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Contribution of Legumes and Phosphorus Fertilizer to Nutrient Balances in a Sorghum Based Cropping System in Njoro Kenya

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Authors' contributions

This work was carried out in collaboration between both authors. Author JJL designed the study and wrote the protocol. Authors JJL and BAT performed the statistical analysis and wrote the first draft of the manuscript. Author BAT managed the analyses of the study. Authors JJL and BAT managed the literature searches and addressed subsequent reviewer comments and suggestions for improvement. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To determine nutrient balances in a sorghum based cropping system, following integration of legumes and phosphorus application.

Study Design: Two field experiments were set up. They comprised either white lupin or chickpea, and are subsequently referred to as lupin-sorghum and chickpea-sorghum, respectively. A split plot in a randomized complete block design was used. Main plots were cropping systems; sorghum monocrop, legume-sorghum rotation and legume/sorghum intercrop. Subplots were phosphorus sources; triple super phosphate and minjingu phosphate rock.

Place and Duration of Study: Njoro Kenya, in the short rains of 2012 and long rains of 2012 and 2013.

Methodology: N, P and K balances were determined using NUTrient MONitoring (now known as MonQi) Tool box.

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Results: Nutrient balances were negative in both experiments, with nitrogen showing more negative values than phosphorus and potassium. Effect of cropping system and phosphorus sources on nutrient balances were significant (*P = .05*) in both experiments. Sorghum monocrop had more negative nitrogen and potassium balances, in both experiments. Phosphorus balance was more negative in the intercrop and monocrop in lupin-sorghum and chickpea-sorghum experiments, respectively. In the lupin-sorghum experiment, more negative nitrogen balance occurred with use of triple superphosphate in all cropping systems; for P with minjingu phosphate rock in intercropping and sole sorghum systems while for K, balances were more negative with minjingu phosphate rock in sorghum monocrop and intercrop. For the chickpea-sorghum experiment, N balance was more negative with the use of minjingu phosphate rock in the monocropping and intercropping system, for P, values were more negative with triple super phosphate in sorghum monocrop and intercropping systems while for K with triple superphosphate in all cropping systems.

Conclusion: Greater nutrient losses occurred in sole sorghum, hence unsustainable. Integration of white lupin or chickpea, in rotation and/or intercropping systems, with application of either phosphorus sources is recommended for enhanced sustainability of the system. An economic analysis of the farms is also recommended in future studies.

Keywords: Chickpea; white lupin; MonQi; phosphate rock; triple superphosphate.

1. INTRODUCTION

Sustainable agriculture aims at meeting the needs of the present without compromising the productive potential for the next generations [1]. In sub-Saharan African countries, continuous cereal monocropping coupled with application of sub-optimal amounts of inorganic fertilizers has led to a decline in soil fertility [2]. Practices that mine the soil resource can be considered unsustainable compared to those that conserve it [3]. Soil health is an environmental indicator of sustainability [1]. Rational soil use practices must allow economically and environmentally sustainable yields, which will only be reached with the maintenance or recovery of soil health [4,1]. According to Altieri [5] and Onwonga [6], farmers can improve resilience of agricultural systems by choosing more suitable crops, rotating them, growing a mixture of crops, and irrigating, mulching and manuring land.

Sustainability of agricultural systems can be assessed by determining nutrient balance, an indicator of soil health [6-8]. A nutrient balance is a measurement of difference (surplus/deficit) between nutrient inputs into, and outputs from, an agricultural system [7]. Positive balances would mean more additions into the system than losses [6]. A nutrient deficit (negative value) is an indication of more losses than gains and therefore declining soil fertility [6] and unsustainability of a farming system [9]. Calculation of nutrient balance provides insight into nutrient gains and losses allowing judicious manipulation of the flows to either reduce nutrient losses or increase nutrient gains [10]. This is notably important with introduction of new technologies and/or farm management practices [11,12].

The NUTtrient MONitoring (NUTMON) Tool box, now known as MonQi, is a decision support tool useful in assessing effect of introduced management initiatives on soil nutrient stocks and flows [10,13]. It has been applied in several studies to measure nutrient balances and subsequently determine sustainability of agroecosystems [10-14]. The objective of the current study was to monitor nitrogen (N), phosphorus (P) and potassium (K) balances, following integration of legumes white lupin and chickpea coupled with phosphorus application in a sorghum based cropping system. Previous studies focused on available soil nutrients and sorghum yield [12,15,16] whilst sustainability assessment is unreported.

2. MATERIALS AND METHODS

2.1 Study Site

Field experiments were conducted at Kenya's Egerton University, Field 7 research station for three rainy seasons; short rains (SRS) of 2012 and long rains (LRS) of 2012 and 2013. The site (2,238 m a.s.l.) lies at latitude of 0°23' South and longitude 35°35' East in the lower highland III Agro Ecological Zone (LH3) [17]. Average maximum and minimum temperatures of the area range from 19 to 22℃ and 5 to 8℃, respectively. Total annual rainfall received ranges from 1200 to 1400 mm. The distribution is bimodal; long rains occur from April to August and short rains from September to November [17]. The soils are predominantly vitric mollic Andosols [17]. The soils at commencement of the study were neutral in pH (H_20) and of sandy loam texture. Initial levels of available P, total N and exchangeable K in soil were high according to Landon's [18] classification (Table 1). The socio economic activities of the residents of Njoro sub-County include large scale wheat and barley farming. Agri-based industries such as vegetable and milk processing and manufacturing industries, such as timber milling and quarrying, are also found in the area [17]. The experimental field had been under Irish potatoes (*Solanum tuberosum*) prior to setting up of the experiment.

2.2 Treatments and Experimental Design

Two field experiments comprising either white lupin (Lp) or chickpea (Cp) legumes, hereafter referred to as lupin- sorghum (LpS) or chickpea-sorghum (CpS), respectively, were set up, side by side. A split plot in a randomized complete block design was used. The main plots were three cropping systems; sorghum monocrop, legume - sorghum (Lp-S and Cp-S) rotation and legume- sorghum (Lp/S and Cp/S) intercrop. The subplots, of size 4.8 m × 3.75 m, were two P (60 kg P ha^{-1}) sources; triple superphosphate (TSP) and minjingu phosphate rock (MPR). There were three replicates. Foot paths of 0.5 m between subplots and 1 m between main plots and blocks were provided. Treatment and cropping sequences are shown in Table 2.

2.3 Agronomic Practices

Land preparation was done prior to the start of rains, using a mould board plough. Harrowing was then performed twice to a depth of 30 cm, using a tractor, so as to obtain a fine, firm and weed-free surface for planting. Phosphorus fertilizers, TSP and MPR, were applied at the rate of 60 kg P ha^{-1} by banding, in all seasons; 2012 LRS, 2012 SRS and 2013 LRS. Sorghum seeds were drilled to a depth of 1 cm, in rows spaced at 75 cm × 20 cm, in the sorghum monocrop and legume-sorghum rotation systems. Chickpea and lupin sole crops were planted at the rate of two seeds per hill and spacing of 30 × 10 cm and 50 × 30 cm, respectively, in the legume-sorghum rotation system. In the intercropping system, sorghum was spaced at 75 cm × 20 cm and lupin or chick pea seeds planted at the inter row spaces, at the rate of two seeds per hill. The intra-row distance of legume sole crops was used. Thinning to one plant per hill was done after crop establishment, for all crops. Gapping was carried out in cases of poor germination. Calcium ammonium nitrate (CAN) fertilizer was top dressed, a month after planting in all plots, at the rate of 60 kg N ha^{-1}.

After crop establishment, the field was hand-weeded once every month so as to keep the fields weed free until a good canopy cover was established. Crop residues of all crops (after removal of grain) were chopped into 5-20 cm small pieces spread across the same plots they were obtained from and incorporated into soil, to a depth of 15 cm, during land preparation for the next crop.

2.4 NUTMON Model and Calculation of Nutrient Balance

2.4.1 Components of the NUTMON tool box

NUTMON-Tool box (now known as MonQi) consists of four modules and two data bases. The modules include: (i) questionnaires for gathering and recording farm specific information on inventory and monitoring of farm environment, farm management, farm household, soils and climate, (ii) data entry module that facilitates entry of data from questionnaires into the computer, (iii) background data module that stores non-farm specific information on crops, residues, animals, inputs and outputs, and (iv) data processing module for calculating nutrient flows, nutrient balances and economic indicators, based on farm-specific data from questionnaires and general data from the background database, using calculation rules and assumptions. Background and farm databases are included in the Tool box. The background data base contains non-specific information such as nutrient contents of crop and animal products, crop and livestock parameters, as well as calibration factors of local units of measurement. A farm data base stores information about the farm [8].

2.4.2 Farm conceptualization

NUTMON Tool box conceptualizes a farm into four components; (i) farm section units (static farm units), (ii) nutrient pools (dynamic farm units); entries other than nutrient pools, which influence farm management, (iii) nutrient and economic flows, and (iv) nutrient and cash flows. The farm section units (FSUs) form the source and/or destination of nutrient and economic flows. A farm is divided into two or more FSUs, with each section having homogenous soil properties (assumed), slope, and flooding regime and land tenure. Crops growing within a given FSU acquire its soil and land characteristics. Nutrient pools comprise primary production units (PPUs = cropping activities); secondary production units (SPUs = livestock activities – group of animals of the same species within the farm which are managed by the farmer as one unit); redistribution units (RUs = nutrient storage and redistribution points); stock (STOCK = staple foods, crop residues and chemical fertilizers temporarily stored for later use); household (HH = a group of people who live in the same house or group of houses who share food regularly from the same "cooking pot"); and the outside/external farm environment (EXT = markets and other families and neighbours who are the sources and destination of nutrient and cash flows) [8].

For this study, the diagnostic phase was done at experimental unit, thus designated FSU. The experimental unit was divided into three blocks/ replicates, each with homogenous properties. Monitoring of nutrient flows into and out of the experimental unit was conducted over the period of time of the experiment i.e. three rainy seasons. Nutrient pools comprised the (i) primary production units (PPU) - constituted treatments which were the cropping systems and phosphorus sources, and (ii) EXT - markets of the external (nutrient). Non-nutrient pool components are soils, climatic factors and markets. Climatic factors included monthly

Table 1. Initial physical and chemical properties of soil

Soil property	Soil depth (cm)			Soil property	Soil depth (cm)		
	0-15	15-30	30-60		0-15	15-30	30-60
pH (H_20)	6.34	6.43	6.5	**Exchangeable bases ($cmol_c\ kg^{-1}$)**			
CEC (C mol kg $^{-1}$)	62.9	42.5	20.4	K	0.6	0.65	0.54
Total N (%)	1.67	0.63	0.63	Mg	0.25	0.25	0.24
Org. C (%)	1.57	1.59	1.5	Ca	0.23	0.4	0.24
Available P (mg kg^{-1})	27.3	27	24.1	% clay	20	20	20
Mineral N (%)	0.79	0.73	0.59	% sand	50	40	36
Bulk density (g cm^{-3})	1.31	1.31	1.24	% silt	30	40	44
Exchangeable Al (%)	0.2	0.3	0.4	Textural class	Sandy loam	Loam	Loam

Table 2. Cropping systems, and phosphorus sources

Cropping system	P source	Cropping sequence		
		2012 LRS	2012 SRS	2013 LRS
Lupin-sorghum experiment				
Monocropping	MPR	Sorghum	Sorghum	Sorghum
(Control)	TSP	Sorghum	Sorghum	Sorghum
Rotation	MPR	Lupin	Sorghum	Lupin
	TSP	Lupin	Sorghum	Lupin
Intercropping	MPR	Lupin/sorghum	Lupin/sorghum	Lupin/sorghum
	TSP	Lupin/sorghum	Lupin/sorghum	Lupin/sorghum
Chickpea-sorghum experiment				
Monocropping	MPR	Sorghum	Sorghum	Sorghum
(Control)	TSP	Sorghum	Sorghum	Sorghum
Rotation	MPR	Chickpea	Sorghum	Chickpea
	TSP	Chickpea	Sorghum	Chickpea
Intercropping	MPR	Chickpea/sorghum	Chickpea/sorghum	Chickpea/sorghum
	TSP	Chickpea/sorghum	Chickpea/sorghum	Chickpea/sorghum

Key; LRS= long rain season; SRS= short rain season; P= phosphorus; MPR = minjingu phosphate rock; TSP= triple superphosphate precipitation (used in a leaching transfer function) and rainfall erosivity, a parameter in Universal Soil Loss Equation (USLE). Soil properties (Table 1) were used in pedotransfer functions for calculating leaching, gaseous losses and erosion [8].

2.4.3 Quantification of nutrient balances in NUTMON Tool box

In farm-NUTMON, nutrient flows are quantified by using primary data, estimates and assumptions. Three categories of flows for calculating nutrient balances in the NUTMON Toolbox are distinguished: inflows (6 flows); internal flows; and outflows (6 outflows). Flows into the farm (inflows) originate from outside (EXT) the farm and their destination is one of the nutrient pools within the farm (IN 1– 6). They are in the form of inorganic fertilisers and feeds (IN 1), imported organic fertilisers/manures (IN 2a) and manure from external grazing (IN 2b), wet and dry deposition from the atmosphere (IN 3), symbiotic (IN 4a) and non-symbiotic biological nitrogen fixation (IN 4b), irrigation and flooding or sedimentation (IN 5) and sub-soil exploitation (IN 6). Flows out of the farm (outflows) are flows from one of the nutrient pools to a destination outside (EXT) the farm (OUT 1–6). They are in the form of harvested products (OUT 1), exported crop residues and manure (OUT 2a) and excretion of manure outside the farm (OUT 2b), leaching from soils (OUT 3a) and redistribution units (OUT 3b), gaseous losses from soil (OUT 4a) and redistribution units (OUT 4b), erosion (OUT 5), and lost human excreta (OUT 6). Internal flows are flows from one nurient pool to another (HH, PPU, SPU, RU, STOCK ↔ HH, PPU, SPU, RU, STOCK). In addition to nutrient flows, product flows and economic flows are also considered. Product flows (physical flows of inputs and outputs, e.g. grains) are converted into nutrient flows by multiplying their quantities with respective nutrient contents. They are also converted into economic flows by multiplying their quantities by farm gate prices. At the same time, there are flows which are purely of an economic nature, e.g. o-farm income. Flows used in economic calculations are those that are “visible” to the farmer or “easy-to- quantify flows”: IN 1, IN 2, OUT 1, and OUT 2. In the NUTMON model, nutrient flows are quantified using four methods: (i) asking the farmer; (ii) using pedo-transfer functions; (iii) using sub-models, e.g. a livestock model; and (iv) assumptions. The calculation rules for nutrient flows and balances and economic performance used in NUTMON have been described by Vlaming et al. [8,19] and are available at http://www.nutmon.org. NUTMON calculates the nutrient balance of a unit (Farm, PPU, RU, etc.) by subtracting the sum of all flows out of a unit from the sum of all flows into a unit. The benefit of this approach is that either a full or partial nutrient balance can be calculated for any unit:

$$\text{Full nutrient balance of a unit} = \Sigma\,(\text{IN } 1 + \text{IN } 2 + \text{IN } 3 + \text{IN } 4 + \text{IN } 5) - \Sigma\,(\text{OUT } 1 + \text{OUT } 2 + \text{OUT } 3 + \text{OUT } 4 + \text{OUT } 5 + \text{OUT } 6) \quad (1)$$

$$\text{Partial nutrient balance of a unit} = \Sigma(\text{IN } 1 + \text{IN } 2) - \Sigma\,(\text{OUT } 1 + \text{OUT } 2 + \text{OUT } 6) \quad (2)$$

2.4.4 Calculation of nutrient balances in the study

In this study, flows were quantified by assessing four inputs and four output processes in the experimental unit. The inflows were; mineral fertilizer (IN 1), organic inputs (returned/incorporated residues; IN 2), atmospheric deposition (IN 3) and biological nitrogen fixation (IN 4). The outflows were farm products (grain; OUT 1), leaching (OUT 3), gaseous losses (OUT 4) and erosion (OUT 5). Sampling and analysis of farm inputs and products were carried out to establish their nutrient contents. A literature review was also conducted to collect local data needed for refining “hard-to- quantify” flow calculations (IN 3, IN 4, OUT 3, OUT 4 and OUT 5). Climatic data (rainfall) was collected for the period of study from the local weather station.

2.4.5 Soil sampling and analysis

Soil sampling was done using transverse method, from the experimental unit, before setting up of experiments. Air- dried samples, sieved through 2 mm mesh were analyzed for pH (Soil: H_20: 1:2.5), texture (hydrometer method), total N and total P by calorimetric measuring methods [20]), CEC according to Chapman’s [21] ammonium saturation method, organic Carbon by Walkley– Black method [22], mineral N and available P according to Okalebo et al. [23]. Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry. For bulk density determination, soil samples were taken at 0-15 cm, 15-30 cm and 30-60 cm depth from the profile pits by use of core rings. The soils were oven dried and bulk density determined according to standard method [23]. Only primary data on clay (%), organic C (%), total N (%), total P (%) and exchangeable K (cmol kg^{-1}), collected at end of cropping season, were used in calculations with NUTMON (for pedotransfer functions). Secondary data also gathered for this purpose were rooting depth (m), N mineralisation rate (% per year), bulk density (kg m^{-3}), erodibility (K factor in USLE equation) and nutrient enrichment factor.

2.4.6 Plant sampling and analysis

At crop physiological maturity, grain and dry matter yield was determined from the middle rows of plots. Grains were threshed manually, dried and weighed. Plant materials were chopped into small pieces and fresh field weight taken. Sub-samples were then oven dried at 70℃ to constant weight. The weight of the oven dry samples was recorded and used to calculate the total above ground crop dry matter (DM) yield. Grain and DM yield were converted to kg ha^{-1} using the following formulae:

$$\text{Grain/DM yield (kg ha}^{-1}\text{)} = \text{kg grain yield m}^{-2} \times 10{,}000\ \text{m}^2$$

Oven dry plant samples were ground and analyzed for N, P and K contents using standard methods [23].

2.5 Data Processing and Analysis

Data collected was processed using NUTMON computer software. Processed data were exported and further analysed using special program for social scientists [24]. Means that were significantly different according to the F-test were separated by LSD test at *P = .05.*

3. RESULTS AND DISCUSSION

3.1 General Trend of Nutrient Balances

N, P and K balances were negative (Table 3) despite the high initial nutrient levels in soil, analyzed chemically (Table 1). The negative balances were indicative of greater nutrient outflow, through crop products (grain), leaching, gaseous losses and erosion, than inflow through fertilizer application, residue decomposition, atmospheric deposition and biological nitrogen fixation. Surendran et al. [13] also reported negative N, P and K balances, in a study on nutrient budgeting in India. This was attributed to a mismatch between input and output/export of nutrients. The observed negative nutrient balances despite high initial values in the top soil, measured chemically, was an indication that although nutrient decline was taking place, large quantities may have still been present in soil (Table 1). This observation was also reported by Onduru and Preeze [25] in a study on ecological and agro-economic study of small farms in sub-Saharan Africa. They reported that although N, P and K stocks in upper 30 cm soil layer, calculated from the chemical analyses of the soil, was high a nutrient decline was observed to be taking place. This presents one of the problems in soil fertility and nutrient balance studies.

3.2 Effect of Cropping System and Fertilizer Type on Nitrogen Balance

Nitrogen balances were more negative than P and K (Table 3). Main effects of cropping system and fertilizer type on N balance, were significant but interaction effects were non significant (Table 4).

Table 3. N, P and K nutrient balances (kg $ha^{-1}yr^{-1}$) as affected by fertilizer type and cropping system

Cropping system	Area (ha)	P source	Full nutrient balances (kg ha^{-1})					
			Lupin sorghum			Chickpea sorghum		
			N	P	K	N	P	K
Monocropping	0.0018	TSP	-41	-13	-13	-36	-14	-11
		MPR	-40	-14	-14	-38	-13	-10
Intercropping	0.0018	TSP	-20	-20	-10	-31	-11	-10
		MPR	-13	-23	-11	-30	-10	-9
Rotation	0.0018	TSP	-21	-11	-9	-28	-10	-10
		MPR	-14	-11	-9	-24	-12	-9

Key; monocropping= sorghum monocroping; intercropping = legume/sorghum intercropping; rotation = legume-sorghum rotation. Values are mean ± SD

Table 4. Summary of analyses of variance for soil nutrient balances in lupin-sorghum and chickpea- sorghum experiments

Source of variation	df	Lupin-sorghum	Chickpea-sorghum
Fertilizer	1	*	*
Stage	2	ns	ns
S × F	2	ns	ns
Cropping system	8	*	*
CR × F	8	ns	ns
CR× S	16	ns	ns
CR × S × F	16	ns	ns

*Key: * = significant (P = .05 level, LSD test); ns= non-significant (P = .05 level, LSD test)*

Sorghum monocropping system registered more negative N balances (Table 3). Nitrogen balance was more negative with use of TSP in all cropping systems in the LpS experiment. For the CpS experiment, N balance was more negative with use of MPR, in the monocropping and intercropping system. For the rotation system, in the CpS experiment, the balance was more negative with use of TSP fertilizer.

More negative N balance, than for P and K, suggests greater nitrogen outflow through harvested products, leaching, gaseous losses and erosion, identified pathways for N loss from soil [13,26]. Plants require N for biomass partitioning [27]. Leaf nitrogen content is usually higher at the start of grain filling, and is subsequently transferred to grain [28]. Legumes are especially important as species in plant production that can support biological nitrogen fixation. However, for high yielding grain legumes there is little or no gain in soil nitrogen because of the large harvest of the seed resulting in removal of soil nitrogen [29]. Losses of N through leaching may partly have been precipitated by the high N levels in soil, analyzed chemically (Table 1). Riley et al. [30] in a study on nitrogen leaching and soil nitrate, nitrite, and ammonium levels under wheat in Northern Mexico, reported that a high residual N in farmers' fields led to a higher leaching of N from soils. Outflow of N through gaseous losses was considered in the calculation of nutrient balances as specified in the NUTMON Model [19].

More negative N balance obtained in the sorghum monocropping system, in both experiments, can also be explained by the low quality of sorghum residues. Carbon to nitrogen ratio (C: N) of residues significantly affects nitrogen cycling. Sorghum straw has large C: N, is difficult to decompose and favours N immobilization [31]. Legume residues, on the other hand, decompose rapidly, due low C: N [32], thereby enriching soil. Additionally, there occurred inflow of N through legume di-nitrogen fixation [33]. This may partly explain the observed less negative N balances in the rotation and intercropping than monocropping system, in both experiments. In general, when residues of grass species are mixed with residues of legumes no immobilization of nitrogen will take place and the gradual mineralization favours availability of nutrients [31]. The strategy for crop associations is to look for species from different families that have different C:N and lignin contents, and that are able to complement both the supply of nutrients and the provision of soil cover for a long time [31]. The ideal crop association is the one that offers enough residues to provide a 'pool' of mineral N from decomposition to attend the commercial crop [31].

Effect of phosphorus fertilizer on nitrogen balance can be explained by its role in increasing grain yields (Table 5) and subsequent N export through harvested products. Phosphorus is a critical plant nutrient element after N. Adequate P supply is required for optimum sorghum growth and reproduction [25,34]. In the rotation and intercropping system, additional N supplied through biological fixation boosted sorghum grain yield (Table 5), and subsequent export of P. Phosphorus was additionally consumed through biological nitrogen fixation (BNF) process, which has high P demand [35-37].

3.3 Effect of Cropping System and Fertilizer Type on Phosphorus Balance

P balance values were less negative than for N, in both LpS and CpS experiments (Table 3). The main effects of cropping system and fertilizer type on P balances were significant (Table 4).

Table 5. Grain yield (t ha-1) as affected by fertilizer type and cropping system (Mean±SD)

P source	Lupin sorghum experiment											
	2012 LRS				SRS 2013				2012 LRS			
	Mon	Inter	Rot	Aver	Mon	Inter	Rot	Aver.	Mon	Inter	Rot	Aver.
TSP	11.27 ±5.1	16.3 (0.41) ±4.04	12 ±2.6	13.19 ±3.9	10.53 ±4.7	17.7(0.43) ±4.2	12.7 ±2.9	13.6 ±3.93	13 ±6.08	18(0.61) ±3.5	15 ±2.6	15.3 ±4.1
MRP	18.3 ±3.7	14.7 (0.42) ±9.3	17.3 ±3.78	16.8 ±5.6	18.3 ±4.7	16.7(0.48) ±7.6	17.7 ±3.2	17.6 ±5.2	18.3 ±4.7	17 (0.71) ±7	16 ±4.9	17.1 ±5.4
	Chickpea-sorghum experiment											
TSP	21.3 ±1.5	15.7(-) ±5.7	16.3 ±5.1	17.8 ±4.1	21.7 ±0.6	16.7 (0.01) ±6	14.3 ±2.1	17.6 ±2.9	21 ±1.7	17.3 (0.01) ±5	14.7 ±3.05	17.6 ±3.26
MRP	24 ±3.5	21.7(-) ±2.5	20.6 ±2.3	22.1 ±2.8	23 ±1.7	21.7(0.02) ±1.5	17.7 ±3.2	20.8 ±2.13	22 ±2	21.6 (0.01) ±1.5	19.3 ±3.05	20.9 ±2.18

Key; P= phosphorus source; TSP= triple superphosphate; MRP= Minjingu phosphate rock; SRS= short rain season; LRS = long rain season; Mon= Sorghum monocropping system; Inter = intercropping; Rot = rotation; Aver. = average; figures in bracket = legume grain yield, - = nil

Effect of interactions was not significant (Table 4). P balance was more negative in the lupin/sorghum intercropping followed by sorghum monocropping and lastly lupin – sorghum rotation system in the LpS system. P balance was more negative with use of MPR in the lupin/sorghum intercropping and sorghum monocropping systems in the LpS experiment (Table 3). For the CpS experiment, the sorghum monocropping system had more negative P balances than chickpea/sorghum intercropping or chickpea-sorghum rotation systems (Table 4). In the CpS experiment, P balance was more negative with TSP use in both sorghum monocropping and sorghum/chickpea intercropping systems.

The less negative P balance registered, than for N, suggests lesser outflow of the former. This can be attributed to its low mobility in soil [25, 38]. In a study on phosphorus leaching, Djodjik [39] reported that in some soils, P leaching was low in spite of high P applications. This was attributed to high P sorption capacity in the subsoil. Soils in this study were, however, not expected to adsorb P (not measured), due to the neutral pH (H_20) value (Table 1). P residual effect, particularly for MPR [25,40] and likely adsorption of inorganic P, from TSP fertilizer, to binding sites of organic residues may have contributed to the less negative P balance. Organic matter sorbs inorganic phosphate [41]. Experimental evidence suggests that inorganic phosphate involves Fe (III) and Al (III) in organic matter as bridging cations (ternary complexes) [42, 43]. In a study on phosphorus leaching in an acid tropical soil “recapitalized” with phosphate rock and triple superphosphate there was hardly any substantial P leached from the soil treated with Gafsa phosphate rock. A combination of manure with GPR resulted in an insignificant P leaching [37].

More negative P balances in intercropping system, in the LS experiments, with MPR use may be attributed to a greater P uptake and yield increase by sorghum (Table 5) and subsequent export of P. Lupin facilitated P acquisition by sorghum, by solubilizing MPR through rhizosphere processes [16,39]. Li et al. [44] reported that rhizosphere facilitation of the intercropped species increases availability of P for crop uptake. Facilitation of P acquisition is a potentially important cause of over yielding (producing more than the highest- yielding monoculture in a particular mixture) in annual intercropping systems [45]. Additionally, harvesting of two crops of the cropping system, in the intercropping system, resulted into greater nutrient removal. A more productive intercropping system, generally removes more nutrients, which will need to be replaced [45]. BNF process may have additionally led to the export of P, in the lupin/sorghum intercropping system. N fixation is a P requiring process [34-36].

Less P outflow with MPR application, in the intercropping system of the CpS unlike in the LpS experiment, may have been due to differences in P solubilizing capabilities of the chickpea and lupin, There was probably greater solubilization effects by lupin hence greater P uptake and subsequent export through grain. Greater P losses with TSP in the intercropping in the CS may have been because TSP is a water soluble and readily available P source for crop uptake [25] and subsequent export through grain. Apart from export of P through grain, losses of P in the monocropping system in both experiments may be explained by low quality of sorghum residue and hence poor recycling of P. Cereal grain residues generally are of low quality [46].

3.4 Effect of Cropping System and Fertilizer Type on Potassium Balances

K balances were less negative than for P and N, in both LpS and CpS experiments (Table 3). The main effects of cropping system and fertilizer type on K balances were significant, in both experiments. Interactions effects were not significant (Table 4). In the LpS experiment, the sorghum monocropping system registered more negative K balances followed by sorghum/lupin intercropping and lupin-sorghum rotation systems in that order. (Table 3). K balances in LpS experiment were more negative with use of MPR in both sorghum monocropping and lupin/sorghum intercropping systems. For the CpS experiment, the sorghum monocropping system had more negative K balances than chickpea/sorghum intercropping or chickpea-sorghum rotation systems (Table 3). K balance was more negative with use of TSP in all cropping systems in the CpS experiment.

The less negative K balance, than for N and P, can be explained by lower crop uptake. Results of a study on N, P and K uptake by sorghum hybrids, showed that a higher percentage of the total N and P needs was taken up during grain development, compared to K [47]. More negative K balance in the sorghum monocropping system, in both experiments, may be attributed to poor K recycling in sorghum straw *vis' a vis'* legumes present in the rotation and intercropping systems. Nutrients are released from the organic fraction depending on the C: N, C: P or even C: K ratio [48].

More negative balance in the monocropping and intercropping systems after MPR application, in the LpS experiment, and with use of TSP in all cropping systems in the CpS experiment can be attributed to contribution of fertilizer to grain and dry matter yield [34], and subsequent nutrient export through grain.

4. CONCLUSION

Nitrogen, phosphorus and potassium balances were negative, in both lupin- sorghum and chickpea- sorghum experiments, with greater losses for nitrogen. Negative balances was an indication that more nutrients were lost than gained. Sorghum monocropping system registered more negative nutrient balances than rotation and intercropping systems. The monocropping system is therefore unsustainable. Phosphorus fertilizers had a significant effect on nutrient balances. This may have been due to its role in increasing grain yields with greater nutrient export where grain yields were higher. The effect of phosphorus type i.e. TSP or MRP was, however, variable among cropping systems.

The integration of white lupin and chickpea together with phosphorus application, either TSP or MRP, in addition to manure application and improved soil conservation is recommended for improving nutrient inflow and stock in sorghum based cropping systems. In future, the study can be projected to farmers' field and also carried out over many cropping cycles and calendar years. This is because sustainability studies are temporal. An economic analysis of the farms is also recommended in future studies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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