The Role of Sorghum Legume Intercroping System in Improving Soil Productivity on Small Holder Farmers in Western Kenya

Josephine Barasa[1], Julius Ochuodho[1], Syphyline Kebeney[1] Augustine Wafula Barasa[2]
[1]*University of Eldoret, School of Agriculture and Biotechnology, Department of Soil Science*
[2]*University of Eldoret, School of Agriculture and Biotechnology, Department of Agricultural Economics and Rural Development*

Abstract: **Declining crops yield in the smallholder farmers cropping systems of sub-Saharan African (SSA) present the need to develop more sustainable production systems. Depletion of essential plant nutrients from the soils have been cited as the main contributing factors due to continues cultivation of cereal crops without application of organic/ inorganic fertilizers. Field experiments to evaluate effect of phosphorus (P) fertilizers, organic and integration of legumes in sorghum cropping systems on soil, available nitrogen (N) and P, were conducted in Busia County of Kenya during the short (SRS) and long rain seasons (LRS) of 2016 and LRS of 2017 respectively. The experiments comprised either soybean, common bean groundnut or sesame grown with sorghum. The design was a split plot in a randomized complete block design. Main plots were fertilizer inputs; Mavuno, FYM or their combination. Subplots comprised of the legume intercrops mentioned above. Application of Mavuno, FYM or their combination resulted in significantly higher legume, sesame crop yields above the control in the second season. Legume crops due to their N-fixation, litter fall and mineralization made availability of P and N. possible. Application of Mavuno, FYM or their combination gave comparable results with respect to the intercrop yields. Since FYM and (Mavuno+FYM) is cheaper than Mavuno, growing either soybean, common bean groundnut or sesame intercropping system with sorghum with application of the above is recommended for improved legume grain yields and soil fertility improvement.**

Keywords: **organic/inorganic inputs, legume cropping system, biomass decomposition, grain yields**

I. INTRODUCTION

In Kenya, challenges of food security, poverty and income inequalities remain a major concern for the Government despite policies on self-sufficiency in food being emphasized (Ombaka *et al,* 2014; Lokuruka, 2020).Continuous monocropping of maize without crop diversification on small pieces of the land with little or no provision for soil fertility maintenance contribute to the rapid depletion of soil nutrients in general and nitrogen in particular (Girijesh *et al.,* 2017; Grote, · 2021).

Attaining optimum crop yields in smallholder farms of Western Kenya remains a predicament with most farmers recording low annual harvests (Mwaura, 2021). This situation further translates into food insecurity and poverty especially in a country like Kenya where majority (> 70 %)of its population depends directly or indirectly on agriculture-related farm and off-farm activities for their livelihoods (Ng'ang'a, *et al.*, 2017). A report by FAO (2018) indicated that 60 percent of the population was living below the 1 dollar-a-day poverty line. Given that agriculture is a major contributor to the country's Gross Domestic Product (GDP) and revenue, this alarming trend is worrying and calls for urgent response in terms of agricultural policies (FAO, 2018).

The causes of these low crop yields are diverse with factors such as declining soil fertility taking the lead position (Vanlauwe, *et al.,* 2008). Soil infertility in Western Kenya smallholder farms is further escalated by various factors such as lack of /or inadequate use of inorganic/organic fertilizers, among other factors (Wawire,2021).In order to address the problem of soil infertility, the Kenyan government through the National Accelerated Agricultural Inputs Access Programme (NAAIAP) introduced subsidized fertilizers (GOK, 2014). This was aimed at raising fertilizer use to optimal levels in order to increase crop productivity from increased input use thereby raising land and labour productivity and food security for small holder farmers who form majority of households in Western Kenya (Ochola, & Fengying, 2015; Birch, 2018). Despite these efforts no much crop yields have been achieved even after devoting much land to the targeted crops under the fertilizer subsidy by 15 percent (Druilhe, & Barreiro-Hurlé, 2012; Lencucha *et al.,* 2020).

Soil fertility management approaches play a leading role in ensuring sustainable crop production on low nutrient soils (Urmi, 2022) such as those in western Kenya region. Increasing human population and the associated increased demand for food production on the other hand and food quality in the world require that proposed agronomic strategies for improvement should, in general, avoid high input costs associated with crop input costs. Organic inputs such as farm yard manure (FYM) and non-acidic fertilizer inputs like Mavuno are steadily gaining increased popularity and recognition from scientists as a means to improving soil productivity (Sharma, 2022). This could be due to the fact that they pose no ecological threats, have a longer-lasting effect on the soil, and, if well managed, they can often out yield recommended doses of chemical fertilizers (Mahdi and Mustafa, 2005; Hlisnikovský, 2022).

Legumes form a major component of every farming systems in SSA, making positive contributions to improving soil fertility and food security (Amede, 2003; Yuvaraj,2020). Legumes are potential sources of plant nutrients that complement/supplement inorganic fertilizers for cereal crops because of their ability to fix biological nitrogen (N) when included to the cropping systems ( ). By fixing atmospheric N_2, legumes offer the most effective way of increasing the productivity of poor soils either in monoculture, intercropping, crop rotations, or mixed cropping systems (Befekadu *et al.*, 2018). The complimentary nature of nitrogen fixing legumes also results in higher crop yields (Fan *et al*.,2006; Karavidas,2022;) besides ensuring economic utilization of land, labour and capital (Jeyabal and Kuppuswamy, 2001; World Bank, 2020).The information regarding optimum legume crop yields and associated soil fertility benefits is invariably unavailable for various agro-ecosystems in Sub-Saharan Africa( ). The present study aims at offering an answer as to whether legume crop diversification through different legume species and other high value traditional crops such as sesame under organic and inorganic inputs can result into improved soil fertility and sustainable increased crop productivity. The information obtained from the study can be used to develop interventions that may eventually result in increasing soil fertility, improving food security and/or improved livelihood for smallholder farmers who are the major players in cultivation of these crops from their farm production. The study considered the challenges the rural people face in farming which is their primary economic activity and tries to come up with innovations of optimizing their production from their small sized pieces of land.

II. MATERIALS AND METHODS

Study areas

Table 1. Characteristics of experimental sites.

Study site	Soil Type	Altitude	Rainfall	Mean Temperature	Latitude	Longitude
Busia Agricultural Training Centre	Orthic Ferralsols	1130-1375 m.a.s.l	1270-1790	14-30^{O}C	0^0 16’45 N,	34^0 20’ 20 E
Teso South (Farmer’s Field)	Gleyic Acrisols	1100-1400 m.a.s.l	1270-1790 mm	26-33 ^{O}C	0^0 33’40 N	34^0 31’ 06 E

Source: Jaetzold, et. al,. (2011)

Experimental design

The experiment was laid out in a split plot arrangement in RCBD design in 3 replications in each site and season. The main plots comprised of the fertilizer materials i.e., Mavuno fertilizer, Manure, Mavuno fertilizer+Manure and the Control. The subplots were formed by the different intercrops

Treatment application

The treatments were applied once at the start of the first season, 2016 in Busia and Teso at their recommended rates (Table 1).The treatments were replicated three times for each site and applied in plots measuring 5x4.5 m giving plot area of 22.5m^2.In the first season (September –December 2016) the crop received the recommended fertilizer levels (band applied) as a blanket inputs under short rains as described in table 1 above. The phosphorus contribution from each input treatment was maintained at 26kg P ha^{-1}for this study, this rate being the recommended P level for most of the cereal crops within the western Kenya region for their optimum performance. The legumes and sesame intercrop were supplied with 30kg P. ha^{-1} according to.(Anochili, 1984)

Planting of field experiment

Field experiments commenced during the 2016 short rain season (SRs) (August to December 2016) and replicated during the 2017 long rains (LRs) (March to May 2017).

Seredo Sorghum variety from Kenya Seed Company was drilled at seed rate of 3 kg ha^{-1}also at the pacing of 0.75 x 0.2 m. The intercrops i.e. common bean and soybean seeds were sourced from KALRO Kakamega and sesame and ground nut seeds were bought from the local markets in western Kenya. These were planted in between the sorghum rows at the recommended spacing of 0.33 from sorghum row x 0.15m within the row. The crop management practices i.e. gapping, weed control and top dressing with nitrogenous fertilizer, were done accordingly.

2.1. Soil Sampling and preparation

Initial composite soil samples were collected from a depth of 0–20 cm before planting the Test legume crops in 2016 short rains. Soil samples were also taken from each plot at planting and after each crop was harvested to assess the changes in soil fertility status due to the effect of legume precursor crop and integrated application of organic and inorganic fertilizers.

Soil pH was measured using Glass electrode method (H_2O) meter. The Walkley–Black method was followed for the determination of soil organic carbon (%OC), whereas the cation exchange capacity (CEC), in centimol (cmol)/100 g soil) was analyzed using ammonium acetate. Total nitrogen (%N) and available phosphorus (mg kg^{-1} soil) were analyzed by the Kjeldahl and the Olsen methods, respectively. The procedures for the methods used are outlined in Okalebo *et al.*, 2002. The result of initial soil analysis showed that the pH was in the strongly acidic range as per the standard classification procedure by Motsara and Roy (2008). Total nitrogen of the sites was highly variable and found in the low to moderate range. The available phosphorus content of the soil was categorized under very low range for both sites. Soil nitrogen and the organic carbon content varied in each site, though it was in the medium range for both sites

Table 2:Physico chemical properties of soil at 0-20 cm depth.

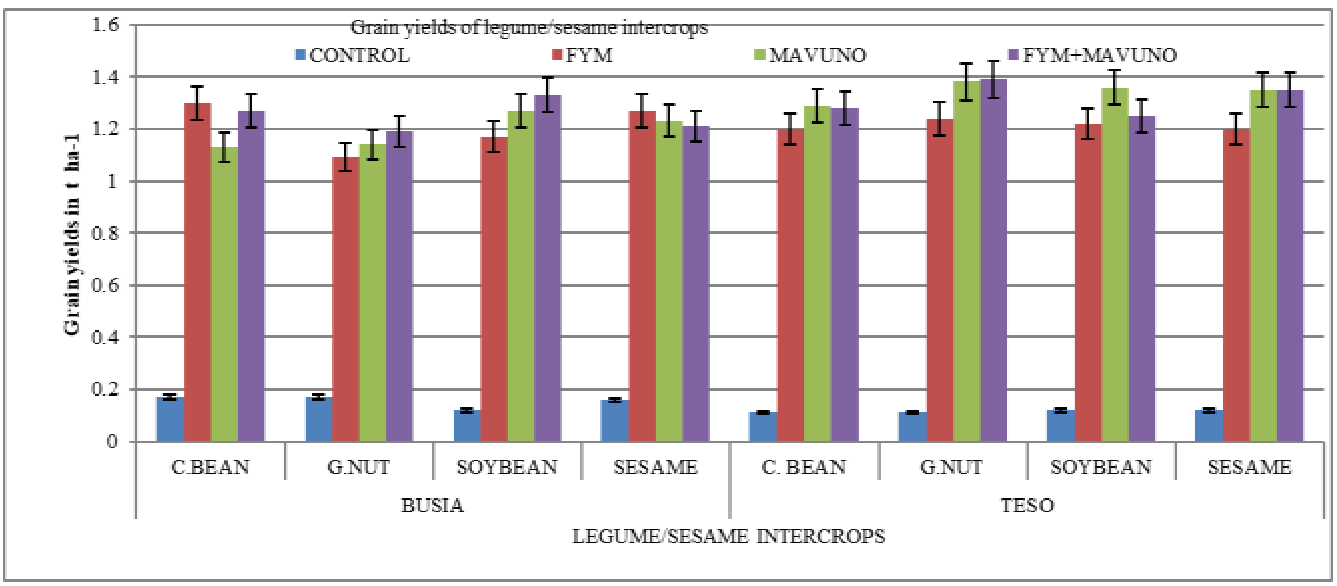
		(mg kg$^{-1)}$	(%)			(cmolkg^{-1}					(%)				
SITE	pH	P.	N	OC	C:N	Ca	Mg	K	Na	Al^{3+}+H^{+}	Sand	Silt	Clay	Text class	Order
Busia	4.85	1.82	0.21	1.50	7:01	0.90	0.35	0.37	0.96	1.95	55	24	21	Loam	Orthic Ferralso ls
Teso	5.13	1.85	0.17	1.54	9:01	0.97	0.46	1.02	0.97	1.86	78	10	12	Sandy Loam	Gleyic Acrisols

III. RESULTS

1.Residual effects of treatment on legume and sesame grain yields

The data on legume intercrop and sesame grain yields are presented in Figure 1.

Figure 1: Effect of treatments on legume intercrop and sesame grain yields (t ha^{-1}) at Busia and Teso during the 2017 LR cropping season.



Of importance to note here is that none of the legume and sesame intercrops planted during the 2016 SR season reached harvesting stage due to intense moisture deficit experienced during this period. However, data for yields obtained from the test intercrops (common beans, groundnut, soybean and sesame) in 2017 LR due to the application of the soil fertility improvement materials during the 2016 SR are illustrated in Figure 1 for Busia and Teso sites. As observed, all the soil inputs gave significantly *($p<0.05$)* higher crop yields above the control.

Fertilizer material application significantly ($p<0.05$) contributed to increased legume and sesame grains above the control at both sites Busia and Teso. In general crop yields were improved when the different nutrient materials were applied irrespective of the nutrient sources. For each of the materials applied, the results could be explained according to the findings of Cooke (1967) and Cui, 2021) who observed that the residual fertilizers left in the soil often raise crop yields that are hard to imitate with fresh fertilizer applications. Soil pH is especially important in maintaining fertilizer nutrient in the available forms. Hence the availability of Ca, phosphorus from *Mavuno* (Table 1) fertilizer applied, moisture supply from the rains during growth period and the possible release of other nutrients from organic matter mineralization with improved uptake that could have contributed to higher yields in the residual experiment. According to (Zerihun, *et al.*, 2013, Ghosh,2022), organic manure alone or in combination with inorganic manure supplies nutrients throughout the season for the growth and development of the crop, in addition to improving soil moisture holding capacity and, thus, leading to increased productivity of the test crops. According to (Barber *et al.*,2014; Mahmud,2022), one of the benefits of applying soil amendments in the soil is to increase available molybdenum which is the main factor that enhances growth of legume crops on acid soils such as those in Busia and Teso study sites. This could partly explain the high yields obtained from the material amended plots in this study. Low soil nitrogen and phosphorus on the other hand are among the major factors limiting production and productivity of legume crops (Salama, 2021). Legume plants that depend on biological N_2 fixation for their N supply like soybean and others in this study require more P than plants receiving fertilizer N since the reduction of atmospheric N by the nitrogenous system is a very energy-consuming process (Stagnari, 2017). Hence, the plants require more P and other nutrients for symbiotic N fixation than for general plant metabolism (Kamara, Kwari, Ekeleme, Omoigui, & Abaidoo, 2008; Schelze, Temple, Beschow, & Vance, 2006; Míguez-Montero, 2020). Nitrogen is the most important nutrient for crop production, and its deficiency occurs in most countries of the world, Kenya included (Schelze, *et al.*, 2006, Kihara,2020). Evidence in the present study reveals the superiority of organic fertilizers in combination with inorganic sources and integration of legume crops in enhancing nutrient availability, optimizing soil environment that contribute to improved crop productivity.

2. Effect of cropping systems on % Soil Nitrogen at Busia and Teso

The results on the effect of intercropping system on % soil nitrogen content are presented in Table 3.

TABLE 3: Effect of Cropping Systems on % soil Nitrogen At Busia and Teso Over the study Period.

	........................DAYS FROM 1ST PLANTING..................							
	BUSIA				**TESO**			
CROPPING SYSTEM	**60**	**120**	**180**	**240**	**60**	**120**	**180**	**240**
S- MONOCROP	0.22a	0.29ab	0.22a	0.27a	0.21ab	0.22 a	0.21ab	0.18a
S+GROUND NUT	0.24ab	0.32b	0.25ab	0.28a	0.21ab	0.22a	0.19a	0.16a
S+SESAM	0.24ab	0.29ab	0.21a	0.29a	0.19 a	0.25 a	0.24 b	0.18a
S+SOYBEAN	0.34b	0.28ab	0.26 b	0.29a	0.24 b	0.23 a	0.24b	0.19a
S+COMMON BEAN	0.26ab	0.27 a	0.24ab	0.27a	0.21a	0.25a	0.22ab	0.18a
MEANS	0.26	0.29	0.23	0.28	0.21	0.23	0.22	0.18
$LSD_{(0.05)}$	0.11	0.05	0.04	ns	0.11	0.05	0.04	ns
CV	25.3	19.5	14.2	8.8	15.8	21.1	26.5	19.5

Means with the same alphabetical letter within a column are not significantly different at 5% probability using Fishers unprotected LSD value.

Ns- Treatment effects not significant according to Fisher's protected LSD

All the legume intercrops planted (common beans, sesame, soybean and common bean) with sorghum significantly ($p < 0.05$) contributed to the total soil nitrogen content for the Busia site in comparison with sorghum mono-crop plots. Sorghum-soybean intercropped plots recorded the highest N. levels of 0.34% N of soils sampled at 60 days from the planting of the first crop. Next was sorghum-common bean intercrop with 0.26%N, then 0.24 % N from the sorghum-common bean and sorghum sesame intercrops respectively. Finally, was control that recorded 0.22%N. General N% increases were observed across all treatments including the sorghum monocrop from soils sampled at 120 days (Table 3). The highest N values were observed with the sorghum-common bean intercrop when compared with the other sorghum intercrop systems. General declines in N% were observed at 180 days across all the intercrops. The highest N% contents were however realized at 240 days. The mean total soil N fluctuated for all treatments across the two cropping seasons. Teso site however recorded lower total N values for all the intercrops as compared to Busia site (Table 3).At (120 days from planting of the first crop) sorghum-soybean intercrop recorded the highest soil total nitrogen content. General N% reductions were observed at 180 and 240 days at Teso site. The fluctuation in soil N content in two sites could be explained in terms of crop nutrient uptake, immobilization by the soil microbes, leaching and volatilization due erratic weather conditions of high rainfall and temperature levels within western Kenya region. The low and declining N levels in Teso as compared to Busia site could be due to their difference in soil texture where soils in Teso had higher sand contents observed (Table 2) which could have encouraged more N leaching as opposed to the soils in Busia site leading to low soil nitrogen levels observed.

The increase in N availability in intercrops hosting legumes occurs because the competition for soil N from legumes is weaker than from other plants. Moreover, non-legumes obtain additional N from that released by legumes into the soil (Pappa *et al.*, 2012, White *et al.*, 2013) or via mycorrhizal fungi (Chen, 2022). Legumes can contribute up to 15% of the N in an intercropped cereal (LI *et al.*, 2009), thus increasing biomass production and carry-over effects (Pappa *et al.*, 2012), reducing synthetic mineral N-fertilizer use and mitigating N_2O fluxes (Beaudette, 2016).

3. Effect of cropping systems on Soil available P. at Busia and Teso

Table 4: effect of cropping systems on soil available phosphorus at Busia and Teso over the study period

	........................DAYS FROM 1ST PLANTING..................							
	BUSIA				**TESO**			
CROPPING SYSTEM	**60**	**120**	**180**	**240**	**60**	**120**	**180**	**240**
S- MONOCROP	5.94a	6.58a	35.04a	40.08a	7.361a	2.05a	41.24ab	49.88a
S+GROUND NUT	6.34ab	6.71a	36.8a	42.36a	9.26a	1.84a	37.68ab	51.18a
S+SESAM	6.71ab	8.28a	31.3a	39.72a	9.13a	1.72a	35.8a	58.7a
S+SOYBEAN	7.59bc	7.19a	39.06a	45.57a	7.31a	1.96a	36.32b	54.43a
S+COMMON BEAN	8.72c	7.84a	29.76a	39.27a	7.68a	2.03a	49.22b	60.32a
MEANS	7.06	7.34	34.4	41.4	8.15	1.92	40.0	54.9
$LSD_{(0.05)}$	1.31	ns	ns	ns	ns	ns	11.7	16.47
CV	22.6	34.9	11.3	14.4	38.6	7.5	22.9	34.7

Means with the same alphabetical letter within a column are not significantly different at 5% probability using Fishers unprotected LSD value.

Ns- Treatment effects not significant according to Fisher's protected LSD.

Legumes intercropped with cereals can provide not only nitrogen, but also other minerals, soil cover, as they also smother weeds, provide habitat for pest predators, and increase microbial diversity, such as vesicular arbuscular mycorrhizae (VAM). VAM, a fungus, plays an interesting role in that it is thought to facilitate nutrient transfer e.g., phosphorus to the other crop. The association with VAM becomes very significant where one crop has the ability to mine different sources of nutrients than the other. Some evidence shows more P, K, Ca, and Mg availability in intercrops than in monocultures (Vandermeer 1992; Li *et al.* 2007; Begum, 2019).

As observed in Table 4 all the intercrops (common beans, sesame, soybean and groundnut) planted with sorghum significantly ($p< 0.05$) contributed to the total soil available P content for the Busia site when compared to the sorghum mono-crop plots. The highest P Contents were observed in the sorghum-common bean intercropped plots which recorded 8.72 ($mgkg^{-1}$) from the soils sampled at 60 days from the planting of the first crop. This was followed by the sorghum-soybean intercrop with 7.59$mgkg^{-1}$P.Next was 6.71 $mgkg^{-1}$**P** which was observed from the sorghum- sesame intercrops. The least P contents were recorded in sorghum-common bean and control plots with the P mean values of 6.34 and 5.94 $mgkg^{-1}$ P respectively. General increases in P values were observed across all intercrops including the sorghum mono-crop except in the sorghum- soy bean intercrop which recorded a decrease in the soil available P content when the soils were sampled at 120 days (Table 4) at Busia site. At 180 days all the intercrop treatments showed an upward trend in available soil P contents. These improvements in available P contents were realized at 240 days from the start of the study period. The mean total soil P followed the same increasing trend for all treatments across the two cropping seasons.

On the contrary, Teso site generally recorded higher available soil P values for all the intercrops as compared to Busia site except for the sorghum-soybean and sorghum-common bean intercrops (Table 4).Similar to Busia site, general reductions in P values were observed at 120 days across all the intercrops, including the sorghum mono-crop. Highest values were still realized at180 and 240 days from the start of the study period which showed an increase in soil available P. Plant nutrients availability may be influenced by some plant growth regulators through synthesizing plant hormones or facilitating the uptake of nutrients from the soil by different direct mechanisms, e.g., atmospheric nitrogen (N) fixation, solubilization of phosphorus (P),and synthesis of siderophores for iron sequestration, making nutrients available to plants,(Glick, *et al.*, 2007;Jaiswal, 2021;). According to (Askegaard & Eriksen, 2008 and Giordano,2021), legumes as a catch crop is able to reduce nitrate and K leaching and act not only as a N_2 fixing crop but also as a catch crop by taking up additional soil minerals N,P, and K . (Flores-Sanchez *et al*., 2013). These nutrients can easily be released in the soil upon litter fall and decomposition which can readily be taken by the crop from the soil solution by the subsequent crop (Giweta, 2020) These findings make legumes an important tool in the cropping systems where N, P and K are the major yield limiting factors such as those found in western Kenya region. The higher P levels observed in the sorghum mono and intercropped plots especially at the later stages of sampling in this study could be due to organic acid mineralization of the soil nutrients from the crops litter fall and decomposition and their easy dissolution in soil solution to release the contained nutrients including the P observed in this study. When plants are subjected to low P soil conditions such as those in Busia and Teso (Table 2), according to (Gilbert *et al.,* 1999; Richardson *et al.*, 2001 and Dixon, 2020), secretion of acid phosphatase from roots is a common response. For example, under such low P soil conditions, white lupin secretes an acid phosphatase capable of phytate degradation into the rhizosphere (Gilbert *et al.,* 1999; Dixon, 2020). P acquisition has also been improved through approaches aimed at increasing citrate synthesis in and/or exudation from plant cells. This approach is based upon the enormous evidence showing that exudation of citrate and malate from roots effectively solubilizes unavailable P sources (Marschner *et al*., 1995; Elhaissoufi, 2021).

In intercropping cowpea–maize, Latati *et al*., (2016) and Tang, 2021, found an increase in P availability at rhizosphere level associated with significant acidification than in sole cropping. Wang *et al.* (2012 and Hallama,2019), in their work related to N and P cycling in the rhizosphere of wheat and grain legumes (faba bean and white lupin) grown in monoculture or in wheat/legume mixtures, found that the less-labile organic P pools (i.e. NaOH-extractable P pools and acid-extractable P pools) significantly accumulated in the rhizosphere of legumes. However, the P uptake and the changes in rhizosphere soil P pools seem to depend also on legume species. Compared with the unplanted soil, the depletion of labile P pools (resin P and $NaHCO_3$-P inorganic) was the greatest in the rhizosphere of faba bean (54 and 39%) with respect to chickpea, white lupin, yellow lupin and narrow-leafed lupin (Hassan *et al.,* 2012). Of the less-labile P pools, NaOH-P inorganic was depleted in the rhizosphere of faba bean, while NaOH-P organic and residual P were most strongly depleted in the rhizosphere of white lupin (Hassan *et al*.,2012).

Some grain legumes, including chickpea, pigeon pea and white lupin can mobilize fixed forms of soil P through the secretion of organic acids such as citrate and malate and other P mobilizing compounds from their roots (Hocking, 2001;Homulle, 2021). Among grain legumes, white lupin most strongly solubilize P, a function that can be facilitated by its proteoid roots that may englobe small portions of soil (Angus, 2015; Pueyo, 2021). Glasshouse experiments using a highly P-fixing soil showed better wheat growth following white lupin than soybean (Hocking and Rindall, 2001), suggesting that the cereal was able to access P made available by the previous white lupin break crop.

Rhizosphere acidification by exudates leads to desorption of PO_4 from the soil matrix with a concomitant increase in P availability. Degraded and infertile soils such as those in western Kenya are realized as a result of continuous monocropping and insufficient organic matter reprocessing coupled with occurrence of rainfall variability marked by common dry spells account for low crop yield (Amos *et al*., 2012; Amwata, 2020). It was further noted that the understanding of the fact that maintenance and improvement of soil fertility cannot be exclusively through the use of predictable fertilizers (Amos *et al.,* 2012; Mucheru-Muna, 2021). As a trait in legumes as cover crops, conservation involves minimum soil disturbance, permanent soil cover with living or dead plant resources, and diversified `cereal cropping system associated by legumes crops (Amos *et al*.,2012; Kocira *et al*.,2020). The difference in soil P content in two sites could be explained in terms of crop nutrient uptake, immobilization by the soil microbes, leaching and P-sorption. The higher P levels in Teso as compared to Busia site could be due to their difference in soil texture and cropping duration. Soils in Teso besides being high in sand contents (Table 2) they were also under some period of fallowing implying higher initial inherent nutrient contents which could have contributed to more P as opposed to the soils in Busia site which are under constant cropping, being a farmers training centre. The situation which leads to soil nutrient depletion due to crop uptake (Swoboda, 2022).

IV. CONCLUSION

Major advantages of legumes include the amount of nitrogen fixed into the soil and the high quality of the organic matter released to the soil in term of C/N ratio. Some legume species have also deep root systems, which facilitate nutrients solubilization by root exudates and their uptake/recycling as well as water infiltration in deeper soil layers.

Legumes that can recover unavailable forms of soil phosphorus could be major assets in future cropping systems. Consequently, those legumes which are able to accumulate phosphorus from forms normally unavailable need to be further studied, since phosphorus represents an expensive and limiting resource in several cropping systems.

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