				23.2	

Table 8. K balance (kgha^{-1}yr^{-1}) as affected by cropping systems and organic inputs in sorghum cropping systems

	KATANGI					
	Year 2 (SR 2010/LR 2011)			**Year 2 (SR 2011/LR 2012)**		
	FYM	**COMP**	**CTRL**	**FYM**	**COMP**	**CTRL**
Sorghum monocrop	16.63 a	-0.60 d	-6.40 f	12.07 ab	-3.2 abcd	-7.8 abcd
Sorghum/Dolichos intercrop	-26.63 i	-40.17 k	-38.20 k	-37.93 efg	-50.13 g	-49.6 g
Sorghum/Pigeon pea intercop	4.67 c	-12.37g	-15.00 h	-2.17 abcd	-15.27 bcdef	-17.67 bcdef
Dolichos-Sorghum rotation	-26.40 i	-40.13 k	-30.20 j	6.53 abcd	-10.8 abcdef	-10.77 abcde
Pigeon pea-Sorghum rotation	13.60 b	-3.37 e	-7.40 f	13.5 a	-3.4 abcd	-7.27 abcd
LSD $^{0.05}$	Cropping systems (o)					
	Organic inputs (o)					
	(c xo)		2.54			28.17
CV%			9.9			13.6
	IKOMBE					
	FYM	**COMP**	**CTRL**	**FYM**	**COMP**	**CTRL**
Sorghum monocrop	16.23 a	-1.00 d	-6.40 f	12.3 a	-3.50 c	-10.43 ef
Sorghum/Dolichos intercrop	13.37 b	-3.70 e	-7.63 g	-22.90 h	-29.10 i	-30.17 i
Sorghum/Pigeon pea intercrop	3.07 c	-12.20 h	-13.73 i	4.23 b	-12.1 efg	-16.03 g
Dolichos-Sorghum rotation	-27.17 j	-41.83 m	-30.13 l	11.17 a	-5.47 cd	-8.7 cd
Pigeon pea-Sorghum rotation	-28.2 k	-42.43 m	-41.83 m	14.53 a	-4.03 c	-9.63 de
LSD $^{0.05}$	Cropping systems (o)					
	Organic inputs (o)					
	(c xo)		2.21			4.96
CV%			6.2			35.6

Table 9. K balance (kgha^{-1}yr^{-1}) as affected by cropping systems and organic inputs in sorghum cropping systems

	KATANGI							MEAN
	Year 2 (SR 2010/LR 2011)			MEAN	Year 2 (SR 2011/LR 2012)			
	FYM	**COMP**	**CTRL**		**FYM**	**COMP**	**CTRL**	**MEAN**
Cassava monocrop	-32.23 abc	-40.37 abc	-28.9 abc		-50.20	-41.1	-31.3	-40.90 a
Cassava/Dolichos intercrop	-111.40 ef	-107.67 de	-96.07 de		-47.70	-42.7	-38.8	-43.07 b
Cassava/Pigeon pea intercop	-59.47 abc	-59.97 abcd	-61.57 abcde		-74.80	-64	-63.7	-67.49 b
Dolichos-Cassava rotation	-71.1 abcde	-79.97 cde	-70.07 abcde					
Pigeon pea-Cassava rotation	-27.53 a	-30.63 abc	-34.83 abc					
MEAN					57.60 a	-49.30 ab	-44.60 cb	
LSD $^{0.05}$	Cropping systems (o)						15.26	
	Organic inputs (o)						9.82	
	(c xo)		50.63					
CV%			9.2				18.9	

	IKOMBE							MEAN
	FYM	**COMP**	**CTRL**		**FYM**	**COMP**	**CTRL**	
Cassava monocrop	-31.7	-29.3	-22.4	-27.80 a	-71.3	-60.6	-31.7	-54.54 a
Cassava/Dolichos intercrop	-81.10	-76.6	-62.4	-73.34 b	-127.50	-97	-61.5	-93.31 b
Cassava/Pigeon pea intercop	-68.00	-72.8	-55.2	-65.34 b	-101.70	-95.9	-79.3	92.29 b
Dolichos-Cassava rotation	-80.00	-77.5	-68.3	-75.28 b				
Pigeon pea-Cassava rotation	-40.30	-44.5	-42.9	-42.54 a				
MEAN	60.20 a	60.10 a	50.20 a		100.20 a	-84.50 b	-57.50 c	
LSD $^{0.05}$	Cropping systems (o)		19.35				29.06	
	Organic inputs (o)						16.26	
	(c xo)							
CV%			24.2				19.6	

4. CONCLUSION

The NPK balances varied according to the type of crop chosen, the cropping systems adopted, the type of legumes and the organic input used. Cassava plots had relatively more losses of NPK from the soil compared to sorghum regardless of the legume, cropping system or organic input used. Stronger nutrient losses in cassava cropping systems were mainly due to removal of both stems and tubers from the soil as well as losses due to leaching. Consequently, if cassava based cropping systems are to be chosen, then technologies such as mulching which reduce leaching need to be explored. Increased application of residues could also compensate for the losses due to crop harvest. Inclusion of legumes in the cropping systems led to more P and K losses relative to the monocrop though N losses were reduced when legumes were included into the cropping systems. N losses were minimized when dolichos was used while with P and K, pigeon pea was the preferred legume. The study showed that rotation with either legume could be preferred to intercropping so as to reduce soil NPK losses. Application of compost also reduced soil N losses compared to FYM but PK losses were reduced under FYM. It is recommended that under N limited conditions, inclusion of dolichos in rotation with compost application would be the method of choice. In P limited conditions however, pigeon pea rotation with sorghum with FYM applied and cassava monocrop with compost applied would be ideal. However, if legumes are to be incorporated into the farming system, rotating with pigeon pea with application of compost would be applicable in the cassava based systems. The same goes for K limited conditions. Most of the nutrient losses in the recommended packages would have occurred due to export of harvested products. Low cost technologies such as use of night soil, rock phosphates in addition to increasing amount of residue incorporation into the soil need to be explored.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. De Jager A, Nandwa SM, Okoth PF. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I. Concepts and methods. Agriculture, Ecosystems and Environment. 1998;71(1-3):37-48.
2. Smestad BT, Tiessen H, Buresh RJ. Short fallows of *Tithonia diversifolia* and Crotalaria grahamiana for soil fertility improvement in western Kenya. Agroforestry Systems. 2002;55(3):181-194.
3. De Jager A, Onduru D, Van Wijk MS, Vlaming J, Gachini GN. Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya. Agricultural Systems. 2001;69(1):99-118.
4. Altieri MA. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment. 1999;74(1):19-31.
5. Altieri MA, Rosset P, Thrupp LA. 1998. The potential of agroecology to combat hunger in the developing world. A 2020 Vision for Food, Agriculture and the Environnent; 2020. Brief.
6. Place F, Barret CB, Freeman HA, Ramisch JJ, Vanlauwe B. Prospects for integrated soil fertility management using organic and inorganic inputs: Evidence from small holder African agricultural systems. Food Policy. 2003;28:365-378.

7. Mokwunye AU, De Jager A, Smaling EMA. Restoring and Maintaining the Productivity of West African soils: Key to sustainable development. IFDC Miscellaneous Studies No. 9, Lome, Togo; 1996.
8. Lawson TL, Sivakumar MVK. Climatic constraints to crop production and fertilizer use. Alleviating soil fertility constraints to increased crop production in West Africa. Springer Netherlands. 1991;33-44.
9. El-Sharkawy MA. Cassava biology and physiology. Plant Molecular Biology. 2003;53:621-641.
10. Gobeze L, Hidoto H, Markos D. Screening of inter and intra row spacing on yield and yield components of cassava in moisture stress. African Crop Science Conference Proceedings. 2005;7:147-150.
11. World Bank. Agricultural Growth for the poor: An Agenda for Development. The international bank for reconstruction and development. The World Bank, Washington, D.C; 2005.
12. Rao MR, Mathuva MN. Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment. 2000;78:123-137.
13. Haque I, Powell JM, Ehui SK. Improved crop-livestock production strategies for sustainable soil management in tropical Africa. In: Lal R, Stewart BA, (Eds.), soil management experimental basis for sustainability and environmental quality. Adv Soil Sci CRC Lewis Publishers Boca Raton, Fl, USA. 1995;293-345.
14. Cheruiyot EK, Mumera LM, Nakhone LN, Mwonga SM. Rotational effects of grain legumes on maize performance in the rift valley highlands of Kenya. African Crop Science Journal. 2001;9(4):667-676.
15. Altieri MA. Agroecology: The science of natural resource management for poor farmers in marginal environments. Agriculture, ecosystems & environment. 2002;93(1):1-24.
16. Tait J, Morris D. Sustainable development of agricultural systems: Competing objectives and critical limits. Futures. 2000;32(3):247-260.
17. Smaling EM, Fresco LO, Jager AD. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture. Ambio. 1996;25:492-496.
18. Vlaming J, Van Den Bosch, Van H, Wijk MS, De Jager A, Bannink A, Van Keulen H. Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON) - Part 1: Manual for the NUTMON-Toolbox. Wageningen, The Netherlands, Alterra; 2001.
19. De Jager A, Kariuku I, Matiri FM, Odendo M, Wanyama JM. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): IV. Linking nutrient balances and economic performance in three districts in Kenya. Agriculture, Ecosystems & Environment. 1998;71(1):81-92.
20. Onwonga RN, Freyer B, Lelei JJ. Traditional soil fertility management strategies: Do they conform to recommendations in organic farming? A case study of the smallholder farmers of the Central Rift Valley Province of Kenya. In Proceedings of the 14th Australian Agronomy Conference. 2008;21-25.
21. Surendran U, Murugappan V, Bhaskaran A, Jagadeeswaran R. Nutrient Budgeting Using NUTMON-Toolbox in an Irrigated Farm of Semi Arid Tropical Region in India-A Micro and Meso Level Modeling Study. World Journal of Agricultural Sciences. 2005;1(1):89-97.
22. Ehabe EE, Bidzanga NL, Mba CM, Njukeng JN, De Barros I, Enjalric F. Nutrient flows in perennial crop-based farming systems in the humid forests of Cameroon. American Journal of Plant Sciences. 2010;1:38.
23. Sombroek WG, Braun HMH, Van Der Pouw BJA. Exploratory soil map and agro-climatic zone map of Kenya, 1980. Scale 1: 1,000,000. Kenya Soil Survey; 1982.

24. World Reference Base for Soil Resources. A framework for International Classification, Correlation and Communication. Rome: food and Agriculture Organization of the United Nations; 2006.
25. Jaetzold R, Schmidt H, Hrnetz B, Shisanya C. Farm management handbook Vol II, Part C, East Kenya. Subpart C1, Eastern Province. Ministry of Agriculture, Nairobi Kenya; 2006.
26. Hazelton P, Murphy B. Interpreting soil test results what do all the numbers mean? 1st ed. Collingwood, VIC: CSIRO Publishing; 2007.
27. Landon JR. Booker Tropical Soil Manual. A handbook of soil survey and agricultural land evaluation in the tropics and sub-tropics. 1st Edn., Longman, London; 1991.
28. Bosch H. Van Den, Jager A. De, Vlaming J. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. Agriculture, Ecosystems and Environment. 1998;71(1-3):49-62.
29. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of soil and plant analysis: A working manual. 2nd ed. TSBF-CIAT and SACRED Africa, Nairobi, Kenya; 2002.
30. Parkinson JA, Allen SE. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Communications in Soil Science & Plant Analysis. 1975;6(1):1-11.
31. Stoorvogel JJ, Smaling EMA. Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Wageningen: Winand Staring Centre. 1990;1.
32. Nandwa SM. Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. Nutrient Cycling in Agroecosy Stems. 2001;61:143-158.
33. Fermont AM, Obiero HM, Van Asten PJA, Baguma Y, Okwuosa E. Improved cassava varieties increase the risk of soil nutrient mining: An ex-ante analysis for western Kenya and Uganda. In Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer Netherlands. 2007;511-520.
34. Howeler RH. Nutrient inputs and losses in cassava-based cropping systems. Examples from Vietnam and Thailand. 2001;20-22.
35. Carsky RJ. Potential of herbaceous legume cover crop fallow systems in the savanna zone. In Floret C, Pontanier R, (Eds.) Fallows in Tropical Africa. Proceedings of the International Seminar, April, Dakar, John Libbey Eurotext, Paris. 2000;594-602.
36. Nnadi LA, Balasubramanian V. Root nitrogen content and transformation in selected grain legumes. Tropical Agriculture (Trinidad). 1978;55:23-32.
37. Giller KE, Cadisch G. Future benefits from biological nitrogen fixation: An ecological approach to agriculture. Plant Soil. 1995;174(1-2):255-277.
38. Mafongoya PL, Giller KE, Palm CA. Decomposition and nitrogen release patterns of tree prunings and litter. Agrofor Syst. 1998;38:77–97.
39. Ayoub AT. The potential contribution of some forage crops to the nitrogen budget and animal feed in the Sudan Gezira farming system. Potentials of Forage Legumes in Farming Systems of Sub-Saharan Africa, ILCA, Addis Ababa. 1986;58-68.
40. Bagayoko M, Mason SC, Traore S, Eskridge KM. Pearl millet/cowpea cropping systems yield and soil nutrient levels. African Crop Sci J. 1996;4:453-462.
41. Rusinamhodzi L, Murwira HK, Nyamangara J. Cotton-cowpea intercropping and its N2 fixation capacity improves yield of a subsequent maize crop under Zimbabwean rain-fed conditions. Plant and Soil. 2006;287(1-2):327-336.
42. Thai Phien, Nguyen Cong Vinh. International workshop on nutrient balances for sustainable agricultural production and natural resource management in southeast Asia. Bangkok, Thailand; 2001.

43. Murwira H, Kirchmann H. Carbon and nitrogen mineralization of cattle manures, subjected to different treatments, in Zimbabwean and Swedish soils, In Mulongoy K, Merckx R, (ed.) Soil organic matter dynamics and sustainability of tropical agriculture. John Wiley & Sons, Chichester, England. 1993;189-198.
44. Ledgard SF, Steele KW. Biological nitrogen fixation in mixed legume/grass pasture. Plant and Soil Journal. 1992;141:137-153.
45. Snapp SS, Mafongoya PL, Waddington S. Organic matter technologies for integrated nutrient management in smallholder cropping systems of Southern Africa. Agric Ecosyst Environ. 1998;71:185-200.
46. Cassman KG, Whitney AS, Fox RL. Phosphorus requirements of soybean and cowpea and affected by mode of N nutrition. Agronomy Journal. 1981;73:17-22.
47. Li SM, Li L, Zhang FS, Tang C. Acid phosphatase role in chickpea/maize intercropping. Ann Bot. 2004;94:297-303.
48. Nuruzzaman M, Lambers H, Bolland MDA, Veneklaas EJ. Phosphorus benefits of different grain legume crops to subsequent wheat grown in different soils of Western Australia. Plant Soil. 2005;271:175-187.
49. Hinsinger P, Gilkes RJ. Dissolution of phosphate rock in the rhizosphere of five plant species grown in an acid, P fixing mineral substrate. Geoderma. 1997;75:231-249.
50. Pearse SJ, VeneklaasEJ, Cawthray G, Bolland MDA, Lambers H. Carboxylate composition of root exudates does not relate consistently to a crop species' ability to use phosphorus from aluminium, iron or calcium phosphate sources. New Phytol. 2007;173:181-190.
51. Pearse SJ, Veneklaas EJ, Cawthray G, Bolland MDA, Lambers H. Triticumaestivum shows a greater biomass response to a supply of aluminium phosphate than Lupinusalbus despite releasing fewer carboxylates into the rhizosphere. New Phytol. 2006;169:515-524.
52. Mpairwe DR, Sabiiti EN, Ummuna NN, Tegegne A, Osuji P. Effect of intercropping cereal crops with forage legumes. African Crop Science Journal. 2002;10(1):81-97.
53. Bauer A, Black AL. Quantification of the effect of soil organic matter content on soil productivity. Am J Soil Sci Soc. 1994;5:185-193.
54. Murugappan V, Santhy P, Selvi D, Muthuvel P, Dhashinsmoorthy M. Land degradation due to potassium mining under high intensive cropping in semi arid tropics. Fert News. 1999;44(5):75-77.
55. Howeler RH. Cassava mineral nutrition and fertilization. In: Hillocks RJ, Thresh JM. and Bellotti AC, (eds.) Cas- sava: Biology, Production and Utilization. CABI, Wallingford. 2002;115-147.
56. Smalling E. An agro-ecological framework for integrated nutrient management with special reference to Kenya. Ph. D. thesis. University of Wageningen, The Netherlands; 1993.
57. Salami BT, Sangoyomi TE. Soil fertility status of cassava fields in south western Nigeria. American Journal of Experimental Agriculture. 2013;3(1):152-164.

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