Research Article

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

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Received 4 September 2017; Revised 5 December 2017; Accepted 24 January 2018; Published 1 March 2018

Academic Editor: Yuanhu Xuan

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The field experiment was carried out in northern Tanzania to assess the effects of intercropping systems, *Rhizobium* inoculation, and fertilization with P and K on chemical properties of soybean rhizosphere soil. The experiment was laid out in split-split plot design with $2 \times 4 \times 7$ factorial arrangement replicated thrice. The main plots had two inoculation treatments and the subplots were comprised of four cropping systems which were sole maize, sole soybean, and two intercropping at different soybean spacing (75×20 and 75×40 cm). The fertilizer levels (kg/ha) control (0 kg/ha); 20 K; 40 K; 26 P; 52 P; 26 P + 20 K; and 52 P + 40 K were assigned to sub-subplots. Statistical analysis was performed using ANOVA. Least Significant Difference was used to compare treatment means at $p = 0.05$ significance level. The results indicated that rhizosphere soil chemical properties such as pH, organic carbon (OC), and macro- and micronutrients (N, P, Ca, Mg, and Na and Fe, Cu, Mn, and Zn, resp.) were significantly increased in the *Rhizobium* inoculated soybean over the control. The supply of P and K fertilizers significantly increased the rhizosphere content of macronutrients (P, K, Ca, and Mg) and also they altered the pH and EC of the rhizosphere soil relative to control.

1. Introduction

Plants require 17 nutrients to perform different plant functions related to growth, development, and reproduction. However, most soils in sub-Saharan Africa are depleted and are deficient in mineral elements to sustain crop production [1–3]. Each of these plant nutrients is needed in different amount by plants and they differ in their mobility and availability in the plants and soil. In agroecosystems where most farmers prefer to grow more than one crop in the same piece of land at the same time, there are maximum interactions between plant roots and soil [4]. The concentration of plant nutrients in the zone of soil-roots interactions (rhizosphere) is reported to be different from bulk soil [5]. Compared

with the bulk soil, rhizosphere soil is said to have high concentration of mineral elements and soil microorganisms (both beneficial and harmful) [6, 7]. Interactions between roots and soil during plant growth induce changes in the soil that make rhizosphere soil to differ from bulk soil [8, 9]. These changes in the rhizosphere may be caused by root uptake of nutrients, microbial activity, and/or components of root exudates [5, 10]. Plants release several low and high molecular weight organic compounds such as sugars, organic acids, amino acids, and phenolics into the rhizosphere [5, 11]. The compounds that are released can lead to dissolution of primary minerals and precipitation or crystallization of secondary compounds and/or minerals and eventually transformation of mineral components in the rhizosphere [6].

Plant Growth Promoting Rhizobacteria (PGPR) also do concentrate in the rhizosphere soil and confer the plants with beneficial effects such as solubilization of mineral nutrients, fixation of nitrogen, and disease suppression resulting from plant pathogens [12–17]. Bambara and Ndakidemi [18] reported a significant increase in soil pH, Ca, and Na following *Rhizobium* inoculation on *Phaseolus vulgaris*. Crop diversity in the field increases concentration of microbes in the rhizosphere soil compared with the single species because of specificity of microbes to plant species. Intercropping cereal with legume crops such as cowpea, mungbean, soybean, and groundnuts can fix and accumulate nitrogen ranging from 80 to 350 kg ha⁻¹ per year [19], thereby improving soil fertility. Intercropping also can enhance nutrient mineralization because it improves the decomposition rates of soil organic matter [20, 21]. Biological nitrogen fixation induces changes in the soil pH resulting in limited availability of some plant nutrients in the soil [22].

Currently, there is limited information about the effect of *Rhizobium* inoculation on the chemical composition in the rhizosphere of soybean intercropped with maize, supplemented with lower and higher rates of phosphorus (P) and potassium (K) fertilizers. Therefore, the current study was carried out to determine the effects of intercropping systems, *Rhizobium* inoculation, and fertilization with different levels of P and K singly or combined application on chemical properties of soybean rhizosphere soil after two consecutive cropping seasons.

2. Material and Methods

2.1. Experimental Design and Treatments. The field experiment was conducted in the same place for two consecutive years (2015 and 2016 cropping seasons). The treatments for year one were repeated in year two in the same spots. The experimental trials were set at Tanzania Coffee Research Institute (TaCRI) farm in northern Tanzania. The experiment followed a split-split plot design with factorial arrangement and replicated thrice. The plot measured 3 × 3 m. The main plots had two Rhizobia inoculation treatments, while the subplots were comprised of the following treatments: maize (sole crop) at a spacing of 75 × 60 cm; soybean (sole crop) at a spacing of 75 × 40 cm; maize/soybean (intercropping system) at a spacing of 75 × 60 cm and 75 × 20 cm, maize, and soybean, respectively; and the last cropping system was maize/soybean (intercropping system) at a spacing of 75 × 60 cm and 75 × 40 cm, maize, and soybean, respectively. The sub-subplots were treated with the following fertilizer levels (kg ha⁻¹): control (0 kg ha⁻¹); 20 K; 40 K; 26 P; 52 P; 26 P + 20 K; 52 P + 40 K. The sources of these elements were Triple Super Phosphate (TSP for P) and Muriate of Potash (MOP) for K. The BIOFIX legume inoculants (*Bradyrhizobium japonicum*) were obtained from MEA Company Nairobi-Kenya, sold under the license from the University of Nairobi. The inoculants were supplied with gum Arabic for sticking as many cells as possible into the seeds. Inoculation was done following manufacturers' instructions where thirty (30) gram of gum Arabic was added to 300 ml of water and mixed to form a solution. 15 kg of soybean seeds was weighed and

300 ml of gum Arabic solution was added and mixed well. 50 gm of legume inoculants was added and mixed well so that all seeds are coated. The inoculated seeds were put under shade for 15 minutes to ensure the inoculants stick well on seeds and the seeds were then sown immediately in a wet moist soil. To avoid contamination of inoculation treatments, the uninoculated plots were sown first followed by inoculated plots.

2.2. Sample Collection. Rhizosphere soil used in this study was collected during the second year of the experimentation when the soybean was at 50% pod formation. The rhizosphere soils were sampled from five plants of middle rows for each plot excluding the border plants. This was achieved by careful excavation of soil from around each plant down to about 10–20 cm depending on root depth of the respective plant and removed with the plant and its roots intact inside the bulge of soil. The rhizosphere soil adhering to plant roots was shaken in the labeled bags, air dried in the laboratory, and sieved (2 mm) ready for determination of pH, organic carbon, and analysis of nutrients. The samples collected from each plot for the two cropping season were pooled together and well mixed to form one sample per treatment.

2.3. Determination of Plant-Available Nutrients in Rhizosphere Soil. Total N was determined by the method of micro-Kjeldahls described by Bremner [23]. Phosphorus was determined by the molybdenum blue method [24]. Concentrations of elements such as Ca, Mg, K, and Na were determined by method described in Hesse [25]. The trace elements such as Cu, Zn, Fe, and Mn were extracted by diethylenetriamine-pentaacetic acid (DTPA) [26] and determined by an atomic absorption spectrophotometer. The rhizosphere soil pH was analysed in 1:2.5 (soil: water) suspension, by the electrometric method [27], and electrical conductivity (EC), measured in a 1:5 (soil:water) suspension, using the electrometric method [27]. The organic carbon was determined by the Walkley and Black method [28].

2.4. Statistical Analyses. The collected data was analysed using statistical software called STATISTICA. The statistical analyses were performed using analyses of variance (ANOVA) in factorial arrangement. Fisher's least significant difference (LSD) was used to compare treatment means at $p = 0.05$ level of significance [29].

3. Results

3.1. Effects of Cropping Systems on Rhizosphere Soil Chemical Properties. The results indicated that, except for sodium (Na), cropping systems had no significant effects on the chemical properties of the soybean rhizosphere soil. Only sodium was observed to be greater in the rhizosphere soil of soybean grown under maize intercropping systems compared with the rhizosphere soil of soybean pure stand (Table 1).

3.2. Effects of *Rhizobium* Inoculation on Rhizosphere Soil Chemical Properties. *Rhizobium* inoculation was observed to alter the most of the chemical properties of the rhizosphere soil of soybean compared with the rhizosphere soil collected

TABLE 1: Effects of *Rhizobium* inoculation, cropping systems, and the supply of P and K on macronutrients in the rhizosphere soil measure in 2016 season.

Treatments	N	%	OC	Av. P Bray 1. mg/kg	K	Ca	Mg	Na
Crop. system								
SB	0.039 ± 0.001 ^a	2.65 ± 0.05 ^a	3.56 ± 0.56 ^a	2.20 ± 0.15 ^a	8.60 ± 0.41 ^a	1.67 ± 0.06 ^a	0.16 ± 0.01 ^b	
M + B (A)	0.041 ± 0.001 ^a	2.65 ± 0.05 ^a	3.50 ± 0.59 ^a	2.25 ± 0.17 ^a	7.95 ± 0.39 ^a	1.58 ± 0.06 ^a	0.18 ± 0.01 ^a	
M + B (B)	0.040 ± 0.001 ^a	2.67 ± 0.04 ^a	3.42 ± 0.66 ^a	2.27 ± 0.18 ^a	8.55 ± 0.44 ^a	1.62 ± 0.06 ^a	0.19 ± 0.01 ^a	
Rhizobia								
Without	0.038 ± 0.001 ^b	2.59 ± 0.04 ^b	2.18 ± 0.40 ^b	2.32 ± 0.15 ^a	7.81 ± 0.28 ^b	1.50 ± 0.04 ^b	0.15 ± 0.01 ^b	
With	0.042 ± 0.001 ^a	2.72 ± 0.03 ^a	4.81 ± 0.52 ^a	2.16 ± 0.12 ^a	8.92 ± 0.37 ^a	1.75 ± 0.05 ^a	0.20 ± 0.01 ^a	
Fertilizers								
Control	0.038 ± 0.002 ^a	2.61 ± 0.06 ^a	0.60 ± 0.17 ^b	1.51 ± 0.23 ^c	6.92 ± 0.39 ^c	1.59 ± 0.06 ^b	0.14 ± 0.01 ^a	
20 K	0.039 ± 0.001 ^a	2.71 ± 0.06 ^a	2.47 ± 0.95 ^b	2.52 ± 0.15 ^b	6.44 ± 0.42 ^c	1.52 ± 0.10 ^b	0.17 ± 0.01 ^a	
40 K	0.039 ± 0.001 ^a	2.74 ± 0.07 ^a	0.71 ± 0.16 ^b	2.81 ± 0.19 ^{ab}	6.46 ± 0.40 ^c	1.42 ± 0.06 ^b	0.18 ± 0.02 ^a	
26 P	0.040 ± 0.001 ^a	2.62 ± 0.07 ^a	5.60 ± 0.95 ^a	1.32 ± 0.08 ^c	10.14 ± 0.57 ^{ab}	1.85 ± 0.08 ^a	0.17 ± 0.02 ^a	
52 P	0.041 ± 0.002 ^a	2.66 ± 0.05 ^a	5.76 ± 1.04 ^a	1.45 ± 0.12 ^c	10.46 ± 0.72 ^a	1.85 ± 0.11 ^a	0.20 ± 0.02 ^a	
20 K + 26 P	0.041 ± 0.002 ^a	2.56 ± 0.08 ^a	4.69 ± 0.81 ^a	2.83 ± 0.20 ^{ab}	8.77 ± 0.43 ^b	1.50 ± 0.05 ^b	0.18 ± 0.02 ^a	
40 K + 52 P	0.041 ± 0.001 ^a	2.69 ± 0.06 ^a	4.63 ± 0.96 ^a	3.24 ± 0.29 ^a	9.38 ± 0.57 ^{ab}	1.63 ± 0.10 ^{ab}	0.18 ± 0.01 ^a	
3-way ANOVA <i>F</i> -statistics								
CroSyt	0.475 ^{ns}	0.06 ^{ns}	0.02 ^{ns}	0.103 ^{ns}	1.15 ^{ns}	0.62 ^{ns}	3.41 [*]	
Rhiz	16.746 ^{***}	5.76 ^{**}	21.71 ^{***}	1.478 ^{ns}	8.40 ^{**}	15.97 ^{***}	18.79 ^{***}	
Fert	0.810 ^{ns}	0.90 ^{ns}	8.86 ^{***}	19.195 ^{***}	11.65 ^{***}	4.04 ^{***}	1.75 ^{ns}	
CroSyt* Rhiz	1.091 ^{ns}	0.54 ^{ns}	0.90 ^{ns}	2.027 ^{ns}	0.48 ^{ns}	0.19 ^{ns}	0.97 ^{ns}	
CroSyt* Fert	0.898 ^{ns}	1.02 ^{ns}	0.66 ^{ns}	2.578 ^{**}	0.61 ^{ns}	0.52 ^{ns}	0.71 ^{ns}	
Rhiz* Fert	1.467 ^{ns}	0.58 ^{ns}	1.77 ^{ns}	1.225 ^{ns}	0.25 ^{ns}	0.19 ^{ns}	0.48 ^{ns}	
CroSyt* Rhiz* Fert	0.830 ^{ns}	0.70 ^{ns}	1.01 ^{ns}	0.567 ^{ns}	1.41 ^{ns}	0.86 ^{ns}	0.85 ^{ns}	

CroSyt: cropping systems; Fert: fertilizers; Rhiz: *Rhizobium*; SB: sole soybean; M + B (A): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 20 cm, maize, and soybean, respectively; M + B (B): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 40 cm, maize, and soybean, respectively; values presented are means ± SE; ***, **, * significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively; ns = not significant; SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at $p = 0.05$ according to Fischer least significance difference (LSD).

from uninoculated soybean. Rhizosphere soil chemical properties that were significantly increased in the inoculated soybean includes macro- and micronutrients (N, P, Ca, Mg, Na, and OC and pH, Fe, Cu, Mn, Zn, resp.). In this study, *Rhizobium* inoculation treatment did not significantly alter the concentration of EC and K in the rhizosphere soil (Tables 1 and 2). Specifically, *Rhizobium* inoculation increased the concentration of chemical (N, P, Ca, Mg, Na, and OC) in the soil by 10.5, 120.6, 14.2, 16.7, 33.3, and 17.8% respectively. Similarly, the rhizosphere pH and micronutrients (Fe, Cu, Mn and Zn) were, respectively, increased by 1.3, 10.6, 31.4, 41.7, and 25% in *Rhizobium* inoculated soybean relative to uninoculated soybean.

3.3. Effects of P and K Fertilization on Rhizosphere Soil Chemical Properties. Fertilization of crop (soybean) with P and K did not significantly change the concentration nitrogen, sodium, and the organic matter content of rhizosphere soil. However, application of these fertilizers significantly increased the rhizosphere content of macronutrients such as P, K, Ca, and Mg (Table 1). P and K fertilization also altered the pH and EC of the rhizosphere soil relative to control (Table 2).

3.4. Interactions. The current study showed that there were significant interactions between cropping systems and fertilizers on rhizosphere soil K content and between cropping systems and *Rhizobium* inoculation on rhizosphere soil pH. Fertilization with two levels of K significantly increased the rhizosphere K over the plots fertilized with P and the control. The plots that were fertilized with P had statistically the same rhizosphere K with the control (Figure 1). The highest rhizosphere K level was recorded in soybean intercropped with maize at wider spacing and fertilized with doubled combined fertilizers, while the lowest level of rhizosphere K was recorded in the control plots (Figure 1). The rhizosphere soil pH was significantly higher in *Rhizobium* inoculated plots over uninoculated one throughout the cropping systems. The highest pH value was recorded in *Rhizobium* inoculated pure stand while the lowest was recorded in uninoculated pure stand soybean (Figure 2).

4. Discussion

The findings of this study showed that *Rhizobium* inoculation altered the chemical composition of rhizospheres soil relative to uninoculated treatments. *Rhizobium* inoculation reduced the soil acidity by increasing the rhizosphere soil pH relative to uninoculated treatments. Similar findings were reported by Bambara and Ndakidemi [18] who found that *Rhizobium* inoculation significantly increased the soil pH in the rhizosphere of *P. vulgaris*. Furthermore, *Rhizobium* inoculation altered the chemical properties of rhizosphere whereby most of the mineral elements were increased in rhizosphere soils of inoculated soybean over the control. There are several possible explanations for increased concentration of macro- and micronutrients in the rhizosphere soils of inoculated soybean. Firstly, it is due to increased soil pH which favoured the availability of most plant nutrients [30, 31]. Increased availability of nutrients in the rhizosphere soil provides

FIGURE 1: Interactive effect of cropping systems and fertilizers on rhizosphere soil K content. SB: sole soybean; M + B (A): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 20 cm, maize, and soybean, respectively; M + B (B): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 40 cm, maize, and soybean, respectively.

FIGURE 2: Interactive effect of cropping systems and *Rhizobium* inoculation on rhizosphere soil pH. SB: sole soybean; M + B (A): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 20 cm, maize, and soybean, respectively; M + B (B): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 40 cm, maize, and soybean, respectively.

normal growth of plants and eventually increased yield. Normally, if there is low soil pH, the soil is acidic which results in poor plant growth and development as most of plant nutrients become unavailable for plants. Secondly, mineralization activities of rhizospheric microorganisms tend to solubilize mineral elements such as P and make it available in the soil [32]. Thirdly, *Rhizobium* produces Fe career compound called siderophores which tends to increase the Fe content in

TABLE 2: Effects of rhizobium inoculation, cropping systems, and the supply of P and K on soil pH, EC, and micronutrients in the rhizosphere soil measure in 2016 season.

Treatments	pH	EC mS/cm	Fe	Cu	Mn	Zn
Crop. system						
SB	5.39 ± 0.03 ^a	0.21 ± 0.01 ^a	40.88 ± 1.00 ^a	15.61 ± 0.72 ^a	9.51 ± 0.44 ^a	0.74 ± 0.03 ^a
M + B (A)	5.35 ± 0.03 ^a	0.24 ± 0.02 ^a	42.04 ± 1.11 ^a	15.87 ± 0.57 ^a	9.80 ± 0.48 ^a	0.69 ± 0.03 ^a
M + B (B)	5.35 ± 0.03 ^a	0.24 ± 0.02 ^a	41.34 ± 1.05 ^a	17.86 ± 1.10 ^a	10.71 ± 0.70 ^a	0.73 ± 0.03 ^a
Rhizobia						
Without	5.33 ± 0.03 ^b	0.22 ± 0.01 ^a	39.34 ± 0.67 ^b	14.22 ± 0.54 ^b	8.28 ± 0.29 ^b	0.64 ± 0.02 ^b
With	5.40 ± 0.03 ^a	0.23 ± 0.01 ^a	43.50 ± 0.89 ^a	18.68 ± 0.69 ^a	11.73 ± 0.48 ^a	0.80 ± 0.02 ^a
Fertilizers						
Control	5.21 ± 0.05 ^c	0.18 ± 0.02 ^d	41.22 ± 1.25 ^a	15.97 ± 1.28 ^a	9.16 ± 0.67 ^a	0.70 ± 0.05 ^a
20 K	5.34 ± 0.06 ^b	0.21 ± 0.01 ^{bcd}	42.00 ± 1.89 ^a	15.92 ± 1.36 ^a	9.90 ± 0.80 ^a	0.70 ± 0.03 ^a
40 K	5.43 ± 0.05 ^{ab}	0.20 ± 0.02 ^{cd}	42.11 ± 1.66 ^a	15.90 ± 1.13 ^a	10.08 ± 1.03 ^a	0.73 ± 0.05 ^a
26 P	5.31 ± 0.03 ^{bc}	0.24 ± 0.03 ^{abc}	43.13 ± 1.57 ^a	17.88 ± 1.13 ^a	9.09 ± 0.70 ^a	0.63 ± 0.03 ^a
52 P	5.36 ± 0.03 ^b	0.26 ± 0.02 ^{ab}	40.95 ± 1.26 ^a	14.37 ± 1.01 ^a	10.36 ± 0.70 ^a	0.71 ± 0.05 ^a
20 K + 26 P	5.42 ± 0.05 ^{ab}	0.26 ± 0.02 ^{ab}	39.54 ± 1.85 ^a	17.42 ± 1.10 ^a	11.93 ± 1.26 ^a	0.81 ± 0.05 ^a
40 K + 52 P	5.49 ± 0.05 ^a	0.27 ± 0.02 ^a	41.01 ± 1.36 ^a	17.67 ± 1.75 ^a	9.52 ± 0.49 ^a	0.73 ± 0.04 ^a
3-way ANOVA <i>F</i> -statistics						
CroSyt	0.7 ^{ns}	0.98 ^{ns}	0.33 ^{ns}	2.51 ^{ns}	1.57 ^{ns}	0.93 ^{ns}
Rhiz	4.9 [*]	0.33 ^{ns}	12.50 [*]	24.74 ^{***}	35.64 ^{***}	27.69 ^{***}
Fert	4.2 ^{***}	2.99 [*]	0.53 ^{ns}	1.14 ^{ns}	1.61 ^{ns}	1.77 ^{ns}
CroSyt* Rhiz	5.0 ^{**}	2.30 ^{ns}	0.21 ^{ns}	1.05 ^{ns}	0.39 ^{ns}	0.31 ^{ns}
CroSyt* Fert	1.6 ^{ns}	1.29 ^{ns}	1.36 ^{ns}	1.37 ^{ns}	0.41 ^{ns}	0.71 ^{ns}
Rhiz* Fert	1.1 ^{ns}	0.90 ^{ns}	0.60 ^{ns}	0.23 ^{ns}	1.26 ^{ns}	0.84 ^{ns}
CroSyt* Rhiz* Fert	0.5 ^{ns}	1.55 ^{ns}	0.30 ^{ns}	0.28 ^{ns}	0.66 ^{ns}	0.79 ^{ns}

CroSyt: cropping systems; Fert: fertilizers; Rhiz: *Rhizobium*; SB: sole soybean; M + B (A): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 20 cm, maize, and soybean, respectively; M + B (B): maize/soybean intercropped at a spacing of 75 × 60 cm and 75 × 40 cm, maize, and soybean respectively; values presented are means ± SE; ***, ***, * significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively; ns = not significant and SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at $p = 0.05$ according to Fischer least significance difference (LSD).

the rhizosphere soil [33, 34]. Fourthly, the decaying cells of microorganisms release nutrients and make them available in the rhizosphere soil [35]. Fifthly, mineral elements can be excreted in the rhizosphere soil as exudates from plant roots [36]. Sixth, the decayed plant biomasses lead to increased nutrients in the soil. The increased biomass due to inoculation means that, as it decays, it will release larger quantities of nutrients into the soil that it has accumulated [37].

All these processes are taking place in the soil and in one way or another may have attributed to the increased chemical properties of rhizosphere soil of *Rhizobium* inoculated soybean. The current study also showed that organic carbon significantly increased in the rhizosphere soil of *Rhizobium* inoculated soybean over the control. The increase in organic carbon content might be attributed to better root growth and deposition of organic materials in first cropping season since these data were taken in the second cropping season. Similar findings were reported by Sharma et al. [38] and Sharma and Verma [39]. However, our findings on organic carbon content in the rhizosphere differed with that of Yusif et al. [40] who found that *Rhizobium* inoculation decreased the soil pH and the organic carbon. They urged that decrease of organic carbon may have been attributed by increased microorganisms which hastened decomposition of organic carbon in the rhizosphere.

The results also showed that P and K fertilization increased the concentration of P, K, Ca, and Mg in the rhizosphere over the control (Table 1). Increased concentration of Ca and Mg in the rhizosphere soil may have been attributed by synergistic effect of P and K which made these nutrients to concentrate more in the rhizosphere soil. The significant increase of P and K in the rhizosphere soil has been attributed by P and K fertilization which increased the availability of these nutrients. Furthermore, root exudates may have contributed to the increased macronutrients in the plots treated with P and K. It was also noted that the rhizosphere soil pH and electrical conductivity (EC) were significantly higher in P and K fertilized plots relative to control. Soil electrical conductivity (EC) provides the measurement of the amount of salts in soil (salinity of soil) [41, 42]. EC affects crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms which influence key soil processes. However, EC does not provide a direct measurement of specific ions or salt compounds. Researchers have correlated it to concentrations of ions such as N, P, K, Ca, Mg, Na, Mn, Zn, and Cu [42–44]. Their finding are in line with our results which showed the increased EC in plots treated with P and K fertilizers compared with the control.

There were significant interactions between cropping systems and fertilizers on rhizosphere soil K content and between cropping systems and *Rhizobium* inoculation on rhizosphere soil pH. Potassium fertilization significantly interacted with cropping system and contributed to the available K in the rhizosphere soil. The highest K level was recorded in rhizosphere soil of soybean intercropped with maize at wider spacing and fertilized with doubled combined fertilizers, while the lowest level of rhizosphere K was recorded in the control plots. The rhizosphere soil pH was significantly higher in *Rhizobium* inoculated plots

over uninoculated one throughout the cropping systems. The highest pH value was recorded in *Rhizobium* inoculated pure stand while the lowest was recorded in uninoculated pure stand soybean suggesting that microorganisms such as *Rhizobium* can help to reduce soil acidity.

5. Conclusion

Rhizobium inoculation altered most of the chemical properties of the rhizosphere soil of soybean in this study. The rhizosphere soil chemical properties such as pH, OC, EC, and macro- and micronutrients (N, P, Ca, Mg, and Na, and Fe, Cu, Mn, and Zn, resp.) were significantly increased in the *Rhizobium* inoculated soybean over the control. These results strongly support the use of microorganism to improve soil chemical properties for improved plant growth, development, and production. The supply of P and K fertilizers significantly increased the rhizosphere content of macronutrients such as (P, K, Ca, and Mg) and also they altered the pH and EC of the rhizosphere soil relative to control.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors are thankful to the Government of Tanzania through Nelson Mandela African Institution of Science and Technology for funding this study.

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