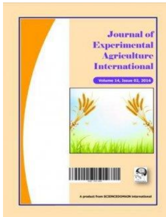

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Legume and Organic Fertilizer Effects on Soil Nutrient Availability, Uptake and Kale Yields in Kabete Sub-county Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author CC designed the study, performed the field experiment, the statistical analysis and wrote the first draft of the manuscript. Authors RNO and RGW reviewed the data, managed the analyses of the study and assisted in writing of the first draft of the manuscript. Author HHJ managed the literature searches and final review of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Declining soil fertility is the main constraint to kale (*Brassica oleracea* var. *acephala*) a common vegetable, production in parts of Kiambu County Kenya. A field experiments to evaluate the effect of legume integration and application of organic fertilizers on soil N and P (and OC), uptake and kale yield was set up in Kabete field station of the University of Nairobi, in the long and short rainy season of 2014. The experimental layout was a Randomized Complete Block Design with a split plot arrangement. The main plots were; (i) sole kale, (ii) kale intercropped with lupin and chickpea (lupin/kale and chickpea/kale) and (iii) Kale succeeding lupin and chickpea (lupin-kale and chickpea-kale). The spilt plots were the organic fertilizers inputs; Minjingu rock phosphate (MRP) and Farm yard manure (FYM), and the control. the nutrients N, P and organic

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carbon, kale N, P uptake and yield were analyzed at intervals of 1, 2 and 3 months of kale development. The plant available N was higher in the lupin/kale intercrops + FYM in both seasons. Plant available P was significantly ($P \leq 0.05$) higher in lupin/kale intercrop + MRP across the two seasons. There were no significant changes in soil organic carbon levels with legume integration and organic fertilizers application throughout the sampling period in both short rain seasons. In both seasons, significant higher N concentration was obtained in a sole kale + FYM whereas P concentration was significantly increased in a lupin/kale intercrop + MRP. Lupin/kale intercrop + FYM and lupin/kale intercrop +MRP showed a positive correlation (R^2=0.99) between soil N and plant N, soil P and plant P respectively in both seasons. Higher kale yields were obtained in lupin-kale rotation + FYM and MRP; chickpea-kale rotation + FYM and MRP and kale monocrop + FYM. Integration of white lupin (intercrop/rotation) + FYM and MRP in a kale production system leads to a significant improvement on soil nutrient status, kale nutrient uptake and yield. Similarly where lupin was integrated positive correlations of soil and plant N and P were recorded and this means that the nutrient supplied was able to replenish the soil as much as plant took them up.

Keywords: Kale; organic fertilizers; legumes integration; soil fertility.

1. INTRODUCTION

The production potential of kale (*Brassica oleracea* var. *acephala* D.C), commonly known as *sukuma wiki,* which is a popular vegetable in many Kenyan smallholder households, is limited primarily by plant availability of nitrogen (N) and phosphorus (P) [1,2]. The plant availability of N and P is generally declining following soils deterioration [3,4]. Nutrients lost from the soil through harvested products are not adequately replenished due to the expensive inorganic fertilizers [5,6] and thus poses a risk of food shortages [7].

Moreover, with the constraints to inorganic fertilizer use in sub-Saharan Africa (SSA) calls for investigation into the possibility of intensifying crop production by substituting and or complementing with alternate and locally available means to meet the nutrient requirements of crops [8].

Minjingu rock phosphate (MRP) could be a viable option to the expensive inorganic P fertilizers. However, its use in soil fertility improvement is limited by it relatively low insolubility. It is envisioned that white lupin (*Lupinus albus* L) and chickpea (*Cicer arietinum* L.) can mobilize P from MRP and increasing crop available N through biological nitrogen fixation.

Most studies on the use of MRP and farm yard manure (FYM) with the integration of legumes have been on cereal-based cropping systems none on kale based cropping system. Previous studies have shown that (MRP) application and integration of legumes; white lupin (*Lupinus albus* L.) and chickpea (*Cicer arietinum* L.) in maize cropping systems could provide a feasible and low-cost alternative for rebuilding soil fertility [9,10,11]. Apart from fixing atmospherically derived Nitrogen [12], legumes can also solubilize sparingly soluble P sources through rhizosphere processes [11] resulting in increased plant available N and P levels in soil. Chickpea and lupin exude carboxylates from their roots that have the capacity to solubilize MRP [13,14].

The objective of the current study was therefore to investigate for the effect of integrating legumes and application of organic fertilizers in kale-based cropping systems of Kabete sub-County, Kenya.

2. MATERIALS AND METHODS

2.1 Site Description

The on-station study was conducted at the Kabete field station of the University of Nairobi, located about 10 km North of Nairobi. The station is about 1940 m a.s.l, coordinates 01.24356S and 36.74186 E and falls under agro-ecological zone III [15]. The site has a bimodal rainfall distribution (mid – March – May, long rains and; October – December, short rains). Kabete has an average annual precipitation of 1000 mm and a minimum and maximum mean temperature of 13.7°C and 24.3°C respectively. The soils are predominantly deep red Nitisols containing 60 – 80% clay particles [16]. The clay mineral is predominantly kaolin white and the parent material is the Kabete *trachyte.* The analyzed initial soil properties were a near neutral pH (H_2O) of 6.3, organic carbon level of 2.83% (moderate) total N 0.32% (moderate), available P of 11 ppm (low), bulk density of 25 g/cm^3 (good for root penetration), and mineral N 25.20 kg/ha (moderate) according to FAO [17] nutrient classification.

2.2 Experimental Design and Treatments

The experimental design was a randomized complete block design with a split plot arrangement. The main plots; (i) sole kale, (ii) kale intercropped with lupin and chickpea (lupin/kale and chickpea/kale) and (iii) Kale succeeding lupin and chickpea (lupin-kale and chickpea- kale). The split plots were the organic fertilizers; Minjingu rock phosphate (MRP) and Farm yard manure (FYM), and the control (Table 1). The treatments were replicated three times giving a total of 45 plots. Plot sizes were 3.75 m by 4.8 m with a 0.5 m and 1 m wide footpath between the plots and blocks respectively.

2.3 Agronomic Practices

All plots were ploughed using hand hoes and residues removed manually before the application of organic fertilizers. Minjingu Rock Phosphate (MRP) was broadcasted at the rate of 60 kg P per ha (496 kg per ha) and then incorporated to a depth of 0 – 0.15 m before planting. Farm yard manure[1] (FYM) was applied at a rate of 10 tonnes per ha. Kale (*Brassica oleracea* var. *acephala* D.C.) were transplanted whereas, chick pea (*Cicer arietinum* L) and white lupin (*Lupinus albus* L*)* were sown as intercrops and pure stands. Kale was planted at a spacing of 60 cm and 45 cm between and within the row in all treatments. Four weeks after transplanting, the seedlings were thinned to one plant per hole. Weeding was carried out after the emergence of weeds and was done twice.

In the intercropping system one row of legume, either lupin or chickpea was sown between two kale rows, at the rate of two seeds per hole. Intra cropping distance of 30 cm for the legumes was maintained. For rotation system, in the SRS, chickpea and lupin were sown at the rate of two seeds per hole as sole crops and at a spacing of 75 × 30 cm. Thinning to one seedling per hole was done four weeks after sowing for all crops. The plots were kept weed free throughout the crop growing season through manual control.

2.4 Soil, Plant Sampling and Analysis

2.4.1 Soil and plant sampling

Composite top soil (0-20 cm) samples, for determination of initial soil properties were collected in a zig-zag manner, from the experimental area for determination of plant available N, P and organic carbon. Thereafter, soil samples were collected after 1, 2 and 3 months of kale transplanting from five randomly selected points in each plot. Kale leaves for N, P and kale yield determination were sampled r 1, 2, and 3 months of kale growth in which kale leaves were randomly sampled from ten kale plants and fresh weights taken using a weighing balance. Soil samples were bagged in polythene bags while the crop samples were put in khaki bags and transported to the laboratory, air- dried to constant weight sieved through a 2mm mesh and stored for analysis.

2.4.2 Soil and plant analyses

The soil samples were analyzed for pH (in H_2O), total nitrogen, plant available P and organic carbon. The pH was measured with a glass electrode pH meter on 1: 2.5 ($^w/_v$) suspension of soil in water after shaking for 30 minutes [18]. The plant available P content was estimated with the Molybdenum Blue method [19] after shaking for 30 minutes at 1:10 ratio with double acid (conc. HCl and H_2SO_4). The organic C was estimated by the Walkley-Black method [20]. The soil total N was measured by the semi-micro Kjeldahl method [20]. Soil texture was determined using hydrometer method [20]. Undisturbed core samples were used in bulk density determination [21].

The dried kale samples were finely ground and 5 grams used for analysis. The N concentration was analyzed using the micro-Kjeldahl method after digestion [20]. For P uptake, 0.5 g of the dried samples was destroyed through oxidation by dry combustion in a muffle furnace at a temperature of 250°C for 12 hours, and the soluble ash, were dissolved in dilute hydrochloric acid. It was later run on a flame photometer [18].

[1] *pH -H2O (8.53), N (1.88%), Organic C (11.92%); P(5 ppm)*

Table 1. Treatments and crop sequence on field experiment for the long rain (LRS) and short rain season (SRS) of 2014

Treatment	Crops	Organic fertilizers	Crop sequence across seasons	
			LRS	SRS
1	Kale	MRP	Kale	Kale
2	Kale	FYM	Kale	Kale
3	Kale	CNTRL	Kale	Kale
4	Lupin-kale	MRP	Lupin	Kale
5	Lupin-kale	FYM	Lupin	Kale
6	Lupin-kale	CNTRL	Lupin	Kale
7	Chickpea-lupin	MRP	Chickpea	Kale
8	Chickpea-lupin	FYM	Chickpea	Kale
9	Chickpea-lupin	CNTRL	Chickpea	Kale
10	Lupin/kale	MRP	Lupin/kale	Lupin/kale
11	Lupin/kale	FYM	Lupin/kale	Lupin/kale
12	Lupin/kale	CNTRL	Lupin/kale	Lupin/kale
13	Chickpea/kale	MRP	Chickpea/kale	Chickpea/kale
14	Chickpea/kale	FYM	Chickpea/kale	Chickpea/kale
15	Chickpea/kale	CNTRL	Chickpea/kale	Chickpea/kale

MRP-Minjingu Rock Phosphates, FYM-Farm Yard Manure, CNTRL-Control
LRS-long rain and SRS-short rain season

2.5 Statistical Analysis

The measured soil and plant parameters were subjected to analysis of variance using Genstat statistical software [22]. Least significant differences (LSD) test was used to identify significant differences among means ($P \le 0.05$) between months and seasons. Correlations analysis for soil and kale N and P were analyzed using the STATA software.

3. RESULTS AND DISCUSSION

3.1 Effect of Organic Fertilizers and Cropping Systems in Soil Nutrients

3.1.1 Organic carbon

There were no significant interaction effects between organic fertilizers and cropping systems in the first month of long rain season. A slight increase was recorded in the lupin/kale intercrop and chickpea-kale rotation with application of FYM. In the second month, there was a slight increase in organic carbon in all plots where FYM was applied; significantly higher amounts of organic C were recorded in lupin/kale intercrop and lupin-kale rotation with application of FYM Moderate increase was recorded in the third month of sampling in a; lupin/kale intercrop and chickpea/kale intercrop with application of FYM (Fig. 1).

In the first month of short rain season, there was a significant ($P \le 0.05$) interaction effects between cropping systems and organic fertilizers (Fig. 1) with significant organic carbon realized in e lupin-kale rotation (FYM), chickpea-kale rotation (MRP). The lowest amounts were recorded in chickpea/kale intercrop (MRP and Cntrl). In the second month, moderate increase in organic C was recorded in lupin- kale rotation with application of FYM and MRP. Similarly, a significant increase in organic C was recorded in chickpea-kale rotation with application of FYM. In the third month, there was a slight decrease in organic carbon levels with application of FYM as compared to second month in which, MRP treated plots had low organic C. The control recorded a slight increase in organic C for the lupin/kale, chickpea/kale intercrops and a decrease in the chickpea-kale rotation and monocrops (Fig. 1).

The organic C kept increasing slowly throughout the sampling periods where lower levels were registered in the first month whereas the second and third month showed a slight increase but non-significant increase. A similar trend was recorded in the short rain season. The slight changes in organic C could be attributed to the plant residues which could have dropped to the soil. Changes in soil organic C is slow and typically take five years [22]. Kouyaté et al. [23] and Myaka et al. [24] had also observed that integration of legumes within cropping systems did not improve soil organic C. Another contributing factor could be due to tillage which opened up the soil and hence increases the decomposition rates. Tiessen et al. [25] reported that soils in the tropics have little stable carbon and cultivation could enhance destabilization and further losses of soil organic C even when residues are incorporated into soil regularly. Bwenya and Terokun [26] reported that return of crop residues is effective in restocking soil organic C.

Higher levels of organic carbon under intercropping plots involving white lupin could be attributed to its higher biomass production compared to chickpea. Engedaw [27] also observed higher above ground biomass by lupin compared to other legumes. A study done by 28 though on sorghum intercropped with dolichos reported higher organic carbon in such interactions due to higher biomass production by dolichos as compared to pigeon pea.

Comparison between intercropping and rotation system in the long rain season, showed that lupin/kale intercrop had higher organic carbon than lupin-kale rotation. Chickpea/kale intercrop also had higher soil organic C during the long rain season than chickpea-kale rotation. This pattern may have been due to the high amount of biomass produced under intercropping leading to crop residues being made available for decomposition. A study [28] on sorghum and cassava being intercropped with dolichos reported similar results on the behavior of organic C in the soil. The high levels of carbon recorded in the crop rotations systems as shown in the short rain season, was a result of crop residues from the legumes would further act as manures thus increasing the soil organic carbon. This was in agreement with a study by Engedaw [29] who found out that legume manure has increased benefits such as the ability to increase soil carbon.

In the short rain season, both intercropping and rotation systems recorded higher levels of soil organic C compared to the monocrop systems. The high soil organic carbon in the rotations could be attributed to the legume residues from the long rain season which underwent decomposition and rather acted as manures. A research carried out by Onwonga et al. [30] also reported that legume manures had increased benefits such as the ability to increase soil carbon.

The adequate levels of organic carbon in the lupin/kale intercrop; chickpea-kale rotation and lupin-kale rotation in the short rain season, was due to the legume residues from the long rain season that were incorporated into the soil hence raising the organic carbon content.

Where Farm yard manure was applied, even in a monocrop system, there was a significant increase in the organic carbon levels. Application of farm yard manure is known to play an important role in increasing soil carbon as it decomposes slowly; similar findings were reported by Knight and Shirtliffe [31], who found that continuous application of FYM to the soil leads to increase in soil organic carbon (SOC) in all the soil fractions. Addition of FYM has been shown to increase soil organic carbon [32,33,34]. Kapkiyai [35] reported that return of crop residue to soil may not be as effective in restocking soil organic carbon compared to addition of farm yard manure. Increased organic carbon levels where FYM was applied conform to the study by Bayu [36] who also concluded that FYM application increased soil organic carbon content by up to 67% over the control treatment.

3.1.2 Total nitrogen

In the long rain season, the total N was significantly ($P \leq 0.05$) high during the first month of sampling in the lupin/kale intercrop (FYM) followed by MRP. In the second month, lupin/kale intercrop registered significant higher levels of N whereas the sole kale monocrop (MRP and Cntrl) recorded the lowest amount. In the third month of sampling, there was no significant increase in nitrogen from the second month. The lupin/kale intercrop with application of FYM had significantly higher amounts of nitrogen in comparison to other combinations (Fig. 2).

In the short rain season, the trend was similar to that of the long rain season, albeit lower levels during the first month cutting across all cropping systems. In the second month of sampling, there was a significant reduction of soil total nitrogen in all combination. In the third month there was a marked increase in the lupin/kale intercrop with application of FYM, followed by the lupin- kale rotation with application of FYM, whereas the lowest

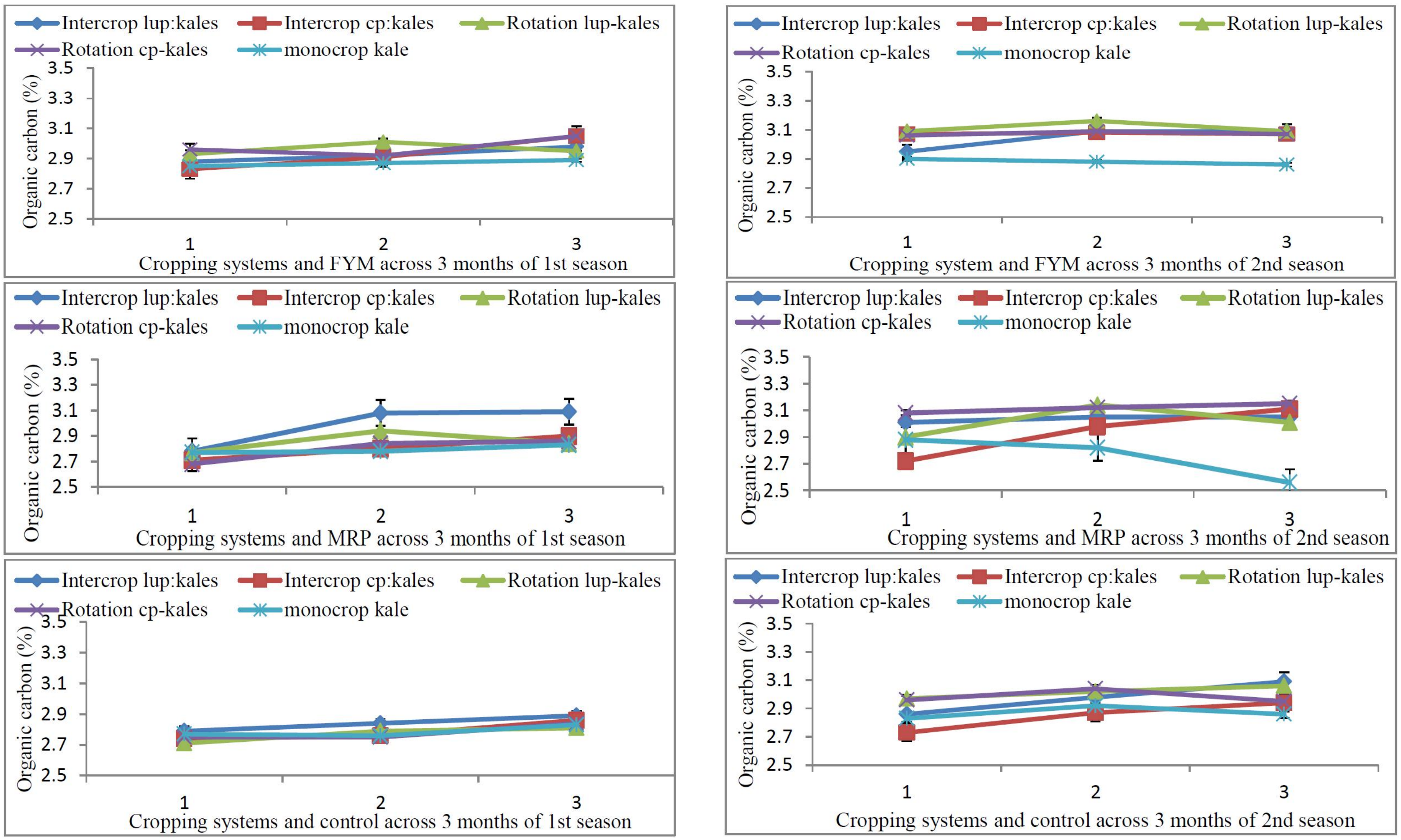

Fig 1. Effects of legume integration and organic fertilizer application soil organic carbon

Key: MRP-Minjingu rock phosphate, FYM- farm yard manure CP-chickpea, LUP- lupin. Values are the mean (n = 3) ± S.E amounts were obtained in the sole kale monocrop with application of MRP (Fig 2).

There was higher nitrogen concentration in the first month of the long rain season, the levels declined during the second month and a slight increase was registered in the third month. A similar trend was recorded in the short rain season but significantly higher levels were registered. The declined amounts of total N at the second month could be attributable to plant uptake. Most crops take up majority of the nutrients during periods of vegetative growth [37].

Significantly higher amounts of total nitrogen in white lupin-kale rotation and chickpea-kale rotation systems registered in short rains season. The significant increase could be attributed to the legume residue from the long rain season. Similarly, white lupin- kale rotation registered higher levels of nitrogen compared to the chickpea-kale rotation. Previous studies have shown that the above ground biomass of lupin is more than that of chickpea and this has been documented by Tiessen [27].

The high levels of total nitrogen observed in the intercropping and rotation systems than mono-cropping system across all seasons could have resulted from N fixed by the legume component. These findings are also similar to those conducted by Anyango and Keya [1] who found that kale- legume intercrop had the highest soil nitrogen content in both seasons if the rotation of kales was not available. In another study conducted by Defra [38], legume intercrops and organic rotations were found to often provide a supplementary boost of N during the fertility depleting phase by the growing of a leguminous crop, such as field beans or peas. Similarly, rotational fallows or relay intercrops have shown to increase nitrogen input and structural stability of the soil according to a study done by Sileshi et al. [39].

In comparing the legumes, where lupin was integrated, significant higher levels of nitrogen were registered as compared to chickpea. The higher levels of total nitrogen recorded where lupin was intercropped could be as a result of nitrogen fixation by legume component. Higher total nitrogen under Lupin/kale intercrop compared to chickpea/kale intercrop could be due to higher fixation of N by lupin compared to chickpea as well as superior litter. Similar findings were documented by Brady and Weil [40] who found out that there were higher rates of nitrogen release through biological fixing where lupin was planted as compared to chickpea.

FYM treated plots registered significant amounts of total N content compared to MRP across cropping systems and seasons. The significant increase could be attributable to the fact that FYM contains high nitrogen levels and the slow nature of N release so its application into the soil resulted in an increase in soil N as compared to application of MRP. Adekayode and Ogunkoya [32] observed higher N content in plots treated with organic fertilizer attributing this observation to direct input of N and ability of manure to make N available for a long time due to slower release of N from the high residual pool. Application of MRP also recorded slightly higher but not significant amounts of total N in comparison to the controls. These findings could be attributed to improved soil condition by the MRP and hence nitrification and hence there was an increased number of nitrifies. Improved total N where MRP was applied have also been documented by Onwonga et al. [41] who did a study on effects of MRP application on soil total nitrogen.

3.1.3 Available phosphorus

Phosphorus significantly ($P \leq 0.05$) increased in the first month of the long rain season even more than the initial value. The lupin/kale intercrop (MRP) followed by chickpea/kale (MRP) recorded higher amounts of phosphorus with the lowest amounts in the sole kale monocrop (Cntrl). In the second month, there was decrease in plant available P levels throughout the cropping systems and organic fertilizers combination. Significant high levels of P were recorded in lupin-kale rotation with application of MRP. The lowest levels were recorded in the chickpea/kale intercrop (Cntrl) (Fig 3). At the third month of sampling, phosphorus was a significantly ($P \leq 0.05$) increased in lupin/kale intercrop (MRP); lupin-kale intercrop, (FYM) whereas the kale monocrop under all organic fertilizers recorded the lowest levels throughout the sampling period (Fig. 3).

In the short rain season, first month plant available P significantly increased in all cropping systems and organic fertilizers combinations. Significant higher amounts of phosphorus were recorded in the white lupin/kale intercrop with application of MRP. The second month recorded a decrease in soil available P levels. The white lupin/kale intercrop with application of MRP recorded highest levels whereas; the lowest levels were recorded in the Chickpea-kale rotation (Cntrl). The third month, recorded slightly higher amounts of soil P in the white lupin/kale; chickpea/kale intercrop with application of MRP whereas, the lowest amount was in kale monocrop (Cntrl) (Fig. 3).

The changes in plant available P across the sampling periods in which the first month registered higher amounts and progressively reduced at the second month through to the third month. The high soil phosphorus recorded at the first month of season one could be attributed to the addition of MRP, legume integration, as well as decomposition of organic residues that were ploughed into the soil. The use of the chickpea and white lupin as either intercrop or in rotation with application of MRP improved the amounts of P. This is because the said legumes have exudates which are acidic in nature and are able to solubilize the P from rock phosphate. Plant and microbial mechanisms can effectively extract P from MRP and release it into soil solution or into the labile fraction of soil [42]. White lupin plants (*Lupinus albus* L.) and chickpea (*Cicer arietinum* L.) have a great ability of mobilizing the sparingly soluble P through changing rhizosphere processes, particularly by citrate exudation [13,43].

There were significantly lower amounts of plant available P in the intercrops as compared to the rotations and monocrops and it is attributable to the high demand for phosphorus by the crops. Phosphorus is an essential nutrient for plant development and hence needed in high quantities. Similar results have been recorded by White and Brown [44] who found out that most crops take up a majority of the nutrients during the periods of vegetative growth which in the case of kales they are more vegetative during the early stages of growth.

Comparing the cropping systems, intercrops and rotations registered significant higher levels of phosphorus compared to monocrops. High plant available P under legume plots could be explained in terms of the solubilizing effect of legume exudates on insoluble P [45]. Legume residues which might have dropped decomposed and contributed to increase soil P either through release of organic acids which increase desorption of P [46] as opposed to monocrop where there was no legume residues returned to soil.

Plots with application of FYM, led to increased level of phosphorus as this could be attributed to the organic molecules, provided by the FYM which enhanced phosphorus availability by binding exchangeable and hydroxyl-Al, the key fixers of phosphorus in acid soils and they also play key roles in dissolving phosphate rock [47]. The controls with lupin in either intercrop or rotation system showed higher levels of P, this is due to the exudates released by lupine which was able to release any P which might have been fixed in the soil [48].

3.2 Effects of Organic Fertilizers and Cropping Systems on Kale Nutrient Uptake

3.2.1 Nitrogen

Significantly high levels of nitrogen were obtained in kale monocrop (FYM), chickpea/kale intercrop (FYM) during the first month of sampling of the long rain season. The cropping systems had no significant effect on nitrogen concentrations (Table 2). During the second month, relatively higher levels of nitrogen were obtained in a kale monocrop (FYM,) and chickpea/kale intercrop (FYM). Lower levels of nitrogen were recorded where, lupin/kale intercrop (control) at the third month of sampling (Table 2).

The short rain season obtained similar trend of nitrogen concentrations as that of the long rain season but slightly higher concentrations. In the first month, a significant high concentration of nitrogen was recorded in the lupin-kale rotation (FYM) and the lowest under the kale monocrop (MRP). The highest nitrogen concentration was recorded in a kale monocrop (FYM, MRP and control); lupin-kale rotation (FYM, MRP and control); lupin/kale intercrop (FYM, MRP and control) at the second month The lowest concentrations of nitrogen was recorded in; chickpea/kale intercrop {FYM (3.20%,), MRP (2.83%,) and Control (2.93%)}; lupin-kale rotation {FYM, (3.27%), MRP (2.93%) and Control (2.71%)} in the third month (Table 2).

The level of nitrogen uptake in the kale leaves kept decreasing as the leaves matured and therefore higher uptake were recorded in the first month and is usually the time when kales produce fresh, lushly leaves. Kale monocrop in the long rain season recorded higher levels of nitrogen as compared to the intercrops and rotation. This is because there was no competition for nutrients by the crops.

The high kale nitrogen concentrations where FYM was applied could be attributed to the improved soil condition by the FYM which led to uptake by the kale tissues. The use of FYM influenced the N uptake markedly which could be because of supply of these nutrients and improvement in the soil physical condition for better plant growth which ultimately led to higher N absorption [49].

The lupin/kale rotation with application of farm yard manure in the short rain season recorded significant high nitrogen contents and this could be attributed to the residues and leaves which dropped from lupin. Lupin is known to have high above ground biomass [27]. Previous studies have also shown that continuous application of FYM lead to an increase in soil N, [31], and this ultimately leads to high nitrogen uptake in the kale tissues.

The lupin/kale intercrop with application of MRP also depicted higher amounts of total nitrogen as compared to other treatments and this could be attributed to the availability of phosphorus after dissolution from the exudates and hence available for plant uptake.

3.2.2 Phosphorus

Throughout the two seasons of kale growth, the amount of phosphorus in leaves were significantly ($P \leq 0.05$) increased by applications of organic fertilizers and integration of the legumes. During the first month of sampling, lupin/kale intercrops (MRP); chickpea/kale intercrop (MRP) recorded higher concentrations of phosphorus as compared to kale monocrop (FYM and MRP). At the second month of sampling, the levels of phosphorus in the kale leaves were generally high, kale monocrop (MRP); chickpea/kale intercrop (MRP); lupin/kale intercrop (MRP) (Table 3). The third month recorded a slight decline in phosphorus concentration. Highest concentrations were registered in the kale monocrop with MRP application.

During the short rain season, the first month of sampling, lowest phosphorus concentration was recorded across all cropping systems and organic fertilizers. The lupin/kale intercrop with application of MRP recorded highest P concentrations whereas; the lowest level was recorded in the sole kale monocrop (Cntrl). The P concentrations were highest at the second month of sampling in lupin/kale intercrop (MRP) and chickpea/kale intercrop (MRP) (Table 3). The lowest levels phosphorus concentration was obtained in a kale monocrop (FYM, MRP and Control) arrangement. In the third month, there was a decrease in the phosphorus level in all cropping system and organic fertilizer interactions, whereas highest concentration were recorded in the sole kale with application of MRP (Table 3).

The changes in phosphorus concentration through the different sampling periods could be attributable to changes in amount of soil P. Phosphorus concentration in plants tissue varies with plant age. Similar results of the trend in phosphorus contents in plant tissue were also recorded by Fageria et al. [50].

High phosphorus concentrations were obtained where MRP and FYM were applied compared to the controls. The increased amount of phosphorus in the kale tissue was contributed to by the additional supply of P after addition of MRP, which contributed to increased root development hence better P uptake and plant growth resulting in more P concentration on the leaves.

The increased P concentration in the white lupin/kale intercrop could be due to higher plant uptake of P by both component crops after lupin mobilization of unavailable P and solubilization of MRP. Jones et al. [51] and Lambers et.al. [52] noted the important role of plant roots in releasing large amounts of organic acids such as citric acid, in order to mobilize nutrients like P when bound to soil particles and inaccessible for direct plant uptake.

Cu et al. [53] and Li et al. [45] also documented that P availability to a less P efficient crop, in this case maize, was increased through intercropping with a P efficient species. Liu et al. [54] and Nuruzzaman et al. [55] also found that the presence of a legume in a cropping system often increases P uptake for the subsequent crop in rotation or companion crop in an intercropping system. The inability of kale to acidify its rhizosphere means reliance on legumes for this and also takes up P upon its mobilization [55]. Liu et al. [53] in a study about maize growth under different cropping systems also found that improved maize growth was not caused by better N nutrition but rather better P uptake. Onwonga et al. [41] also noted that legume rotations had significantly higher yields and this could be attributed to their efficiency in P acquisition from soils.

Table 2. Effects of legume integration and application of organic fertilizers on kale nitrogen uptake (%)

Months of kale growth	Cropping systems	Crop	Long rain season 2014				Short rain season 2014			
			FYM	**MRP**	**CNTRL**	**MEAN**	**FYM**	**MRP**	**CNTRL**	**MEAN**
1	Intercrop	Lupin/kale	4.00^{ab}	3.90^{ab}	3.70^{a}	3.87^{a}	4.33^{ef}	4.12^{def}	3.52^{ab}	3.99^{ab}
	Intercrop	Chickpea/intercrop	4.15^{b}	3.80^{ab}	3.75^{a}	3.90^{a}	4.17^{def}	4.13^{def}	4.00^{cde}	4.10^{c}
	Monocrop	Kales	4.87^{c}	4.00^{ab}	4.17^{b}	4.35^{d}	4.34^{ef}	3.31^{a}	4.04^{cde}	3.89^{a}
	Rotation	Lupin-kale	-	-	-	-	4.40^{f}	3.83^{bcd}	3.55^{ab}	3.94^{ab}
	Rotation	Chickpea-kale	-	-	-	-	4.13^{def}	3.64^{abc}	3.78^{bcd}	3.85^{a}
2	Intercrop	Lupin/kale	3.67^{b}	3.77^{bc}	3.41^{a}	3.62^{a}	4.32^{fg}	4.31^{fg}	3.32^{bc}	3.99^{c}
	Intercrop	Chickpea/kale	4.09^{d}	3.77^{bc}	3.40^{a}	3.75^{a}	4.16^{efg}	3.95^{def}	3.13^{b}	3.75^{ab}
	Monocrop	Kales	4.47^{e}	3.99^{cd}	4.22^{d}	4.23^{de}	4.19^{efg}	4.11^{efg}	2.62^{a}	3.64^{a}
	Rotation	Lupin-kale	-	-	-	-	4.05^{efg}	4.07^{efg}	3.45^{bc}	3.86^{b}
	Rotation	Chickpea-kale	-	-	-	-	3.93^{de}	4.31^{fg}	3.62^{cd}	3.95^{c}
3	Intercrop	Lupin/kale	2.97^{bcd}	2.92^{bc}	2.21^{a}	2.70^{a}	4.02^{g}	3.91^{g}	3.20^{c}	3.71^{d}
	Intercrop	Chickpea/kale	3.10^{cde}	3.00^{cd}	2.70^{b}	2.93^{b}	3.53^{f}	2.82^{ab}	3.04^{abcd}	3.12^{c}
	Monocrop	Kales	3.37^{e}	3.23^{de}	2.90^{bc}	3.17^{c}	3.27^{def}	3.03^{abcd}	2.75^{a}	3.02^{b}
	Rotation	Lupin-kale	-	-	-	-	3.27^{def}	2.93^{abcd}	2.71^{a}	2.97^{b}
	Rotation	Chickpea		-	-	-	4.04^{g}	3.17^{def}	2.96^{abcd}	2.70^{a}

Key: MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin, - rotational system where kale was not planted. Means followed by the same letters in the same month and season in a column is not significantly different at P ≤ 0.05

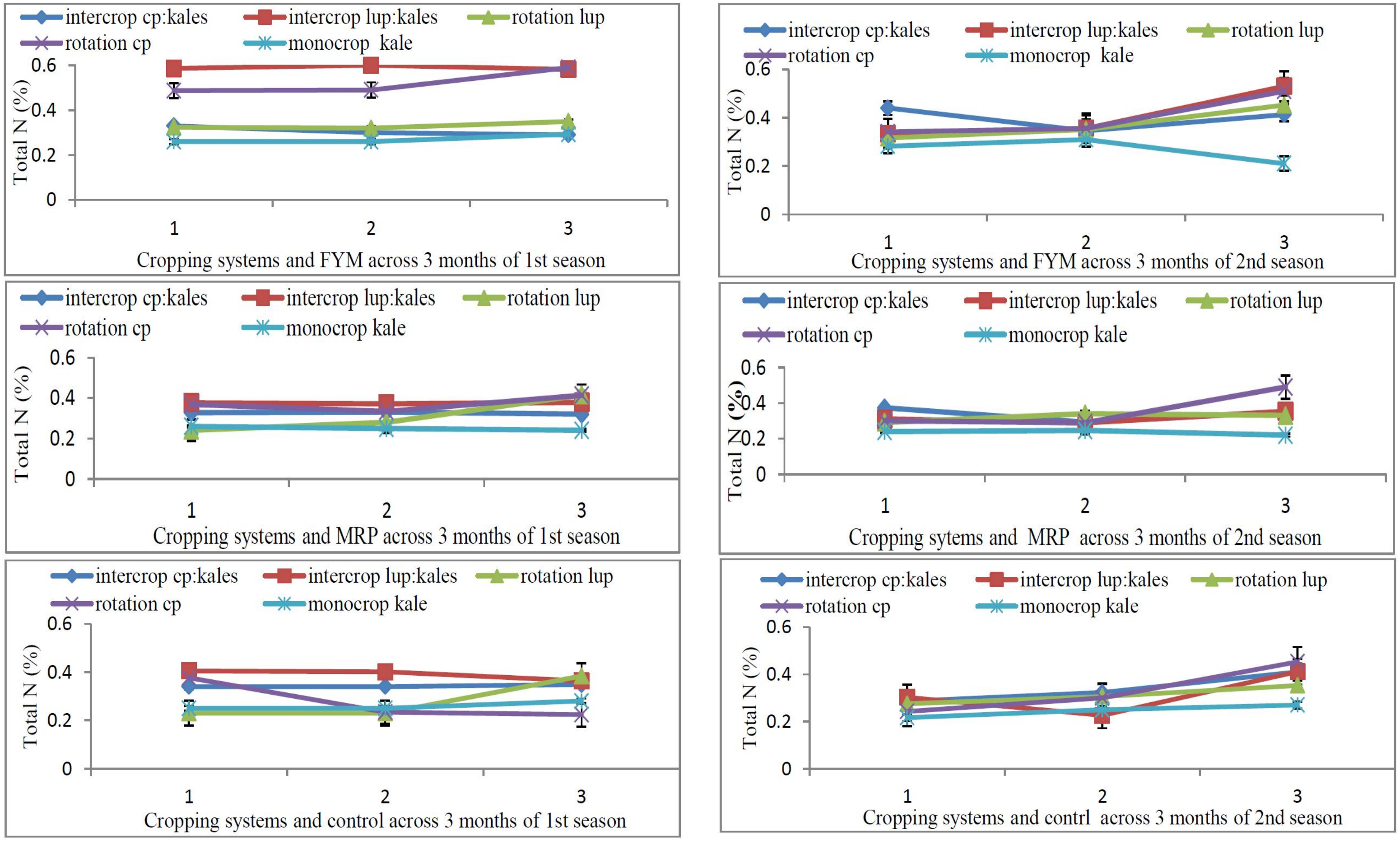

Fig. 2. Effects of legume integration and organic fertilizer application on Total N (%)

Key: MRP-Minjingu rock phosphate, FYM- farm yard manure, CP-chickpea, LUP- lupin. Values are the mean (n = 3) ± S.E

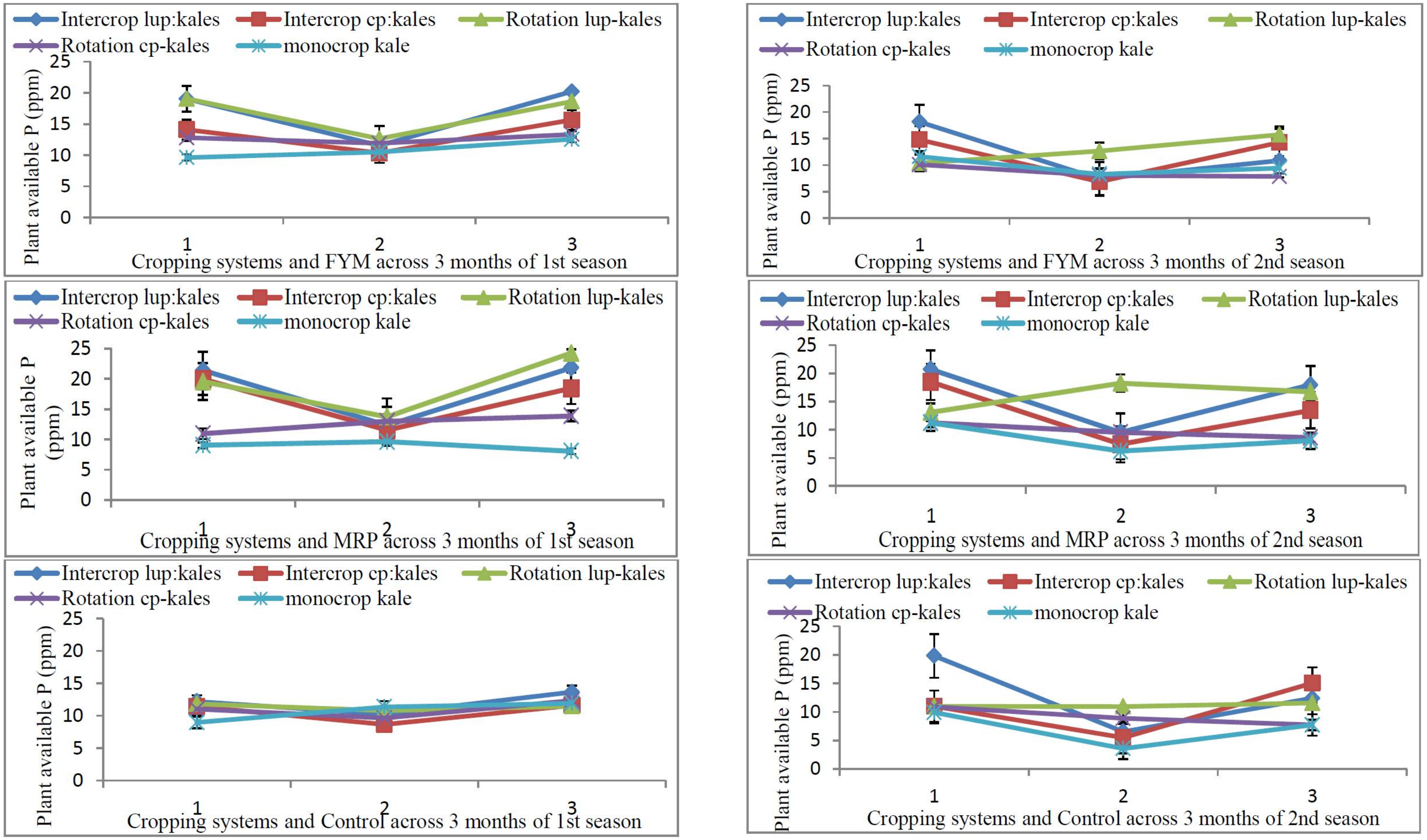

Fig. 3. Effects of legume integration and organic fertilizer application on soil available P

Key: MRP-Minjingu rock phosphate, FYM- farm yard manure CP-chickpea, LUP- lupin. Values are the mean (n = 3) ± S.E

Table 3. Effects of legume integration and organic fertilizer application on kale phosphorus concentration (PPM)

Months of kale growth	Cropping system	Crop	Long rain season 2014				Short rain season 2014			
			FYM	MRP	CNTRL	MEAN	FYM	MRP	CNTRL	MEAN
1	Intercrop	Lupin/kale	1400 ^{ab}	1700 ^{b}	1400 ^{ab}	1500^{d}	1478 ^{g}	2983 ^{i}	1476 ^{g}	1979^{f}
	Intercrop	Chickpea/kale	1000 ^{ab}	2900 ^{c}	927 ^{ab}	1609^{e}	1076 ^{d}	1776 ^{h}	1003 ^{c}	1285^{bc}
	Monocrop	Kale	587 ^{a}	1283 ^{ab}	1600 ^{b}	1156^{b}	705 ^{a}	902 ^{b}	659 ^{a}	755^{a}
	Rotation	Lupin-kale	-	-	-	-	1370 ^{f}	1444 ^{g}	1288 ^{e}	1367^{c}
	Rotation	Chickpea-kale	-	-	-	-	1407 ^{fg}	1429 ^{fg}	1259 ^{e}	1365c
2	Intercrop	Lupin/kale	3000 ^{ab}	4433 ^{abc}	4400 ^{abc}	3944^{b}	5139 j	6432 ^{l}	4871 ^{i}	5480e
	Intercrop	Chickpea/kale	3200 ^{abc}	3567 ^{abc}	2600 ^{a}	3122^{a}	3318^{c}	6432 ^{l}	2751 ^{a}	4167^{cd}
	Monocrop	Kales	5000 ^{cd}	6333 ^{d}	4733 ^{bcd}	5355^{e}	3126 ^{b}	4554 ^{h}	4547 ^{h}	4075^{c}
	Rotation	Lupin-kale	-	-	-	-	4008 ^{f}	4192 ^{g}	3279 ^{c}	3826^{b}
	Rotation	Chickpea-kale	-	-	-	-	4232 ^{g}	5360 ^{k}	3862 ^{e}	4518^{d}
3	Intercrop	Lupin/kale	3200 ^{bc}	3867 ^{d}	2300 ^{a}	3122^{b}	3373 ^{de}	4042 ^{h}	2467 ^{a}	3294^{c}
	Intercrop	Chickpea/kale	2933 ^{b}	3100 ^{bc}	2133 ^{a}	2722^{a}	3104 ^{bc}	3268 ^{def}	2319 ^{a}	2897^{ab}
	monocrop	Kale	3400 ^{bcd}	4533 ^{e}	3533 ^{cd}	3822^{f}	3570 ^{efg}	4718 ^{i}	3707 ^{fg}	3998^{g}
	Rotation	Lupin-kale	-	-	-	-	3745 ^{g}	3537 ^{defg}	2911 ^{b}	3397^{d}
		Chickpea-kale	-	-	-	-	3468 ^{def}	4510 ^{i}	2860 ^{b}	3612^{e}

Key: MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin, - rotational system where kale was not planted. Means followed by the same letters in the same month and season in a column is not significantly different at P ≤ 0.05

3.3 Correlation between Soil and Kale Nutrient Concentrations

In the first month of long rain season, the soil and kale N and P were positively correlated in the monocrop cropping systems with application of FYM (R^2 =0.59) and MRP (R^2= 0.69) for N and P respectively. Perfectly strong correlation (R^2=0.99) was obtained for P in a lupin/kale intercrop with application of MRP. In the second month, negative correlations were obtained for N in most cropping systems and organic fertilizers interactions except for kale monocrop with application of FYM (R^2= 0.59). Soil and kale P correlations were positively correlated in the lupin and chickpea/kale intercrop with application of MRP (R^2= 0.86, R^2= 0.52). During the third month, all cropping systems and organic fertilizers interactions obtained negative correlations with kale monocrop (FYM) (R^2= 0.59) P (MRP) (R^2= 0.36) and sole kale monocrop with application of MRP (R^2= 0.96) (P) obtaining positive correlations (Table 4).

In the short rain season, first month, there was perfect correlations between soil and kale N and P concentrations in all plots applied with FYM except for P correlation in lupin/kale intercrop (R^2= -0.78). Application of MRP obtained negative correlation for N in the lupin-kale intercrop. The control obtained perfect N correlations in a chickpea-kale rotation and kale monocrop (R^2= 0.99) whereas soil and kale P a perfect positive correlation was obtained in the lupin/kale intercrop (R^2= 0.99). In the second month, all plots with FYM application had positive N correlations except for kale monocrop. The MRP treated plots; positive P correlations were obtained in all plots whereas the controls obtained negative correlations. The third month obtained negative N correlations where FYM was applied except in the lupin/kale intercrop where perfect positive correlation was obtained (R^2= 0.995). Soil and kale were positively correlated with application of FYM except for the lupin-kale rotation (R^2= -0.994). Where MRP was applied, there was negative soil and kale N correlation whereas soil and kale P was positively correlated. The control plots obtained both negative and positive correlations a similar trend obtained for P (Table 5).

The positive correlations recorded in the first month with application of MRP could be attributed to improved soil quality and kale was still at the initial development stages, as the kale took up the nutrients the rock phosphate was able to supply more P to the soil. The lupin/kale intercrop with application of MRP showed strong positive correlation between soil and plant P. This could be attributed to the lupin releasing exudates which could have activated the release of the insoluble P in the soil and in the MRP making them available. White lupin plants (*Lupinus albus* L.) have a great ability of mobilizing the sparingly soluble P through changing rhizosphere processes, particularly by citrate exudation [13,41]. Perfect positive correlations between soil and plant N recorded in the FYM treated plots could be attributed to the high amounts of nitrogen supplied by the fertilizer. Application of FYM in the second month of long rains obtained a perfect positive correlation; as much as kale took up nitrogen, FYM was able to replenish it. These results were

Table 4. Effect of legume integration and organic fertilizers application on correlations between soil and kale N and P during the long rain season

Month	Cropping system	Crop	Soil and kale nutrient LRS (Long rain season)					
			FYM		MRP		CNTRL	
			N	P	N	P	N	P
1	Intercrop	Chickpea/kale	-0.19	-0.179	-0.5	0.89	-0.65	-0.98
	Intercrop	Lupine/kale	-0.56	-0.174	-0.76	0.99	-0.188	-0.79
	Monocrop	Kales	0.59	0.69	-0.79	0.37	-0.93	-0.914
			N	P	N	P	N	P
2	Intercrop	Chickpea/kale	-0.19	0.52	-0.5	0.23	-0.65	-0.43
	Intercrop	Lupine/kale	-0.56	0.86	-0.76	0.39	-0.188	-0.41
	Monocrop	Kales	0.59	-0.09	-0.79	-0.605	-0.93	-0.465
			N	P	N	P	N	P
3	Intercrop	Chickpea/kale	-0.19	-0.99	-0.5	-0.49	-0.65	0.58
	Intercrop	Lupine/kale	-0.56	-0.92	-0.76	0.912	-0.188	0.58
	Monocrop	Kales	0.59	0.36	-0.79	0.96	-0.93	-0.98

Key: FYM-Farm yard manure, MRP-Minjingu rock phosphate, CNTRL- control, P-phosphorus, N-Nitrogen

Table 5. Effect of legume integration and organic fertilizers application on correlations between soil and plant N and P short rain season

Month	Cropping system	Crop	Soil and kale nutrients SRS (Short rain season)					
			FYM		MRP		CNTRL	
			N	P	N	P	N	P
1	Intercrop	C/pea/kale	0.99	0.92	0.15	-0.23	-0.87	0.29
	Intercrop	Lupine/kale	0.97	-0.78	1	-0.84	0.55	0.99
	Rotation	C/pea-kale	0.99	0.98	0.99	0.99	0.99	-0.59
	Rotation	Lupine-kale	0.94	0.89	-0.32	0.93	0.54	0.73
	Monocrop	Kales	0.89	0.82	0.484	0.96	0.99	-0.89
			N	P	N	P	N	P
2	Intercrop	C/pea/kale	0.79	-0.99	-0.29	0.81	-0.95	-0.46
	Intercrop	Lupine/kale	0.99	-0.76	-0.83	0.99	-0.88	-0.97
	Rotation	C/pea-kale	0.22	-0.97	-0.52	0.99	-0.52	-0.10
	Rotation	Lupine-kale	0.42	-0.76	-0.10	0.82	-0.32	0.92
	Monocrop	Kales	-0.50	-0.50	-0.11	0.29	-0.29	-0.10
			N	P	N	P	N	P
3	Intercrop	C/pea/kale	-0.37	0.98	-0.64	0.63	-0.39	0.99
	Intercrop	Lupine/kale	0.99	0.99	-0.19	0.97	0.41	-0.94
	Rotation	C/pea-kale	-0.99	0.99	-0.98	0.68	-0.99	0.17
	Rotation	Lupine-kale	-0.15	-0.94	-0.94	0.94	-0.84	-0.58
	Monocrop	Kales	-0.97	0.11	-0.91	0.99	0.65	0.99

Key: FYM-Farm yard manure, MRP-Minjingu rock phosphate, CNTRL- control, P-phosphorus, N-Nitrogen, C/pea- chickpea

similar to those of the short rain season. Previous studies have shown higher soil organic matter due to addition of FYM has been proven to closely correlate with amount of N in soil [34].

The intercrop systems with application of FYM obtained negative correlations. This could be attributed the plants taking up nutrients and at this point there were two plants competing for nutrients. Most crops take up majority of the nutrients during periods of vegetative growth [36]. The controls obtained negative correlations this happened because no fertilizers was applied and as the crops were taking up the nutrient, the plant available nutrients in the soil was being depleted. In the second month, the negative correlations between soil and plant P could be attributed to the much P taken by kale as during these periods, the P concentration on the kale tissue was high. This later translated to lesser phosphorus in the soil. The weak positive relationships obtained in the intercrops (chickpea and lupin) with application of FYM and MRP could be attributed to the fact that as much as the plant took up the nutrients a significant amount was left in the soil, and this was due to application of FYM and MRP which improved the soil nutrient status. Both chickpea and lupin are known to release exudates which help to release any P in the soil and in the MRP.

The cropping systems intercrops and monocrops obtained similar positive correlations between soil and plant N and P. The legumes chickpea and white lupin could have obtained such results due to its ability to fix nitrogen which lead to an increase in plant available N, whereas the positive correlation in the monocrop could be attributed to the lack of competition for nutrient uptake. IITA [56], reported faster nutrient uptake and hence competition under intercropping systems. Higher plant available N under intercropping with lupin compared to rotation could be attributed to better nitrogen fixation that may occur under intercropping compared to when legumes are mono cropped as well as higher amount of residue available for decomposition. It has also been reported that intercropping may result in increased amount of nitrogen fixed by legumes as the companion non-fixing crop utilizes excess nitrates in the root zone which would otherwise retard N fixation if they accumulate [57].

3.4 Effects of the Legume Integration and Organic Fertilizers Application on Kale Yields

The kale yield was significantly affected by the organic fertilizers and integration of legumes. In the long rains season, first month, sole kale monocrop with application of FYM recorded highest yields, followed with the lupin/kale intercrop with application of FYM. The lowest yield was recorded kale monocrop (Cntrl). The second month recorded significantly high yields as compared to the first month. There was a notable increase in a kale monocrop (FYM); chickpea/kale intercrops (FYM). The third month there was a slight decline in kale yield. Intercropping kale with lupin with application of MRP recorded the highest yields followed by the kale monocrop with application of FYM (Fig. 4).

During the short rain season, first month, highest yields were recorded under, kale monocrop (FYM and MRP); lupin/kale intercrop (FYM, MRP and Control). The second month of sampling, highest yields were recorded in, lupin-kale rotation (FYM, MRP); chickpea/kale intercrop (MRP and FYM); kale monocrop (FYM, MRP and Control) (Fig. 4). The third month recorded a decline in yield, however higher yield was recorded lupin-kale rotation (FYM); chickpea-kale rotation (FYM) and the lowest was recorded in the chickpea and lupin/kale intercrop (Cntrl) (Fig. 4).

Higher kale yields were realized in lupin-kale rotation (MRP) followed by lupin-kale intercrop (FYM) and lowest in kale/lupin intercrop (FYM). The high kale yields in treatments involving lupin as a rotation with application of MRP is possibly due to better N fixation by lupin compared to chickpea and P availability. Lupins have been known to be the top legumes with respect to fixing N. Lupins not only have effective nitrogen symbiotic fixing bacteria, but also have symbiotic root fungi that make soil phosphate available to plants [11].

The high kale yield recorded in lupin-kale rotation; lupin/kale intercrop with application of MRP could be attributed to better lupin response to P compared to chickpea. This in turn led to better nitrogen fixation and hence higher yield of kale. A previous study conducted by Lelei and Onwonga [11] showed that under P deficiency conditions, lupin has been found to respond to P fertilizer application in grain yield.

The high kale yields observed under farm yard manure application may be as a result of its ability for improving soil properties which enhances nutrient uptake [58]. Applying organic fertilization (compost and animal manure) is widely found to have positive effects on crop yields. The findings are in line with those found by Nalatwadmath et al. [59] who reported significant grain yields when FYM and P fertilizers were used as compared to control treatments. This implies the possibility of replacing chemical fertilizers for organic fertilizers in places where organic fertilizers are plenty and of high quality. This is supported by Prasad and Sinha [60] who reported that FYM could substitute 50% NPK for wheat production.

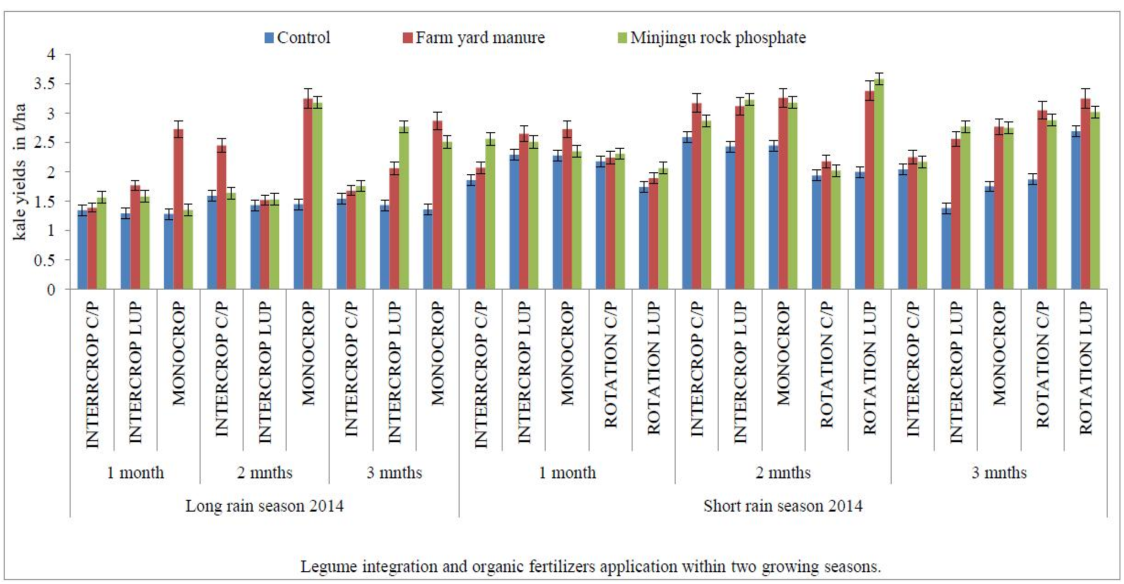

Fig. 4. Effects of legume integration and organic fertilizers application on kale yields
Key: C/P-chickpea, LUP-lupin

Similarly, increased yield due to FYM and MRP may be due to its beneficial effects both on soil and plant by making sufficient amounts of nutrients available to plant throughout the growth period resulting in better uptake, plant vigor and superior yield attributes [61].

In terms of cropping systems, there was no marked difference in kale yield between sole kale and legume-kale rotation (lupin-kale and chickpea-kale) systems across all organic fertilizers. There was however a significant difference between kale monocrop and kale/legume intercrop across all the organic fertilizers. This could be attributed to lack of competition as the crops were planted as stand alone. Similar findings were found by Von Richthofen et al. [62] who did a study on grains with legumes in rotation and found that yields increased in a rotation system. Despite the lower kale yield obtained by the legume intercrops, farmers are able to harvest more than one crop form the same piece of land. A study conducted by Kasenge et al. [63] whose study was on maize/bean intercrop reported that intercropping maize with beans was more beneficial in terms higher produce from the same piece of land as compared than mono-cropping of either crop.

The rotation systems had higher yields compared to the intercrop and sole kale monocrop systems. The main reason for the high yield in the rotation was due to the nitrogen fixed in the soil by the previous legume and was now available for kale uptake hence the high yields. This is in agreement with [39] who noted that legume rotations significantly had higher yields and can be attributed to their efficiency in P acquisition from the soils. Crop rotation has been widely recommended as an effective cultural practice for increasing soil quality and crop yields in southern Brazil. Despite the emphasis given to the matter, studies on effects of crop rotation on yield are still scarce and results achieved have been contradictory [64].

4. CONCLUSION

The current study was carried out to investigate the effect of legume integration in a kale cropping system with application of organic fertilizers in Kabete Sub County during the LRS (long rain season) and SRS (Short rain season) of 2014. From the results, it was found out that; lupin/kale + FYM had highest soil OC during the long rain season. Lupin-kale rotation + FYM recorded the highest amounts of organic carbon during the long rain season. Significantly higher amounts were recorded in the chickpea-kale + FYM. Significant high amounts of P were recorded in a lupin/kale intercrop (MRP) during both seasons. Similarly in the short rain season, lupin-kale rotation + MRP recorded high P levels. Lupin/kale (FYM) had highest soil N in both growing seasons. Lupin-kale rotation (FYM) accumulated highest soil N in the short rain season. Application of FYM in a sole kale monocrop increased the nitrogen uptake. Lupin/kale intercrop (FYM) also improved the nitrogen uptake in the kale tissues. Chickpea/kale intercrop with application of FYM improved the nitrogen concentration in the kale tissue. Phosphorus uptake in the kale tissues was improved where lupin or chickpea was intercropped with kale with MRP applied. Kale yield was improved with application of FYM in the monocrop. Although the monocrop outperformed the intercrops, there is also a benefit of harvesting more than one crop from the same piece of land. In the short rain season, lupin-kale rotation (FYM) kale yield was increased; similarly chickpea-kale rotation with application of FYM also recorded high yields. Lupin/kale intercrop (FYM) obtained a positive correlation between soil and plant N in both seasons. Lupin/kale intercrop with application of MRP obtained positive correlations between soil and plant P in both seasons. This implies that the use of the organic fertilizers (MRP and FYM) improved the soil nutrient status and therefore improving crop nutrient uptake. Integration of legumes into cropping systems and application of organic fertilizers thus improved soil nutrient status in the kale based cropping systems. Intercropping kale with chickpea or lupin proved better at enhancing soil organic carbon and N P levels compared to other cropping systems. In addition, if legumes are preferred within cropping system, then use of lupin rotation is recommended. Use of organic fertilizers increased soil nutrients with FYM being superior to MRP in both cases. To enhance fertility of soil, it is therefore recommended that kale with lupin alongside application of FYM may be adopted as a sustainable option towards enhanced soil fertility in smallholder farming systems of the Kabete sub county. Moreover, the MRP and FYM are locally available, thus making it an ideal and economical source of nutrients for smallholder farmers and they get to enjoy a diversity of crops to harvest from the same piece of land.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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