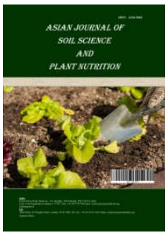

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Response of Soil Chemical Properties to *Rhizobium* and Rock Phosphate Fertilizer Application under Green - Grams in Tharaka Nithi County, Kenya

F. K. Mbaka[1*], H. O. Ndukhu[1] and G. O. Oloo-Abucheli[1]

[1]*Department of Plant Sciences, Chuka University, P.O. Box 109-60400, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. Author FKM come up with the research gap, designed the study and wrote the first draft of the manuscript. Author HON performed the statistical analysis, managed the analyses of the study and author GOOA managed the literature searches and editing of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Soil fertility decline is one of the major constraints in agricultural productivity. Biological nitrogen fixation (BNF) in legumes can offer a cost-effective and sustainable means towards soil fertility management. There is limited information on green-gram BNF enhancement through *Rhizobium* inoculation with rock phosphate fertilizer. The objective of this study was to determine the effects of *Rhizobium* and rock phosphate fertilizer application on soil chemical properties under green-gram varieties. The study was carried out at Chuka university horticultural research farm in two seasons (November 2019 - January 2020 and February - April 2020). A factorial experiment of 2 x 2 x 2 was laid out in a randomized complete block design (RCBD). There were three factors; varieties (N26 and KS20), rock phosphate (0 and 30 kg P ha^{-1}) and *Rhizobium* inoculation (0 and 100 g ha^{-1}) making a total of eight treatments which were replicated three times. Soil sampling and analyses were done for soil pH, fixed-N, total nitrogen (TN), exchangeable cations (EC), available Phosphorous (P), total organic carbon (TOC), and exchangeable potassium (K) before planting and after harvesting of green-grams for the two seasons. Data was analysed using GENSTAT 15th edition (P≤0.05). Results from both seasons indicated that combined application of rock phosphate at 30 kg P ha^{-1} and *Rhizobium* inoculation at 100 kg ha^{-1} showed significant (P≤0.05) higher

**Corresponding author: Email: mbakafelister3@gmail.com;*

increase in soil chemical properties over other treatments. However, treatment R1P1KS20 recorded significantly higher results in soil pH (7.54), TN (0.58%), TOC (3.45%), P (68.20 ppm) and EC (0.95 $CmolKg^{-1}$), fixed-N (0.50%) and K (1.75 $CmolKg^{-1}$). On the other hand treatment R0P0N26 recorded significant (P≤0.05) lower results in soil pH (5.23), TN (0.04%), TOC (1.86%), P (8.76 ppm), EC (0.21 $CmolKg^{-1}$) and K (0.58 $CmolKg^{-1}$). Therefore, *Rhizobium* inoculation in green-grams in combination with rock phosphate is an important legume nitrogen fixation enhancement method. This method is cost effective for farmers in sustainably supplementing nitrogen and phosphorous in their farms for improved soil fertility management. Based on the findings, combining *Rhizobium* 100g ha^{-1} and rock phosphate 30 kg P ha^{-1} with variety KS20 were recommended for a sustainable soil fertility management in Tharaka Nithi County.

Keywords: Agricultural productivity; nitrogen fixation; RCBD; Rhizobium inoculation; green-gram varieties, soil fertility.

1. INTRODUCTION

Low soil fertility is a major limitation to agricultural production in Africa [1]. Soil nutrient deficiency has been a major constraint to efforts by both government and non-governmental organizations to improve food security and curb hunger in Africa [2]. Nitrogen (N) and phosphorous (P) are the most common deficient nutrients in soils [3]. Agricultural development is vital to Africa's economic growth, food security, and poverty alleviation. The problem of low crop yields as a result of low soil fertility can be partly corrected with the application of phosphatic and nitrogenous fertilizers [4]. The increasing cost of fertilizers and their impact on the environment have necessitated the search for alternative sources of soil fertility management, hence increasing attention towards biological nitrogen fixation interventions [5]. Biological nitrogen fixation (BNF) in legumes can reduce or eliminate farmers' needs for inorganic fertilizers [6]. Green-gram legume can approximately fix 30-251 kg N /ha/year [7,8]. The rate of N-fixation varies considerably with type of legume cultivar, presence of appropriate *Rhizobia* and other soil variables [9]. Furthermore, symbiotic N-fixation has high Phosphorous demands because the process consumes large amounts of energy [10] and energy generating metabolism strongly depends upon availability of P [11].

Legume cultivation in the tropics and sub-tropics mostly occurs on soils with low P content and this is mainly due to processes such as weathering, erosion and P fixation [12]. In Most soils in arid and semi-arid lands (ASALs) including, parts of Tharaka Nithi County have a low extractable P [13]. This is because this region is dominated by nitisols which have phosphorous sorption [14]. This therefore makes low P availability one of the major limiting factors for legume production in these areas. However, variability in response to *Rhizobium* inoculation, among different legume varieties hinders the nitrogen-fixation efficiency. Green-gram is a drought tolerant legume and well adapted to ASALs and provides an affordable source of protein for the low-income consumers especially in the ASALs. Green-grams also play a key role in health management [15].

Biological nitrogen fixation of green-grams has been reported to potentially increase wheat growth, development and yield when followed after green-grams as compared to fallow [16]. Cereals grown following green-gram take up the surplus N and P in soil for their growth and development [17]. Thus, incorporation of green-grams can reduce or eliminate farmers' needs for inorganic N [5]. *Rhizobium* inoculation and phosphate rock fertilizer application enhances uptake of P, K, Ca, Zn, and Mo [18]. Green-gram varieties that respond positively to *Rhizobium* inoculation and make use of applied P in fixing nitrogen could contribute a key step in improving the productivity of green-grams and sustainable soil fertility management. However, there is limited information on the BNF efficiency through *Rhizobium* inoculation and rock phosphate among farmers' preferred green-gram varieties (N26-nylon and KS20-uncle) in Tharaka Nithi County. Therefore, the objective of this research study was to determine the interactive effect of *Rhizobium* inoculation, rock phosphate fertilizer application and KS20 and N26) green – grams varieties on soil chemical properties.

2. MATERIALS AND METHODS

2.1 Site Description

The study was carried out at Chuka University horticultural research and demonstration field, Meru South Sub-County in Tharaka-Nithi County for two seasons (November 2019 - January 2020 and February - April 2020). The site is situated at latitude 0.3195°S, longitude 37.6575°E with an altitude of 1401 m above local sea level and in midland agro- ecological zone [19]. The average annual temperature is 20.8°C whereby, lowest average temperatures in the year occur in July, when it is around 17.9°C. Annual rainfall is 1599 mm distributed bi-modally with the months of March to May being long rains season and October to December short rains season [17]. The Soils are classified as nitisols of volcano origin with basic and ultra-basic igneous rocks which are highly leached [20]. Yield potential is high especially during the long rains season. The climate is favourable for cultivation of tea, coffee, maize, green-grams, cowpeas, pigeon peas and variety of other food crops and livestock keeping [18].

2.2 Experimental Design

A factorial experiment of 2 x 2 x 2 was laid out in a randomized complete block design (RCBD). There were three factors; varieties (N26-nylon and KS20-uncle), rock phosphate (MRP) at two levels 0 and 30 kg P ha^{-1} and *Rhizobium* inoculation at two levels: 0 and 100 g ha^{-1} making a total of eight treatments. The treatments were replicated three times making 24 experimental plots. Each plot measured 1.5 x 1.8 m with spacing of 45 cm between rows and 15 cm between plants, making a population of 148,149 plants per hectare. There were four rows each with 10 plants. The distance between guard rows and blocks measured 0.5 m.

2.3 Inoculation Process and Planting of Green-Grams

The two green-grams varities (KS20 and N26) were purchased from Simlaw seeds company-Nairobi. The biofix commercial inoculum for green-gram MEA 716 was procured from MEA Company limited (Nairobi) and administered as per manufacturer's instructions (5 g of inoculant per 15 kg of seeds). Seeds requiring *Rhizobium* inoculant were prepared by first wetting the seeds with warm water then coating them with a filter mud containing inoculum using gum Arabica (supplied with the inoculum). The inoculated seeds were planted first in order to avoid cross contamination. Rock phosphate fertilizer was applied at the rate of 63 g P per plot as per the treatment arrangement. Two seeds per hill were planted at a spacing of 45 cm between rows and 15 cm between plants at depth of 3 cm and followed by light compaction to enhance seed-soil contact.

2.4 Data Collection

Data collection was done on soil chemical properties before planting and after harvesting of green-gram on; soil pH, total organic carbon, total nitrogen, available phosphorous, fixed nitrogen, exchangeable cations, and potassium. Soil pH was determined using a glass electrode pH meter in a 1:2.5 suspension of soil in water, and in 0.01 M $CaCl_2$ solution, in all cases after shaking for 30 minutes [21]. Total nitrogen was determined using the semi-macro Kjeldahl method [22]. Total organic carbon was determined using the modified walkley and black procedure by Nelson and sommers [23]. The available phosphorous was estimated by shaking the soil solution for 30 minutes at 1:10 ratio with double acid (Conc. HCl and H_2SO_4) extraction method [24]. The exchangeable cations were determined by 1M ammonium acetate method at pH 7 [25]. The amount of fixed nitrogen in the soil was calculated by subtracting N content in treated plots from that of control plots.

2.4.1 Statistical analysis

Data was analysed using GENSTAT ($P \leq 0.05$) 15th edition. Data collected was subjected to analysis of variance (ANOVA) as implemented in GENSTAT. Significant means were separated using Least Significant Difference (LSD) at probability level of 5%.

3. RESULTS AND DISCUSSION

3.1 Interactive Effects of *Rhizobium,* Rock Phosphate and Green-Gram Varieties (KS20 and N26) on Soil pH, Total Nitrogen (TN), Available Phosphorous (P) and Fixed – N

At the end of the experiment in both Seasons there were significant ($P \leq 0.05$) changes in the tested soil chemical properties. Combined application of *Rhizobium* and rock phosphate recorded significantly higher soil chemical properties compared to sole application of the treatments. However, variety KS20 recorded significantly ($P \leq 0.05$) higher soil pH, TN, P, K, TOC, EC, and fixed-N over variety N26. Plots with sole application of rock phosphate and

Rhizobium resulted to significant (P≤0.05) slight increase in soil chemical properties under KS20 variety over N26.

3.1.1 Soil pH

Treatment R1P1KS20 recorded significantly (P≤0.05) higher soil pH values of 6.95 and 7.54 compared to R1P1N26 in the first and second seasons, respectively as shown in (Table 1) below. The increase in soil pH due to combined application of *Rhizobium* and rock phosphate could be attributed to the effectiveness of *Rhizobial*-phosphorous on soil pH which might have increased microbial activities resulting in high water, soil pH and nutrient availability [26]. These differences in soil pH could be attributed to the varietal differences in response to treatments application. Treatments with sole application of rock phosphate resulted to slightly higher soil pH values over *Rhizobium* alone, with R0P1KS20 recording higher soil pH values of (6.45 and 6.60) than R0P1N26 with 6.20 and 6.34 (Table 1). This reconciles with the results of Yakubu et al. [27], who reported that rock phosphate fertilizers have got substantial amount of calcium ranging from 24-33% and this provides a liming effect which increases the soil pH over inoculation alone. *Rhizobium* inoculation alone had no significant (P≤0.05) differences in soil pH between R1P0KS20 and R1P0N26 as shown in (Table 1). The low pH values in *Rhizobium* inoculation alone could be due to the acidic exudates released by green-gram roots leading to decline in soil pH [28]. Furthermore, treatments with no rock phosphate or *Rhizobium* lower soil pH values with R0P0N26 recording lowest pH values of (5.20 and 5.23) for both seasons, respectively (Table 1). The results demonstrated that combined application of rock phosphate and *Rhizobium* lead to an increase in soil pH that is favourable for green-gram growth and *Rhizobium* survival in soils [29].

Table 1. Effects of *Rhizobium,* rock phosphate and green-gram varieties on soil pH, Total nitrogen (TN), Available phosphorus and fixed nitrogen

Seasons	Treatments	pH	TN (%)	ppm P	Fixed-N (%)
	R0P0KS20	5.44^{*c}	0.0833^{ab}	9.78^{ab}	0.083^{a}
I	R0P1KS20	6.45^{ef}	0.2033^{cd}	19.59^{de}	0.1867^{c}
	R1P0KS20	5.80^{d}	0.2867^{ef}	17.78^{cd}	0.2767^{d}
	R1P1KS20	6.95^{g}	0.5633^{h}	25.81^{f}	0.4867^{fg}
	R0P0N26	5.23^{ab}	0.0400^{a}	8.76^{a}	0.04^{a}
	R0P1N26	6.20^{e}	0.1500^{bc}	17.71^{cd}	0.1200^{b}
	R1P0N26	5.59^{d}	0.2367^{de}	16.39^{c}	0.223^{d}
	R1P1N26	6.43^{f}	0.430^{g}	20.96^{e}	0.3567^{e}
II	R0P0KS20	5.41^{bc}	0.080^{ab}	16.17^{c}	0.08^{a}
	R0P1KS20	6.60^{f}	0.2161^{cde}	31.50^{h}	0.210^{c}
	R1P0KS20	5.77^{d}	0.330^{f}	29.13^{g}	0.2833^{d}
	R1P1KS20	7.54^{i}	0.580^{h}	68.20^{j}	0.500^{g}
	R0P0N26	5.203^{a}	0.0567^{a}	11.71^{b}	0.05^{a}
	R0P1N26	6.34^{ef}	0.1833^{ab}	27.06^{fg}	0.190^{c}
	R1P0N26	5.89^{d}	0.250^{e}	27.37^{fg}	0.243^{cd}
	R1P1N26	7.16^{h}	0.4467^{g}	45.80^{i}	0.4267^{f}
	C.V (%)	1.0	8.6	2.7	9.1
	Mean	6.1381	0.2604	24.607	0.2177
	$LSD_{0.05}$	0.1010	0.03751	1.0958	0.01146

*Legend: *Means followed by the same letter in the same column are not significantly different from each other at (P≤0.05) level of significant. R0P0KS20- Rhizobium 0 g/ha X phosphate rock 0 kg/ha X KS20, R0P1KS20- Rhizobium 0 g/ha X phosphate rock 30 kg/ha X KS20, R1P0KS20 - Rhizobium 100 g/ha X phosphate rock 0 kg/ha X KS20, R1P1KS20 - Rhizobium 100 g/ha X phosphate rock 30 kg/ha X KS20, R0P0N26- Rhizobium 0 g/ha X phosphate rock 0kg/ha X N26, R0P1N26 - Rhizobium 0 g/ha X phosphate rock 30 kg/ha X N26, R1P0N26-Rhizobium 100 g/ha X phosphate rock 0kg/ha X N26, P1P1N26 - Rhizobium100 g/ha X Phosphate rock 30 kg/ha X N26, C.V- Coefficient of Variations, LSD- Least Significant Difference*

3.1.2 Total Nitrogen (TN)

Combined application of *Rhizobium* and rock phosphate significantly (P≤0.05) had greater influence on TN over other treatments for the two seasons. Whereby, treatment R1P1KS20 recorded relatively higher TN of 0.56 and 0.58% than R1P1N26 which registered TN of 0.43 and 0.44% in the first and second season, respectively (Table 1). The increase in total nitrogen levels were consistent with the findings of Ndakidemi [30], who reported increments in soil nitrogen after inoculation and P fertilization in soybeans after two consecutive seasons. Also different studies have shown that decaying microorganisms such as *Rhizobium* cells release nutrients especially nitrogen into the rhizosphere [2] and this explains increases in total nitrogen. Also sole application of *Rhizobium* resulted in significantly (P≤0.05) increase in TN compared to rock phosphate alone. However, R1P0KS20 recorded slightly higher TN of (0.28 and 0.033%) than R1P0N26 with 0.23 and 0.25% (Table 1). This increase of TN in *Rhizobium* could be due to the increased number of effective *Rhizobia* strains in the soils and biomass resulting from inoculated *Rhizobia* contributing to larger nutrient deposition such as soil N. These results were in agreement with those of Okalebo et al. [31], who confirmed bioavailability of nutrient especially N due to *Rhizobium* inoculation.

On the other hand, rock phosphate alone recorded significant (P≤0.05) slightly higher TN in R0P1KS20 of (0.20 and 0.21%) compared to R0P1N26 with 0.15 and 0.18% (Table 1). This could be attributed to the role P plays during nitrogen fixing. Phosphorous is an essential ingredient for *Rhizobium* bacteria to convert atmospheric N_2 into an NH_4^+ form usable by plants. R0P0N26 and R0P0KS20 had statistically (P≤0.05) similar lower TN with variety N26 recording slightly lower TN (0.040 and 0.056%) for both seasons (Table 1). The differences in inoculation response of this study could be as a result of differences in green - gram variety as they response to *Rhizobia* inoculation is highly unpredictable [32]. Contrary, studies by Chapman [4] confirmed that *Rhizobia* inoculant application does not always give the positive results on nitrogen present in soils.

3.1.3 Available phosphorous

The interactive effects of combined application of rock phosphate and *Rhizobium* inoculation significantly (P≤0.05) influenced available P under KS20 and N26 varieties in both seasons (Table 1). Available P in treatment R1P1KS20 was a significantly (P≤0.05) higher 25.80 and 68.8 ppm P compared to treatment R1P1N26 with 20.96 and 45.8 ppm for the two seasons (Table 1). The lower levels of available P in the first season could partly be attributed to the initial soil P demand for biological nitrogen fixation in KS20 and N26 varieties. Also the increase in available P in the second season could be due to the residual effect of rock phosphate fertilizer. Soil inoculation of cowpeas and application of P fertilizer resulted in higher positive soil phosphorus balance than planting the same cowpeas variety with either sole application of treatments [33].

Treatment R0P1KS20 with sole application of rock phosphate recorded increase in available P of (19.5 and 31.5 ppm) which was notably higher compared to R0P1N26 (Table 1). This was in agreement with the findings of 0 [3] who observed that, in Malawi, available soil P was higher in soybean that received P fertilization, indicating that there was build-up of P in the soils that received P fertilization. Inoculated treatments recorded a slight increase amount of available P which insignificant between KS20 and N26 varieties (Table 1). According to Gicharuet al. [34], *Rhizobium* inoculation prevents P applied as fertilizer from entering into the immobile pools through precipitation reaction with highly reactive aluminium (Al^+) and iron (Fe^{3+}) in acidic soils [35].

Treatments without P or *Rhizobium* recorded the least amount of available P which were statistically (P≤0.05) similar for the first season and significantly (P≤0.05) different in the second season with R0P0KS20 recording slightly higher available P (16.17 ppm). This Lower available P could be due to decline in soil pH which led to leaching of basic cations leaving behind highly reactive oxides of aluminium and iron which increase P - fixation hence making P unavailable [36]. Also due low cation exchange capacity do not give a sink for Ca - ions released from rock phosphate and thus, slow down its dissolution and this may end in a decrease in P and agronomic effectiveness of RP [37].

3.1.4 Fixed nitrogen

A significant (P≤0.05) increase of fixed nitrogen was observed with combined application of *Rhizobium* and rock phosphate over other treatments. However, a significant (P≤0.05) difference in fixed-N between KS20 and N26 varieties was observed with R1P1KS20 recording significantly (P≤0.05) higher fixed - N of 0.48 and 0.50% than R1P1N26 which recorded 0.35 and 0.42% (Table 1). These differences in fixed-N can be attributed to the variability in response to inoculation. These results corroborate with those of [13] and [19], who reported differences in N-fixation among inoculated cultivars of climbing beans in central Kenya. Also, *Rhizobium* inoculation alone resulted in higher amount of fixed – N over rock phosphate alone with R1P0+KS20 having slightly higher fixed – N of (0.27 and 0.22%) than R1P0N26 with (0.22 and 0.24%) for both seasons, respectively (Table 1). The low fixed–N in *Rhizobium* inoculation alone clearly demonstrated the key role played by phosphorous in N - fixation process. It is reported that inadequate P restricts root growth, the process of photosynthesis, translocation of sugars, and other such functions, which directly or indirectly influence nitrogen fixation by leguminous plants [38]. Also Wasike et al. [39], observed application of P significantly increased fixed–N in cowpea. These results were in agreement with those of [16], who observed increase in fixed-N in cowpeas with P fertilizer application.

Treatment R0P0N26 recording lowest fixed – N of (0.04 and 0.05%) for the two seasons, respectively (Table 1). This demonstrated clearly the need for commercial *Rhizobium* inoculation and rock phosphate for enhanced fixed - N in green-grams. The variable extent of nitrogen fixation by green–gram varieties was probably due to differences in symbiotic effectiveness of *Rhizobia* strains and their compatibility. Selections of host variety - compatible inoculant have been recognized as an important method for increasing nodulation and nitrogen fixation in legumes [40]. These variations in fixed nitrogen were in agreement with the findings of [41], who reported variations in nitrogen fixation ability of different dry bean varieties. Nevertheless, Plaxton [10] reported that higher nodulation does not always translate into higher nitrogen fixation since nitrogen fixation is much dependent on effective nodules.

3.2 Interactive Effects of *Rhizobium,* Rock Phosphate under Green-Gram Varieties (KS20 and N26) on Soil Potassium (K), Total Organic Carbon (TOC) and Exchangeable Cations (EC)

3.2.1 Total Organic Carbon (TOC)

Total organic carbon significantly (P≤0.05) increased with combined application of *Rhizobium* and rock phosphate for the two seasons. Treatment R1P1KS20 recorded higher TOC of 3.06 and 3.45% than R1P1N26 which recorded 2.44 and 2.57% for the two seasons, respectively (Table 2). This Higher TOC in combined application of the treatments could be due to the increased P levels in soils that were used by the microbes in mineralization and BNF process instead of symbionts using organic carbon available in the soil pools [42]. Sole application of rock phosphate resulted to a significant effect (P≤0.05) on TOC between the two varieties with R0P1+KS20 recording slightly higher TOC of (2.34 and 2.37%) over R0P1N26 with 2.24 and 2.28% (Table 2). These results were higher compared to *Rhizobium* inoculation alone. This is because the phosphorous was used as a source of energy by the *Rhizobia* strains rather than organic carbon that was available in the soils.

Furthermore, inoculated treatments R1P0N26 and R1P0KS20 recorded slightly higher TOC values which were significantly (P≤0.05) different between KS20 and N26 varieties in the first season but similar in the second season (Table 2). The lower total organic carbon in *Rhizobium* alone agrees with the findings of Mburu et al. [43], which attributed this trend to increased microorganisms which hastened decomposition rates of soil organic carbon in the study site thus decline in TOC. Lower TOC values were recorded in both with no *Rhizobium* or rock phosphate which were significantly (P≤0.05) similar between KS20 and N26 varieties. However, R0P0KS20 recorded slightly higher TOC values of (1.93 and 1.88%) over R0P0N26 (Table 2). However, studies by McWilliams et al. [44] showed that total organic carbon levels were very low with application of commercial inoculant.

3.2.2 Soil Exchangeable Cations (EC) and potassium (K)

The interactive effect of combined application of rock phosphate and *Rhizobium* inoculation resulted in an increase in EC and K for the two seasons. There were significant (P≤0.05) differences in EC and K between KS20 and N26 varieties with R1P1KS20 recording higher EC of (0.84 and 0.95 $CmolKg^{-1}$) and K (1.65 and 1.75 $CmolKg^{-1}$) for the two seasons, respectively (Table 2). This was significantly (P≤0.05) different from treatment R1P1N26 which recorded EC (0.61 and 0.73 $CmolKg^{-1}$) and K (1.35 and 1.14 $CmolKg^{-1}$) for the two seasons, respectively (Table 2). The increase in EC and K could be due to increased bioavailability of cations and

Table 2. Interactive effects of *Rhizobium,* rock phosphate and green-gram varieties on soil potassium (K), total organic carbon (TOC) and exchangeable cations (EC)

Seasons	Treatments	$CmolKg^{-1}$ EC	$CmolKg^{-1}$ K	% TOC
I	R0P0KS20	1.930 *abc	0.2133a	0.587a
	R0P1KS20	2.340fg	0.4167d	0.967b
	R1P0KS20	2.267f	0.437cd	1.090bcd
	R1P1KS20	3.060i	0.8400h	1.657f
	R0P0N26	1.860a	0.210a	0.540a
	R0P1N26	2.243ef	0.353bc	0.940b
	R1P0N26	2.033cd	0.3267b	1.040bcd
	R1P1N26	2.443gh	0.6167f	1.143cd
II	R0P0KS20	1.887ab	0.2067a	0.583a
	R0P1KS20	2.377fg	0.4567d	0.980bc
	R1P0KS20	2.107de	0.5367e	1.163d
	R1P1KS20	3.450j	0.9567i	1.750f
	R0P0N26	1.823a	0.1800a	0.530a
	R0P1N26	2.283f	0.4833de	0.950b
	R1P0N26	2.107de	0.4167cd	1.070bcd
	R1P1N26	2.57h	0.7300g	1.350e
	C.V (%)	1.9	4.6	5.3
	Mean	2.2927	0.454	1.021
	$LSD_{0.05}$	0.0738	0.0172	0.0907

*Legend: *Means followed by the same letter in the same column are not significantly different from each other at (P≤0.05) level of significant. R0P0KS20- Rhizobium 0 g/ha X phosphate rock 0 kg/ha X KS20, R0P1KS20- Rhizobium 0 g/ha X phosphate rock 30 kg/ha X KS20, R1P0KS20 - Rhizobium 100 g/ha X phosphate rock 0 kg/ha X KS20, R1P1KS20 - Rhizobium 100 g/ha X phosphate rock 30 kg/ha X KS20, R0P0N26- Rhizobium 0 g/ha X phosphate rock 0kg/ha X N26, R0P1N26 - Rhizobium 0 g/ha X phosphate rock 30 kg/ha X N26, R1P0N26-Rhizobium 100 g/ha X phosphate rock 0kg/ha X N26, P1P1N26 - Rhizobium100 g/ha X Phosphate rock 30 kg/ha X N26, C.V- Coefficient of Variations, LSD- Least Significant Difference*

nutrients enhanced by *Rhizobium* inoculation. This was in agreement with the findings of Olivera et al. [45], who reported influence of both *Rhizobium* inoculation and phosphorous in bioavailability of macro-nutrients such as K and exchangeable cations in soils. Sole application of *Rhizobium* led to a significant (P≤0.05) increase in EC and K than rock phosphate alone. However, R1P0KS20 recorded greater EC (0.43 and 0.53 $CmolKg^{-1}$) and K (1.09 and 1.16 $CmolKg^{-1}$) compared to R1P0N26 for the two seasons, respectively (Table 2). According to Vanlauwe and Giller [28], *Rhizobium* inoculation improves rhizosphere pH resulting in bioavailability of soil nutrients. Also, treatment R0P1KS20 with sole application of rock phosphate, recorded slightly higher EC (0.41 and 0.45 $CmolKg^{-1}$) and K (0.96 and 0.98$CmolKg^{-1}$) over R0P1N26 (Table 2). Treatments ROPON26 and R0P0KS20 recorded least amounts of EC and K $CmolKg^{-1}$ which were statistically (P≤0.05) similar for both seasons The decline in EC may have resulted from reduced organic carbon in the soils which may have depressed the cation sites in the soil [46].

4. CONCLUSION

Results from this study showed that synergetic effects of *Rhizobia* inoculation and RP fertilizer application on soil chemical properties were more pronounced in combined application of *the* treatments than sole application of *Rhizobium* or RP fertilizer. Moreover, despite the promiscuous status of KS20 and N26 varieties they also need inoculation or P fertilizer application or both for higher yields. Selection of efficient green-gram variety that is responsive to inoculant *Rhizobia* strain(s) form the basis for increased green-gram BNF which greatly improves the soil fertility status sustainably. Farmers should put extra efforts in farming practices that stimulate symbiotic effectiveness and improve soil productivity including, *Rhizobia* inoculation that adds beneficial strains to the soil and adequate amount of organic RP fertilizer use. These attempts will be met with greater success through a consideration of other factors. From this research study KS20 and N26 varieties showed significant (P≤0.05) differences due to *Rhizobium* and rock phosphate application.

Variety KS20 was superior to N26 in the tested soil chemical properties Therefore, combined application of *Rhizobia* inoculation at 100 g ha^{-1} and rock phosphate fertilizer at 30 kg P ha^{-1} with KS20 variety could be recommended for sustainable soil fertility improvement in the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Shisanya CA, Gitonga NM. Evaluation of nitrogen fixation using 15 N dilution methods and economy of maize-tepary bean intercrop farming system in Semi-arid SE-Kenya. Advances in Intergrated Soil Fertility Management in Sub-Saharan Africa. 2007;42(5):389-400.
2. Makoi JH, Ndakideni PA. Micronutrients uptake in common bean as affected by rhizobium inoculation, and supply of lime. Plant Omics Journal. 2012;4(1):40-52.
3. KALRO. Production of drought tolerant seeds. Greens-grams production in Kitui, Makueni and Tharaka Nithi. Retrieved from farmbizafrica.com/farmbizopinion. 2015;3:86 – 104.
4. Chapman HD. Cation exchange capacity. In methods of soil Analysis. Black CA, Series Agronomy: Am. Inst. Agronomy, Madison, Wisconsin. 1965;9(2):891-901.
5. Sarkodie-AddoJ, Adu-Dapaah H, Ewusi-Mensah N, Asare E. Evaluation of medium-maturing soybean (*Glycine max (L) Merrill*) lines for 168 their nitrogen fixation potentials. Journal of Science and Technology (Ghana). 2006;26(2):34-39.
6. Rashid M. Response of lentils to *Rhizobium* inoculation. Genetic diversity of Rhizobia nodulating lentils legumes. Review Research. 2013;26(3):99-112
7. Herridge DF, Peoples MB, Boddey RM. Global inputs of biological nitrogen fixation in agricultural systems. Plant and Soil. 2014;31(1):1-18
8. Patra RK, Pant LM, Pradhan K. Response of soybean to inoculation with Rhizobial strains: Effect on growth, Yield, N Uptake, and Soil N Status. Worlicescultural Scien Journal of Agru. 2012;8(1):51–54.
9. Danga BO, Ouma JP, Wakindiki IIC, Bar-Tal A. Chickpea-wheat rotation for higher production in a humid tropical region. Agronomy Journal. 2010;102:363-371. DOI: 10.2134/agronj 2009.0145
10. Plaxton WC. Plant response to stress, biochemical adaptations to phosphate deficiency. In: R. Goodman (Ed). Encyclopaedia of plant and crop science. Marcel Dekker, New York. 2004;2(5):976-980.
11. Onduru D, De Jager A, Muchen, F, Gachani, G and Gachimbi L. Exploring potentials of Rhizobium inoculation in enhancing soil fertility and agro economic performance of cowpeas in Sub-saharan Africa: a case study in semi – arid Mbeere, Eastern Kenya. Am. Eurasian J. sustains. Agric. 2008;2(25):185- 197.
12. Solomon T, Pant LM, Angaw T. Effects of inoculation by *Bradyrhizobium japonicum* strains on nodulation, nitrogen fixation, and yield of soybean (*Glycine max* L. Merill) varieties on nitisols of] Utilization of nitrogen (N) and phosphorous (P) in an organic dairy farming system in Norway. Agric Ecosys Environ. 2012;104:509-522.
13. Gachimbi LN, Jager A, Van KK, Thuranira EG, Nandwa SM. Participatory diagnosis of soil nutrient depletion in semi-arid areas of Kenya. Managing Africa's soil and improvement of phosphorus efficiency in soybean: a radical approach. Annals of Botany. 2002;29(265):245-274.
14. Wang X, Yan X, Liao H. Improvement of phosphorus efficiency in soybean: A radical approach. Annals of Botany. 2010;41(4): 145-159.
15. Jaetzold R, Hornetz B, Shisanya C. Farm management handbook of Kenya, Natural conditions and farm management information, Part C Eastern Kenya, Subpart CI Eastern province. Nairobi Kenya, Ministry of Agriculture. 2013;I(2): 235-254.
16. Asim MM, Aslam NI, Hashmi, Kisan NS. Mungbean (Vigna radiata) in wheat based cropping system: An option for resource conservation under rainfed ecosystem. 2016;37(4):1197-1204.

17. Hoorman J, Islam R, sundermeier A. Sustainable crop rotations with green-grams cover crops. 2009;1(2):121-132.
18. Miller R, Kaiser J, Ogle DG. Technical note in Legume inoculation, USD NRCS Bosie, Idaho. 2010;1(26):214-228.
19. Jaetzold R, Schmidt H, Hornetz B, Shisanya C. Farm management handbooks of Kenya, Vol. II: Natural conditions and farm management information, Part C East Kenya, Subpart CI Eastern province. Nairobi Kenya, Ministry of Agriculture. 2007;2(7):105-112
20. Hussain A, Ali Akhtar J, Yasin M Effects of phosphorous in combination with rhizobium inoculation on growth and yield parameters of mungbean. Crop and environment. 2010;2(1):53-56
21. Nelson DW, LE Sommers. Total carbon, organic carbon, and organic matter. In: A.L. Page, R.H. Miller and D.R Keeney) methods of soil analysis. Part 2 Chemical and Mcrobiological Properties.1982;45(6): 539-579.
22. Bambara KS. Effect of *Rhizobium* inoculation, molybdenum and lime on the growth and Nitrogen fixation in *P. vulgaris L.* Cape Peninsula University of Technology. Theses and Dissertations. 2009;25(5):102-106.
23. Mehlich A. Determination of P, Ca, Mg, K, Na, and NH_4. *North Carolina Soil Test Divisio.*1953; 20(4): 23-89.
24. McCulley ME. Niches for bacterial endophytes in crop plants: A plant biologist's view. Australian Journal of Plant Physiology. 2001;28(2):983–990.
25. Catroux G, Hartmann A, Revellin C. Trends in *Rhizobial* inoculant production and use. Plant and Soil. 2001;230(1):21-30.
26. Adeniyan ON, Ojo O, Akinbode O, Adediran J. Comparative study of different NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils. Journal of Soil Science and Environmental Management. 2011;2(1):9-13.
27. Yakubu H, Kwari J, Sandabe M. Effects of phosphorous fertilizer on nitrogen fixation by some grain legume varieties in sudano-Sahelian Zone of North Eastern Nigeria. Nigerian Journal of Basic and Applied sciences. 2010;18(1):44-49.
28. Vanlauwe B, Giller K.E. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystem and Environment. 2006;116(1):34-46.
29. Kimani PM, Gicharu GK., Mburugu N, Boga, Cheruiyot R. Nodulation and yield of bush and climbing beans inoculated with rhizobial strains. Bean improvement cooperative. Annual Report (USA). 2007; 16(50):181-182.
30. Ndakidemi. Response of Faba Bean and nutrient uptake to rhizobium inoculation and phosphorous application. 2011;1(1): 36-54.
31. Okalebo JR, Gathua KW, Woomer PC. Laboratory methods of soil and plant analysis: a working manual. TSBF Programme, Nairobi. 2002;2(7):36-37.
32. Daria J, Bangnikon J, Abeka-Afari, H, Hanif C, Addaquay J, Antwi V, Hale A. The Market for maize, rice, Soy and Warehousing in northern Ghana. USAID Enabling Agriculture Trade (EAT) Project. 2012;42(3):245-261.
33. Nyoki D, Ndakidemi PA. Selected chemical properties of soybean rhizosphere soil as influenced by cropping systems, *Rhizobium* inoculation, and the supply of phosphorus and potassium after two consecutive cropping seasons. International Journal of Agronomy. 2018; 10:321 –354.
34. Gicharu G, Gitonga N, Boga H, Cheruiyot R, Maingi J. Effect of inoculating selected climbing bean cultivars on nitrogen fixation. 2013;2(11):78-92.
35. Kimiti JM, Odee DW, Vanlauwe B. Area under grain legumes cultivation and problems faced by smallholder farmers in legume production in the semi-arid Eastern Kenya. Journal of sustainable Development in Africa. 2009;11(4):410-428.
36. Maida JHA. Phosphorus status of some Malawi soils. African Journal of Agricultural Research. 2013;8(32):4308-4317.
37. Asuming-Brempong S, Wiafe Y, Aggrey MK. Nodulation of cowpea at different levels of phosphorous in Typic Kandiustalf. Agricultural science Research Journal. 2001;3(12):387-394.
38. NITHI CG. Retrieved April 20TH, 2019, From County Government of Tharaka Nithi; 2013.
39. Wasike VW, Lesueur D, Wachira FN, Mungai NW, Mumera L, Sanging N. Genetic diversity of indigenous *Bradyrhizobium* nodulating promiscuous soybean (*Glycine max* (L) Merr.) varieties

in Kenya: Impact of phosphorus and lime fertilization in two contrasting sites. Plant and Soil. 2009;322:151–163.

40. Sanchez PA. Soil fertility and hunger in Africa. Science (Washington). 2002;295 (5562);209-2020.
41. Date R. Inoculated legumes in cropping systems of the tropics. Field Crops Research. 2000;65(2):123-136.
42. Chemining'wa GN, Muthomi J, Theuri S. Effect of rhizobia inoculation and starter-N on nodulation, shoot biomass and yield of grain legumes. Asian Journal of Plant Sciences. 2007;6(7):1113-1118.
43. Mburu M, Okalebo J, Lesucur D, Pypers P, Ng'etich W, Mutegi E, Mutua S, Majengo C, Njoroge R, Nekesa O. Evaluation of biological commercial inoculants on soybean production in Bungoma County, Kenya. In African Crop Science Conference Proceedings. 2011;10(2):605-661.
44. McWilliams DA, Berglund DR, Endres GJ. Soybean growth and development quick guide. North Dakota State University; University of Minnesota. Reviewed and Reprinted August. 2004;5(20):1-5.
45. Olivera RV, Tilburg MF, Van Santos RQ, Moreno FB, Monteiro-moreira ACO, Moura A. Effects of cashew nut meal on ram sperm proteins. Acta vet. Bras. 2004;8 (I.2):264-247.
46. Zin Z, ulkifli H, Tarmizi AM, Hama-dan AB, Khalid H, Raja ZRO. Rock phosphate fertilizers recommended for young oil pam planted on inland soils. MPOB Information Series. 2005;16(2):511-7871.

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