SOIL & CROP SCIENCES | RESEARCH ARTICLE

Bradyrhizobium inoculation has a greater effect on soybean growth, production and yield quality in organic than conventional farming systems

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Abstract: Globally, organic farming and bradyrhizobia inoculation are gaining popularity as agronomically and environmentally sound soil management strategies with great potential to alleviate declining soil fertility, maintain environmental quality and enhance soybean production. However, the role of bradyrhizobia in organic farming system is poorly understood. Field experiment was conducted to evaluate the effects of bradyrhizobia inoculation and organic farming on growth parameters and yield quality of soybean varieties: SC squire, SB19 and Gazelle. The experimental treatments included native bradyrhizobia, commercial Bradyrhizobium japonicum, mixture of native + commercial bradyrhizobia and uninoculated control. The experimental design was a split-split plot, with three replications. The results demonstrated significant improvement in soybean nodule dry weight (NDW), shoot dry weight (SDW) and seed dry weight (SEDW) following bradyrhizobia inoculation. Remarkably, organic farming significantly out-performed conventional systems in nodulation, SDW and SEDW. Moreover, seed nutrient content differed depending on farming system; where nitrogen, phosphorus, potassium and organic carbon were higher in organic farming. Soybean varieties differed significantly on SDW, NDW and SEDW; where SC squire performed better than SB19 and Gazelle. The results demonstrate the importance of organic farming and bradyrhizobia inoculation in enhancing soil fertility, yield production and quality, a key step towards sustainable food production.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Microbiology;

Keywords: Nitrogen fixation; promiscuous; nodulation; soil fertility; organic fertilizer

PUBLIC INTEREST STATEMENT

Organic farming and bradyrhizobia inoculation play a crucial role in enhancing biological soil fertility, soybean growth, production and yield quality, a key step towards sustainable production of healthy foods and maintaining environmental quality.

These agronomic practices are affordable to smallholder farmers who are resource-constrained and can’t afford expensive inorganic fertilizers. They have great potential to sustainably restore soil fertility, increase food production and support global food security in an eco-friendly manner.

The results revealed the importance of organic farming and inoculation in stabilizing soil pH, enhancing soil fertility and production at a reduced cost; which resonates with Mwenda, 2010; Parr, 2014, who documented similar findings on organic farming.

The results support study by Reddy 2013 that organic farming is increasing in popularity due to its sustainability in production of inexpensive healthy foods.

The study recommends that inoculation should be adopted in organic farming to enhance production.
1. Introduction

Sustainable crop production remains a great concern and it is increasingly drawing attention of the scientific community, policy makers and agri-business sector. Globally, human population has risen steadily and scarcity of arable land has led to increased pressure on agricultural systems to provide food for the growing population. To counter the food shortage crisis, farmers are reported to increase pressure on agricultural systems to provide adequate food for the high population (Ochieng et al., 2016). In Kenya, this has led to drastic land-use changes within smallholder farming systems with farmers interchanging between conventional and organic farming depending on their preferences and market demands.

In conventional farm management systems, the identification of a limitation in nutrient supply is followed by the application of that nutrient as inorganic fertilizer. Research has revealed that despite the availability of numerous sources of nutrient to enhance soil fertility and improve crop yield, inorganic chemical fertilizers have been prioritized by some farmers as the best solution to alleviate soil nutrient deficiency (Gentili et al., 2006; Otieno et al., 2009). This philosophy gives rise to a system that usually involves a high supply of externally derived inorganic inputs. Ideally, conventional farming permits the use of huge quantities of inorganic fertilizers and other agrochemicals to improve crop production and resilience. Unfortunately, most of these inorganic inputs contribute significantly to environmental degradation (Abou-Shanab et al., 2017) and are not sustainable in smallholder farming systems. Furthermore, the ever-increasing cost of chemical fertilizers renders it unaffordable to most resource-poor smallholder farmers (Argaw, 2012). Additionally, increased and continuous application of chemical fertilizers in agricultural production leads to frequent deleterious environmental consequences of local and global concern (Ashoka et al., 2017). For instance, the intensive application of inorganic fertilizers and other agrochemicals has been linked to biodiversity reduction, increased emissions of greenhouse gases, and eutrophication effects on surface and underground drinking water (Khanal, 2009; Pearson et al., 2010; Pimentel, 2005; Pimentel et al., 2005). These concerns and negative impacts posed by conventional farming gave birth to organic farming.

Organic farming system is characterized by strict limitation of inorganic fertilizers and other agrochemicals, where soil management is through the application of organic fertilizer and other strategies such as crop rotation (IFOAM, 2006). Organic farming, ideally, involves no use of any synthetic pesticide or synthetic fertilizer, rather, mainly relies on crop rotation, use of plant residues, animal wastes, off-farm organic wastes, mineral grade rock additives and other biological systems of nutrient mobilization, solubilization and plant protection (Reganold & Wachter, 2016). This mode of farming relies more on agroecological services rather than on the use of expensive external inputs. Profitable and sustainable organic farming enterprises at the local and global levels are emerging in response to unmet consumer demands for organic food, concerns about human and environmental health. Worldwide, organic farming systems are increasing due to consumer demand for healthier food, the need to conserve the environment and biodiversity (Willer & Kilcher, 2012). Organic products are perceived to be healthier and the local and foreign market opportunities are constantly expanding and therefore, more farmers are expected to practice this cheaper and eco-friendly system to enhance production in the coming decades (Conway, 2012; Sahota, 2013). Therefore, many farmers have developed interest in organic farming as an alternative and profitable agricultural strategy in Kenya (Bett & Ayieko, 2017) and this is evident by the recent dramatic increase in the amount of land under organic farm management system.

To promote crop production and in a sustainable way, there is need to adopt cheaper and eco-friendly strategies of alleviating loss of soil fertility and improve crop production (Argaw, 2012; Otieno et al., 2009). The use of beneficial soil microorganisms in organic farming is a promising smart-technology that could be used to reduce the intensive use of inorganic fertilizers (Ncho et al., 2016) and with potential to promote soil fertility and maximize nutrient cycles. Bradyrhizobia species are key components of soil microbiota that are essential in soil fertility, plant growth,
nutrition and play an important role in organic agriculture by compensating for the reduced application of inorganic fertilizers and other agrochemicals. Bradyrhizobia colonize roots of leguminous plants and form symbiotic association that leads to enhanced water and nutrient uptake (Mahanty et al., 2017; Srivastava et al., 2017). Bradyrhizobia are able to biologically fix atmospheric nitrogen (N) and help accessing other nutrients such as nitrogen and phosphorous from soil stocks and organic fertilizers (Almanza. et al., 2010). Thus, inoculation of legumes with bradyrhizobia constitutes one of the major agronomic practices targeting improvement of symbiosis in sustainable agriculture.

Soybean (Glycine max (L.) Merrill) is an important legume grown world-wide and account for nearly 50% of the world’s area under legume cultivation (Herridge et al., 2008). It’s also one of the most traded legumes in the world accounting for over 84.5% of the traded grain legumes (Murage et al., 2019) due to its nutritional importance as a key source of vegetable oil and protein for human food and animal feeds (Abou-Shanab et al., 2017). In most countries, soybean serves as a source of food and food supplements for human and as livestock feed (Da Silva Júnior et al., 2018). Thus, soybean has contributed greatly to human health and socio-economic well-being of low-income rural populations across the globe (Maphosa & Jideani, 2017; Masciarelli et al., 2014). Like other legumes, soybean plants are known for their high nitrogen-fixing ability (Abate et al., 2011) and they contribute to soil nitrogen through biological nitrogen fixation, some of which could benefit the subsequent crops (Carsky et al., 2006). However, the growth of soybean in Eastern Kenya by smallholder farmers has not been sustainable in the past one decade (Njeru et al., 2013). This could be attributed to the region being characterized by low economic growth and reduced soil fertility that is contributed by conventional farm management practices (Lesueur et al., 2012). This necessitates the use of other alternative systems of production that could favor sustainable soybean productivity.

Soybean yield can be increased through inoculation with bradyrhizobia which improves nitrogen fixation and nutrient acquisition. Soybean inoculation with bradyrhizobia has sufficient potential to promote soybean yields through increased growth, enhanced soil fertility and nutrient efficiency (Jansa et al., 2011; Meng et al., 2015). Inoculation of soybean with bradyrhizobia inoculants significantly reduce cost of soybean production and improve economic status of soybean farmers; as inoculants are cheaper than inorganic N fertilizers (Ronner et al., 2016). The natural roles of these beneficial bacteria may have been marginalized in intensive agriculture, since microbial communities in conventional farming systems have been modified due to tillage (Kerry et al., 2018; Yadav et al., 2018) and high inputs of inorganic fertilizers, herbicides and pesticides (Malhotra et al., 2015; Prashar & Shah, 2016).

Although field studies show that organic farming tend to increase crop yield production and quality than conventional farming; the effect of bradyrhizobia inoculation on organic farming has not been tested fully. Moreover, little attention has been focused on the possibility of raising the inoculum potential of commercial and indigenous bradyrhizobia isolates by appropriate farm management practices; a strategy that would be fundamental in organic farming, which rely more on agroecological approaches than on the use of external inputs. A better understanding of these bradyrhizobia strains, their interactions and role is a key step towards the development of sustainable agriculture, increased food production and enhanced soil fertility.

In this research, we tested the hypothesis that inoculation and co-inoculation with bradyrhizobia in organic and conventional farming will provide a significant increase in soybean growth, production and yield quality. The objectives of this study are to (i) investigate the potential of organic and conventional farming to enhance the functional activity of bradyrhizobia species in promoting soybean growth, production and yield quality, (ii) to evaluate the effects of inoculation and co-inoculation with bradyrhizobia strains on promiscuous and non-promiscuous soybean variety and (iii) to assess arbuscular mycorrhizal fungi (AMF) root colonization and its effects on soybeans growth and production under organic and conventional farming.
2. Materials and methods

2.1. Study site
Field experiments were conducted in three strictly organic and three conventional managed farms in Meru South district, Tharaka Nithi County, Kenya at 0° 19’ 59.38” N and 37° 38’ 45.13” E. The area is in the upper midland 2 and 3 (UM2 and UM3) agroecological zones and has an altitude of approximately 1373 m above sea level. It experiences bimodal rains, which range from 1200 to 1400 mm and a mean temperature of 20°C annually. The long rains are from March to June, and the short rains are from October to December. The predominant soil types are humic nitisols, commonly called the red Kikuyu loams. The soil is deep, well weathered, and free draining with a friable clay texture and moderate to high fertility (Joetzold et al., 2006).

2.2. Experimental design
Field experiments were conducted for two consecutive years: during October to December 2015 (short rain) and March to June 2016 (long rain). The six farms had no previous history of bradyrhizobia inoculation or soybean cultivation. However, other legumes were previously cultivated but without any form of inoculation. The organic farmers are trained, certified and organic farms had three years after conversion and no recent history of herbicide, pesticide and inorganic fertilizer application while conventional farms had a long history of herbicide, pesticide and inorganic fertilizer application. Organic farmers use organic fertilizers derived largely from animal and plant wastes and biological nitrogen fixing by leguminous plants for soil nutrient replenishment. The experiment was set up in a split-split plot design with the farm management as the main factor, soybean varieties and bradyrhizobia inoculation as the sub-factor and in triplicate. Each plot had three soybean varieties: SC Squire, SB 19 and Gazelle inoculated with Native bradyrhizobia, Commercial *Bradyrhizobium japonicum* USDA110, and mixture of Native + Commercial *Bradyrhizobium japonicum* USDA. The control subplots were left uninoculated. A total of 12 different treatments were represented in 12 subplots per farm. Each subplot occupied 3 m x 4 m area with an alley of 1 m between the subplots. A total of 72 subplots constituted the whole experimental layout of both organically and conventionally managed farms. The approximate size of each farm used was 14 m x 15 m.

2.3. Soil sampling
Soil sampling was carried out across and diagonally in all the six selected organic and conventional farms before onset of 2015 short rain and 2016 long rain. At each sampling point, four soil cores were obtained from the upper part of each subplot at a depth of 20 cm using a hand shovel and soil sampled from each subplot mixed to form a homogenous composite sample. A total of 72 soil samples were collected from the 72 subplots that constituted the whole experimental layout. The soils were air-dried, ground, passed through a 2-mm sieve prior to analysis. Soil pH was determined using a pH meter in a prepared soil-water suspension ratio of 1:2.5. The percentage nitrogen was determined following the Kjeldahl method (Hanon K9840 Kjeldahl apparatus) as described by Vauclare et al. (2013) while soil organic carbon was determined by Walkley-Black combustion method (Ashworth et al., 2014). The available soil potassium and phosphorus were determined according to Mehlich-3 (M-3) procedures (Furseth et al., 2012).

2.4. Inoculant and soybean source
Field trapping of native bradyrhizobia was carried out during the long rain, between March and June 2015 in both organic and conventional farms using soybean as the host plants. Forty-five (45) days after crop emergence, four healthy soybean plants were randomly selected and harvested from each of the treatment, native bradyrhizobia isolated from the root nodules, authenticated and effectiveness determined. The most effective native bradyrhizobia was used to prepare inoculum as per the standard procedure (Somasegaran & Hohen, 1985) and used as inoculant during subsequent field experiments. Commercial *Bradyrhizobium japonicum* (USDA 110) inoculant was obtained from MEA Company Nakuru-Kenya, sold under license from the Microbiological Resources Centre (MIRCEN), University of Nairobi. Soybean seeds were sourced from the Kenya
Agricultural Research Institute (KARI) Njoro, Nakuru. Soybean SB 19 is a promiscuous variety hence it nodulates freely with a wide range of bradyrhizobia strains. Besides, it is tolerant to soybean rust and has high biomass and grain yield. SC Squire is a promiscuous soybean variety that nodulates with diverse bradyrhizobia species and produces large seeds with high oil content. Gazelle is a high yielding non-promiscuous soybean variety that is suitable for low-medium productive areas. Soybean matures within 4 to 5 months.

### 2.5 Planting and field management

Primary land preparation was done by ploughing using a hand hoe to a depth of 15 cm and harrowed to a fine tilth. The plots and subplots for the experiment were then demarcated and labeled. Each subplot (experimental unit) measured 3 m × 4 m. Before sowing, soybean seeds with homogenous appearance were coated by mixing them with bradyrhizobia inoculants to supply (10<sup>9</sup> cells/g seed), as per the procedure stipulated by products manufacturer. Gum Arabic was used as an adhesive. Uninoculated seeds were planted before inoculated ones to avoid contamination during planting. During planting, two soybean seeds were sown per hole at 75 cm inter-row and 10 cm intra-row, with 1 m spacing between the subplots. Each subplot had six rows of soybean lines along the 3 m length. Weeds were controlled using hand hoeing over the plant growth period.

### 2.6 Sampling in the field

Four (4) plants per subplot were sampled randomly during the early flowering stage (45 days after emergency) from the central rows of each subplot. A hand shovel was used to carefully uproot the plants without damaging the nodules and root system. The plant nodules, shoots and roots were separated and placed in separate khaki bags and transported to the laboratory for analyses. Nodules obtained were enumerated and nodule number recorded per plant. Thereafter, the nodules, shoots and roots were oven-dried at 70°C to a constant dry weight which was obtained between 48 and 60 hours. The nodule, root and shoot dry weighed obtained were recorded in g plant<sup>−1</sup>. Shoots were preserved in sealed khaki bags for nutrient content analyses. The sub-samples obtained from roots of each subplot were also used to determine AMF root colonization. Final harvesting was done after reaching physiological maturity which was about 145 days after planting. At this stage, four plants were randomly selected from the four central rows excluding border rows in each subplot. The selected plants were manually harvested, pods detached and threshed. The recovered seeds were dried to a constant dry weight and seed weight recorded in g plant<sup>−1</sup>.

### 2.7 Analyses of plant nutrient content

The plant samples (shoot and seed) were oven-dried at 40°C for 48 hours, ground and digested in triple acid of perchloric acid, sulphuric acid and nitric acid (2:1:1). The Kjeldahl method was applied to determine the concentration of nitrogen (N) as described by Vauclaire et al. (2013). The total shoot P and K were determined by injecting samples into an inductively coupled plasma mass spectrometer as described by Furseth et al. (2012). Organic carbon was determined by Walkley-Black combustion method as described by Ashworth et al. (2014).

### 2.8 Mycorrhizal root colonization

To determine AMF root colonization, root samples obtained from randomly selected plants per subplot were cleaned with tap water and cleared with 10% KOH in the water bath at 80°C for 15 min. The roots were then neutralized in 2% aqueous HCl, and stained with 0.05% trypan blue in lactic acid. AMF root colonization was assessed under a dissecting microscope at × 40 magnifications by the gridline intersect method (Giovannetti & Mosse, 1980).

### 2.9 Data analyses

Data from field experiment on nodulation, shoot dry weight, root dry weight, seed dry weight and AMF root colonization were statistically subjected to analysis of variance (ANOVA) using GLM (General Linear Model) procedure in SPSS computer software version 20. Means were separated
by Tukey’s Honest Significance Difference (HSD) at 5% probability level. Pearson’s correlation coefficient was used to determine the relationship between percentage mycorrhizal colonization and soybean nodulation, shoot N, P, K and organic carbon. Principal component analysis (PCA) to display the relationship between inoculation and different farming systems on tested plant growth parameters was done using PAST software version 3. Redundancy analysis (RDA) was also carried out using CANOCO software version 5, in order to study the relationship between soil characteristics and plant growth parameters.

3. Results

3.1. Soil characteristics

Generally, the chemical and physical characteristics of the soil varied significantly between organic and conventional farming systems. However, the variation between the two years (2015 and 2016) was relatively marginal and insignificant (Table 1). All the soils were characteristically acidic with organic farming recording significantly ($p < 0.0001$) higher pH (5.75) than conventional farming (4.52). Unlike conventional farming, the soil from organic farming system had nitrogen concentration above the critical value of 0.25 and significantly ($p = 0.012$) higher than in conventional farming. On the contrary, organic carbon for both conventional and organic farms was below the critical value of 3.0%. However, organic farming system led to significant ($p = 0.003$) variation in organic carbon level. The available soil phosphorus in both farming systems was above the critical value of 15 ppm; with organic farming significantly influencing its availability. Although the level of available soil potassium was higher in organic farming compared to conventional farming, the difference was statistically insignificant (Table 1).

3.2. Effects of *Bradyrhizobium* inoculation on soybean production

The effect of *Bradyrhizobium* inoculation on nodule number (NN) ($F_{15, 47} = 3.54, p = 0.001$), nodule dry weight (NDW) ($F_{15, 47} = 9.81, p = 0.001$), (SDW) ($F_{15, 47} = 12.79, p = 0.001$) and seed dry weight ($F_{15, 56} = 5.62, p = 0.001$) of soybean varieties differed significantly (Table 2). Soybean varieties inoculated with commercial *Bradyrhizobium* (CB) had the highest NN and NDW followed by the mixture of CB and native bradyrhizobia (NCB) while uninoculated control had the lowest values. Soybean varieties inoculated with CB and NCB had higher SDW and seed dry weight compared to the uninoculated control. Inoculation of soybeans with *Bradyrhizobium* resulted to significant ($F_{15, 56} = 53.00, p = 0.001$) increase in AMF root colonization. Soybeans inoculated with CB recorded the highest AMF root colonization while the uninoculated control had the lowest AMF root colonization.

There was a significant difference among the three soybean varieties on NN ($F_{5, 56} = 9.12, p = 0.001$), NDW ($F_{3, 56} = 11.03, p = 0.002$), SDW ($F_{11, 56} = 13.88, p = 0.001$) and seed dry weight ($F_{1, 56} = 5.34, p = 0.001$) (Table 2). Soybean varieties SB 19 and SC Squire recorded a higher NN, NDW and SDW than Gazelle variety. Similarly, AMF root colonization differed significantly ($F_{5, 56} = 9.12, p = 0.001$) among the soybean varieties with SC Squire (58.95%) and SB 19 (57.75%) scoring higher AMF root colonization than Gazelle (55.28%). Farm management practices significantly affected NN ($F_{6, 65} = 7.83, p = 0.001$), NDW ($F_{10, 65} = 3.69, p = 0.001$), SDW ($F_{6, 56} = 3.69, p = 0.001$) and seed dry weight ($F_{10, 65} = 7.27 p = 0.001$) (Table 2). Soybean grown in organic farms recorded higher NN, NDW, SDW, and seed dry weight when compared to the conventionally produced soybean. AMF root colonization of soybean roots planted in different farm management practices was significantly affected with soybean planted in organic farms having a higher AMF root colonization compared to those grown in the conventional farms.

There was no significant difference in NN ($F_{10, 65} = 10.51, p = 0.294$), SDW ($F_{21, 65} = 41.49 p = 0.051$), AMF root colonization ($F_{10, 65} = 7.83, p = 0.059$) and seed dry weight ($F_{10, 65} = 86.26, p = 0.211$) of soybeans planted in 2015 and 2016. However, a significant variation between the two years was observed on NDW ($F_{10, 56} = 3.69, p = 0.013$) with soybean grown in 2015 having a higher NDW than those of 2016 (Table 2). Notably, there was significant interactive effect between *Bradyrhizobium* inoculation x farm management practices on NDW ($F_{6, 143} = 17.22, p = 0.001$),
Table 1. Farm soil characteristics in conventional and organic farms during the two years

| Year | pH   | N (%) | K (cmol/kg) | P (ppm) | OC (%) |
|------|------|-------|-------------|---------|--------|
| 2015 | 5.13±0.159a | 0.24±0.007a | 0.97±0.008a | 26.62±0.321b | 2.68±0.059a |
| 2016 | 5.14±0.172a | 0.25±0.005a | 0.98±0.022a | 27.39±0.342a | 2.69±0.072a |

**Farm Management**

| Farm  | pH   | N (%) | K (cmol/kg) | P (ppm) | OC (%) |
|-------|------|-------|-------------|---------|--------|
| Organic | 5.75±0.082a | 0.26±0.005a | 0.99±0.016a | 28.13±0.238a | 2.85±0.052a |
| Conventional | 4.52±0.063b | 0.22±0.004b | 0.96±0.016a | 25.87±0.176b | 2.52±0.051b |

**P Values**

| Year | pH   | N (%) | K (cmol/kg) | P (ppm) | OC (%) |
|------|------|-------|-------------|---------|--------|
| Year | 0.140 | 0.972 | 0.923 | <0.001 | 0.178 |
| Farm management | <0.001 | 0.012 | 0.996 | 0.001 | 0.003 |
| Farm | 0.001 | 0.001 | 0.678 | 0.012 | 0.001 |

**Key:** Means followed by a different letter(s) within the same column differ significantly at p < 0.05 using Tukey’s HSD test. OC, organic Carbon; N, Nitrogen; K, Potassium; P, Phosphorus; ppm: parts per million; GO, HO and JO are organic farms, while GC, HC and JC are conventional farms.

**SDW (F<sub>3, 143</sub> = 27.32, p = 0.001), seed dry weight (F<sub>3, 143</sub> = 11.57, p = 0.007) and AMF root colonization (F<sub>3, 143</sub> = 13.23, p = 0.002).** Similarly, there was a significant interactive effect between soybean varieties x farm management on NDW (F<sub>2, 143</sub> = 6.90, p = 0.001) and SDW (p = 0.011). Remarkably, there was significant three-way interactions between farm management x variety x inoculation (Table 2). For instance, promiscuous soybeans SC Squire and SB 19 had the highest % AMF root colonization in organic farms due to inoculation with CB. The two promiscuous soybean varieties (SC Squire and SB 19) recorded the highest shoot and seed dry weight due to inoculation with CB in organic farms (Figure 1).

The inoculation of soybeans with bradyrhizobia varied depending on farm management system and inoculation regime. The results revealed that soybean nodule dry weight had significant positive correlation coefficient with shoot dry weight (R<sup>2</sup> (143) = 0.869, P < 0.05) and seed dry weight (R<sup>2</sup> (143) = 0.888, P < 0.05). The nodule number also showed positive correlation coefficient (R<sup>2</sup> (143) = 0.938, P < 0.05) with nodule dry weight. Similarly, shoot dry weight and nodule dry weight showed strong positive correlation with % AMF root colonization. In addition, root dry weight strongly correlated positively with % AMF root colonization (Table 3). The inoculation of soybeans with different bradyrhizobia had varied impacts on growth parameters. The AMF root colonization was higher in soybean plants with highest nodule dry weight and shoot dry weight due to their strong positive correlations (Table 3).

**3.3. Soybean shoots nutrients**

The bradyrhizobia inoculants had significant effect on shoots P (F<sub>35, 171</sub> = 51.86, p = 0.001), total N (F<sub>35, 171</sub> = 53.11, p = 0.001), K (F<sub>35, 171</sub> = 21.15, p = 0.001) and OC (F<sub>16, 171</sub> = 14.64, p = 0.001) (Table 4). Organic carbon (OC), N, K and P accumulation was highest in soybeans treated with CB followed by NCB and isolate NB, while the control had the lowest amounts. Commercial
Table 2. Effect of bradyrhizobia inoculation, soybean varieties, farm management and their interaction on NN, NDW, SDW, seed dry weight and AMF root colonization

|                        | Nodule Number (NN) | Nodule Dry weight (NDW). (g plant⁻¹) | Shoot Dry Weight (SDW). (g plant⁻¹) | Seed dry weight (g plant⁻¹) | AMF root colonization. (% plant⁻¹) |
|------------------------|-------------------|--------------------------------------|--------------------------------------|-----------------------------|----------------------------------|
| **Year**               |                   |                                      |                                      |                             |                                  |
| 2015                   | 4.58±0.58a        | 0.08±0.01a                           | 2.99±0.010a                         | 4.45±0.16a                  | 57.79±1.31a                      |
| 2016                   | 4.24±0.57a        | 0.06±0.01b                           | 2.87±0.113a                         | 4.37±0.16a                  | 56.79±1.36a                      |
| **Farm Management**    |                   |                                      |                                      |                             |                                  |
| Organic                | 5.71±0.68a        | 0.09±0.01a                           | 3.20±0.05a                          | 4.86±0.16a                  | 62.43±1.31a                      |
| Conventional           | 3.11±0.39b        | 0.05±0.01b                           | 2.67±0.04b                          | 3.95±0.14b                  | 52.16±1.04b                      |
| **Varieties**          |                   |                                      |                                      |                             |                                  |
| Gazelle                | 3.23±0.50b        | 0.06±0.02b                           | 2.68±0.10c                          | 4.07±0.17c                  | 55.28±1.50b                      |
| SB                     | 4.66±0.78a        | 0.07±0.01ab                          | 2.89±0.02b                          | 4.39±0.20b                  | 57.75±1.58a                      |
| SC                     | 5.33±0.75a        | 0.08±0.01a                           | 3.23±0.16a                          | 4.76±0.21a                  | 58.85±1.97a                      |
| **Inoculation**        |                   |                                      |                                      |                             |                                  |
| CB                     | 10.92±0.78a       | 0.17±0.01a                           | 3.99±0.14a                          | 6.18±0.16a                  | 68.97±1.30a                      |
| NB                     | 1.83±0.17c        | 0.02±0.02c                           | 2.49±0.43c                          | 2.91±0.08c                  | 55.73±0.92c                      |
| NCB                    | 4.6±0.64a         | 0.09±0.01b                           | 3.19±0.03b                          | 4.60±0.12b                  | 61.12±1.04b                      |
| Control                | 0.25±0.07d        | 0.01±0.01d                           | 2.07±0.04d                          | 2.91±0.09d                  | 43.36±0.90d                      |
| **P Values**           |                   |                                      |                                      |                             |                                  |
| Year                   | 0.294             | 0.013                                | 0.051                               | 0.211                       | 0.059                           |
| Farm management        | 0.001             | 0.001                                | 0.001                               | 0.001                       | 0.001                           |
| Variety                | 0.001             | 0.002                                | 0.001                               | 0.001                       | 0.001                           |
| Inoculation            | 0.001             | 0.001                                | 0.001                               | 0.001                       | 0.001                           |
| Farm management*       | 0.001             | 0.001                                | 0.001                               | 0.007                       | 0.002                           |
| Inoculation            | 0.210             | 0.001                                | 0.011                               | 0.847                       | 0.284                           |
| Farm management*       | 0.234             | 0.933                                | 0.001                               | 0.001                       | 0.956                           |

**KEY** Means followed by a different letter(s) within the same column differ significantly at p < 0.05 using Tukey’s HSD test. CB, Commercial Bradyrhizobium; NB, Native bradyrhizobia; NCB, Native and commercial Bradyrhizobium.

Bradyrhizobium significantly fixed more nitrogen compared to NB, NCB and the uninoculated control.

There was a significant interactive effect between shoots nutrition of soybean varieties and Bradyrhizobium inoculation on P (F = 16.03, p = 0.015), total N (F = 11.44, p = 0.001), K (F = 3.16, p = 0.001) OC (F = 8.31, p = 0.012). In this regard, promiscuous soybeans SC Squire and SB 19 inoculated with CB in organic farms had the highest shoot P content, shoot % N, and shoot OC (Figure 2). The accumulated shoot nutrients differed significantly, N (F = 12.45, p = 0.001), P (F = 13.42, p = 0.001), K (F = 74.83, p = 0.001), and OC (F = 38.72, p = 0.001), for all the three soybean varieties. Promiscuous soybean varieties SC Squire accumulated a higher total N concentration, P, K and OC than SB 19 and the non-promiscuous Gazelle variety (Table 4). Soybean shoot nutrition varied significantly, (P = 50.31, p = 0.001), % N (F = 73.83, p = 0.001), K (F = 47.17, p = 0.001) and OC (F = 39.02, p = 0.001) across the different farm management practices. The shoot nutrient accumulation was generally higher in organic farm management systems than conventional farms (Table 4). Yearly variation in shoot nutrition was insignificant for P (F = 0.41, p = 0.058) and OC (F = 0.16, p = 0.203) content.
However, a significant (F \(_{3, 143} = 57.66, p = 0.001\)) N variation was observed where soybean shoots grown in 2015 recorded a higher concentration than in 2016.

### 3.4. Soybean seed nutrients

Inoculation with bradyrhizobia significantly enhanced soybean seed P (F \(_{41, 143} = 51.86, p = 0.001\)), % N (F \(_{41, 143} = 89.02, p = 0.001\)), K (F \(_{41, 143} = 85.74, p = 0.001\)) and OC (F \(_{41, 143} = 41.97, p = 0.001\)) nutrient contents, whereby seeds from bradyrhizobia inoculated soybeans had the highest nutrition contents compared to the uninoculated control (Table 5). Commercial inoculant CB produced soybean seeds with the highest nutrition values followed by isolate NCB while the uninoculated control had the lowest values in all the tested nutrition parameters. Farm management practices significantly affected seed nutrition quality, N (F \(_{3, 143} = 11.51, p = 0.001\)), P (F \(_{6, 143} = 13.13, p = 0.001\)), K (F \(_{3, 143} = 6.82, p = 0.001\)) and OC (F \(_{2, 143} = 57.66, p = 0.001\)). Seeds from organic farms had the highest amount of P (4522.68 ppm), N (5.49%), K (14,603.47 ppm) and OC (26.05%) while conventional farms had the lowest values of P (4371.64 ppm), N (5.35%), K (14,336.54 ppm) and OC (25.36%).

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**Figure 1.** Field interactive effects of bradyrhizobia inoculation on soybean varieties planted in both conventional and organic farming systems. Bars followed different letters are significantly different using Tukey’s test (P ≤ 0.05). CB, Commercial Bradyrhizobium japonicum; NB, Native bradyrhizobia; NCB, Native and Commercial Bradyrhizobium japonicum; AMF, Arbuscular mycorrhizal fungi; A, Effect of inoculation on shoot dry weight in conventional farms; B, Effect of inoculation on shoot dry weight in organic farms; C, Effect of inoculation on seed dry weight in conventional farms; D, Effect of inoculation on seed dry weight in organic farms; E, Effect of inoculation on % AMF root colonization in conventional farms; F, Effect of inoculation on % AMF root colonization in organic farms.
Table 4. Effects of bradyrhizobia inoculation, soybean varieties, farm management system and farming years on shoots phosphorus, nitrogen, potassium and organic carbon

| Year  | P (ppm)   | N (%)     | K (ppm)   | OC (%)   |
|-------|-----------|-----------|-----------|----------|
| 2015  | 3592.00±64.75a | 2.90±0.06a | 15430.71±109.05a | 24.84±0.25a |
| 2016  | 3562.51±43.81a | 2.79±0.05b | 15325.97±60.79b | 24.56±0.23a |
| Farm Management | | | | |
| Organic | 3720.63±85.87a | 3.02±0.083a | 15655.11±96a | 25.21±0.25a |
| Conventional | 3434.04±49.32b | 2.68±0.053b | 15101.57±69b | 24.19±0.21b |
| Varieties | | | | |
| Gazelle | 3464.31±61.41c | 2.71±0.058c | 15106.94±143.15c | 24.31±0.25c |
| SC | 3686.96±69.76a | 2.96±0.075a | 15595.46±93.16a | 25.08±0.31a |
| SB19 | 3580.50±68.54b | 2.87±0.062b | 15432.63±141.81b | 24.79±0.31b |
| Inoculation | | | | |
| CB | 4109.78±67.36a | 3.37±0.06a | 17344.31±178.31a | 27.09±0.24a |
| NB | 3485.00±56.56c | 2.77±0.06b | 15139.25±151.07c | 24.16±0.21c |
| NCB | 3618.33±39.06b | 2.85±0.04b | 15509.11±141.81b | 25.19±0.13b |
| Control | 3095.92±23.64d | 2.41±0.04c | 13520.69±100.12d | 22.34±0.12d |
| P Values | | | | |
| Year | 0.058 | 0.001 | 0.021 | 0.203 |
| Farm management | 0.001 | 0.001 | 0.001 | 0.001 |
| Variety | 0.001 | 0.001 | 0.001 | 0.001 |
| Inoculation | 0.001 | 0.001 | 0.001 | 0.001 |
| Farm M*Inoculation | 0.012 | 0.001 | 0.001 | 0.001 |
| Farm M*Variety | 0.063 | 0.269 | 0.145 | 0.235 |
| Variety*Inoculation | 0.015 | 0.001 | 0.001 | 0.012 |
| Farm M*Variety*Inoculation | 0.001 | 0.001 | 0.001 | 0.001 |

KEY: Means followed by a different letter(s) within the same column differ significantly at p < 0.05 using Tukey’s HSD test. N, Nitrogen; OC, Organic Carbon; K, Potassium; P, Phosphorus; ppm, parts per million; CB, Commercial Bradyrhizobium; NB, Native bradyrhizobia; NCB, native and commercial Bradyrhizobium; Farm M; farm management.
| Farm Management          | Year | P (ppm)          | N (%)             | K (ppm)          | OC (%)             |
|--------------------------|------|------------------|------------------|------------------|-------------------|
| Organic                  | 2015 | 4457.56±84.32a   | 5.44±0.03a       | 14508.03±100.50a | 25.85±0.22a       |
|                          | 2016 | 4436.76±46.17a   | 5.39±0.03b       | 14490.99±105.85a | 25.55±0.24a       |
| Conventional             | 2015 | 4522.68±72.15a   | 5.49±0.03a       | 14603.47±98.55a  | 26.05±0.22a       |
|                          | 2016 | 4371.64±62.28b   | 5.35±0.02b       | 14336.54±105.54b | 25.36±0.24b       |
| Varieties                | Gazelle | 4383.48±87.42b  | 5.35±0.04c       | 14391.38±108.16b | 25.42±0.25b       |
|                          | SC    | 4530.80±48.67a   | 5.47±0.04a       | 14569.46±145.34a | 26.05±0.29a       |
|                          | SB19  | 4427.25±80.66b   | 5.43±0.04b       | 1449.19±123.34b  | 25.66±0.26b       |
| Inoculation              | CB    | 5180.92±67.42a   | 5.81±0.02a       | 15712.94±89.36a  | 28.53±0.19a       |
|                          | NB    | 4306.11±27.86c   | 5.25±0.01c       | 14208.42±39.78c  | 25.01±0.12c       |
|                          | NCB   | 4494.28±26.03b   | 5.42±0.03b       | 14413.25±32.47b  | 25.63±0.11b       |
|                          | Control | 3806.33±61.01d  | 5.19±0.02d       | 13545.42±73.51d  | 23.66±0.12d       |

| P Values                  | Year  | 0.394 | 0.001 | 0.101 | 0.134 |
|---------------------------|-------|-------|-------|-------|-------|
| Farm management           | 0.001 | 0.001 | 0.001 | 0.001 |
| Variety                   | 0.001 | 0.001 | 0.001 | 0.001 |
| Inoculation               | 0.001 | 0.001 | 0.001 | 0.001 |
| Farm M*Inoculation        | 0.003 | 0.001 | 0.001 | 0.002 |
| Farm M*Variety            | 0.148 | 0.039 | 0.145 | 0.235 |
| Variety*Inoculation       | 0.011 | 0.081 | 0.173 | 0.012 |
| Farm M*Variety*Inoculation| 0.001 | 0.001 | 0.001 | 0.100 |

**KEY** Means followed by a different letter(s) within the same column differ significantly at p < 0.05 using Tukey’s HSD test. N, Nitrogen; OC, Organic Carbon; K, Potassium; P, Phosphorus; ppm, parts per million; CB, Commercial Bradyrhizobium; NB, Native bradyrhizobia; NCB, native and commercial Bradyrhizobium. Farm M, farm management.

There were significant interactive effects recorded between farm management, soybean variety and inoculation on seed nutrition; % N (F 6, 143 = 3.16, p = 0.001), P (F 5, 143 = 9.17, p = 0.001) and OC (F 6, 143 = 11.44, p = 0.001). In this regard, promiscuous soybeans SC Squire and SB 19 inoculated with isolate CB in organic farms had the highest seed P content and seed %N (Figure 3). The seed nutrition quality in the three soybean varieties significantly varied in all the parameters tested (Table 5). For instance, seeds from promiscuous SC Squire soybean variety had the highest amount of P, N, K and OC compared to seeds from promiscuous SB 19 and non-promiscuous Gazelle soybean varieties (Table 5). There was no significant difference in P (F 3, 143 = 1.51, p = 0.394), K (F 1, 143 = 0.43, p = 0.101), and OC (F 2, 143 = 0.70, p = 0.134) seed nutrient contents between 2015 and 2016. On the contrary, N concentration differed significantly between the two years with soybean seeds harvested in 2015 recording higher % N (5.44) concentration than in 2016 (5.39%).

The study showed that soybean % N had significant positive correlation coefficient with SDW (R = 0.879, P < 0.05), AMF root colonization (R = 0.0647, P < 0.05) and NN (R = 0.756, P < 0.05). In addition, SDW correlated positively with soybean shoot % N. The amount of K in soybean shoots had strong positive correlation with SDW and shoot % OC (Table 6). The shoots available P also had strong positive correlation coefficient with % AMF root colonization, NN, NDW and shoot % OC. The
increase in SDW also indicated positive significant increase in soybean shoots available P. Similarly, SDW, NN and NDW showed strong positive correlation with shoot % OC. The AMF root colonization was higher in soybean plants with highest NDW and SDW due to their strong positive correlations (Table 6).

Based on the redundancy analysis (RDA) of soil properties and plant growth parameters, a positive effect of soil characteristics on all the measured plant growth parameters was revealed (Figure 4). In general, the soil chemical parameters P, K, N % and pH positively influenced soybean percentage arbuscular mycorrhizal fungi root colonization (% AMF), nodule number (NN), nodule dry weight (NDW), shoot dry weight (SDW), root dry weights (RDW) and seed dry weight (SEDW). Specifically, soil P had strong positive influence on root and shoot dry weight while soil K had the greatest influence on nodule dry weight. Additionally, soil pH and % N had greater influence on soybean % AMF root colonization, nodule number and seed dry weight than P and K.
4. Discussion

The conservation of soil fertility in agricultural farms is important for sustainable crop production systems and the levels of soil nutrient content can be maintained at an optimum level over time if good farm management practices are adhered to by farmers. The soil from the organic farming system significantly varied with those from conventional farming; that showed a relatively higher deviation from the critical values described by Okalebo et al. (Okalebo et al., 2005) for crop production in the tropical areas. Therefore, its advisable for farmers to select farm management practices that improves soil properties for enhanced fertility and crop production. The high acidity of the soils from the conventional farms could be attributed to the excessive use of chemical fertilizers, insecticides and herbicides (Clark & Tilman, 2017; Fess et al., 2018). Soybean crops require neutral to slightly acidic soil pH for growth and especially when they rely on nitrogen from biological nitrogen fixation (Li et al., 2016). The slightly high soil pH in the organic farms may be due to application of organic fertilizers that neutralize the low soil acidity and maintain beneficial soil microorganisms that promote soil nutrient recycling. According to Mairura et al. (2008), soil pH below 5.5 does not favor soybean production due to suppression of nodulation and symbiotic nitrogen fixation and as well limits the availability of other essential and trace elements.

The organic farm soil had recommended N levels while in conventional farms it was below the critical value of 0.25 (Okalebo et al., 2005), which could be attributed to increased leaching and acidity that limits symbiotic nitrogen fixation and crop growth (Oberson et al., 2013). Soil bradyrhizobia are specifically sensitive to variations in soil pH levels which affect the symbiotic N-fixing process. The quantity of N fixed during biological nitrogen fixation (BNF) process can be reduced by up to 30% in a very low pH of 4 (Solomon et al., 2012). Hunt et al. (2019) reported similar results where conventional farming had low % N, which was contributed by loss of exchangeable bases such as K, Mg, and Ca through leaching following the use of inorganic chemicals.

Both organic and conventional soil had phosphorus levels within the required standard range (15–31 ppm) (Clement et al., 2015). Phosphorus is an essential element necessary for legume production and its usually incorporated into the soil as organic and/or inorganic fertilizers. In most cases, Kenyan agricultural soils are deficient in phosphorus, therefore, limiting nitrogen fixation and farmers are left with no other choice but the use of fertilizers to supplement the soil P making crop production a costly enterprise to smallholder farmers (Kaizzi et al., 2012).

Soil organic carbon is a key component that revitalizes native microbial functioning and consequently enhances the provision of important agroecosystem services such as biological nitrogen fixation, nutrient recycling, increase P and N availability. The percentage of soil organic carbon in
both conventional and organic farms was below the critical value of 3.00% (Okalebo et al., 2005). This signifies the need for agronomic management practices and interventions that would lead to more carbon sequestration, and such practices that create soil carbon imbalance like farm intensification should be avoided.

The field results showed that inoculation of soybeans with bradyrhizobia significantly enhanced nodule formation, shoot dry weight and seed yield with commercial *Bradyrhizobium* consistently showing superior performance compared to the native bradyrhizobia, the mixture of both native and commercial *Bradyrhizobium* and uninoculated control. The effective performance demonstrated by the commercial *Bradyrhizobium* could be due to their ability to successfully infect the promiscuous and non-promiscuous soybean varieties, cause nodulation and biological nitrogen fixation (Sivparsad et al., 2016). The pink color, typical of healthy and effective nodules, is due to the presence of leghemoglobin which binds oxygen and creates a low oxygen environment within the nodule which allows rhizobia to thrive and fix nitrogen. The low performance of the native bradyrhizobia may be attributed to their low level of symbiotic effectiveness, compatibility with the soybean varieties and the presence of microbial contaminants (Koskey et al., 2017; Thilakarathna & Raizada, 2017).

The inoculation of soybeans with commercial *Bradyrhizobium japonicum* had the highest AMF root colonization percentage which is an indication of effective tripartite symbiosis (Oruru & Njeru, 2016). Moreover, *Bradyrhizobium japonicum* USDA 110 outperformed the other inoculant strains by achieving the best performance in the parameters tested and in all the soybean cultivars, which support existing documentation that *Bradyrhizobium japonicum* USDA 110 is symbiotically effective with a wide range of soybean varieties (Agoyi et al., 2016; Khojely et al., 2018). According to Antunes et al. (2006), the activity of one microbial symbiont in a tripartite symbiosis affects the presence and activity of the other within the interaction pyramid which may be the case in this study.

Promiscuous soybeans demonstrated better growth and symbiotic performance in all the parameters tested in this study compared to that of non-promiscuous soybeans. For instance, both SC Squire and SB 19, which are promiscuous soybean varieties, had the highest nodule number, nodule dry weight, shoot dry weight and seed dry weight compared to Gazelle, which is a non-promiscuous variety. The promiscuous soybeans form an association with diverse soil bradyrhizobia, which is not the case for the host-specific non-promiscuous Gazelle variety. Similarly, soybean parameters from different farm management system differed significantly. The organic farms had

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**Table 6. Pearson’s correlation (R2) coefficients between soybean growth parameters on shoot phosphorus (P), nitrogen (N), potassium (K) and organic carbon (OC), arbuscular mycorrhizal fungi (AMF) root colonization, nodule number (NN), nodule dry weight (NDW) and shoot dry weight (SDW)**

|          | N (%) | K(ppm) | P(ppm) | OC (%) | AMF | NN  | NDW | SDW |
|----------|-------|--------|--------|--------|-----|-----|-----|-----|
| % N      |       |        |        |        |     |     |     |     |
| K        | 0.136 | 1      |        |        |     |     |     |     |
| P        | 0.623** | -0.125 | 1      |        |     |     |     |     |
| OC       | 0.946** | 0.915** | 0.586** | 1      |     |     |     |     |
| AMF      | 0.647** | 0.195** | 0.756** | 0.801** | 1  |     |     |     |
| NN       | 0.756** | 0.433*  | 0.568** | 0.724** | 0.266* | 1  |     |     |
| NDW      | 0.499** | 0.479** | 0.892** | 0.592** | 0.528* | 0.965** | 1  |     |
| SDW      | 0.879** | 0.956** | 0.479** | 0.963** | 0.758** | 0.682** | 0.582** | 1  |

*Correlation is significant at the 0.01 level (2-tailed)
**Correlation is significant at the 0.05 level (2-tailed)
better performance compared with the conventional farms, which appears to result from the favorable soil conditions for biological nitrogen fixation (Pandey et al., 2017; Schneider et al., 2017). Conventional farms were highly acidic and this hinders the establishment of effective nodulation (Kawaka et al., 2014; Koskey et al., 2017). Wyngaard et al. (2016) indicated that continuous soil disturbance and use of inorganic fertilizers promote leaching and mineralization of important ions such as phosphorus and potassium, which are vital for plant growth. The organic farms had the highest AMF root colonization which is explained by the moderate soil pH and nitrogen concentration that support the colonization of soybeans by indigenous AMF (Cavagnaro et al., 2015). However, this study contrasts with the works of Antunes et al. (2006) which support the hypothesis that the benefits of bacterial symbions do not affect the infectivity of indigenous AMF in their environment.

Nitrification and mineralization are enhanced by soil microorganisms, which is the likely cause of significant variations on shoots P and % N observed in this study. Legume nodulation and biological nitrogen fixation requires energy. Phosphorus accumulation in plants positively influences nodule development through its basic functions as an energy source. Adequate P promotes root growth, activates nodules, increases their number and size which directly enhance N fixation. The CB proved to have superior nitrogen fixation potential and led to enhanced shoot P and OC accumulation. Effective bradyrhizobia converts atmospheric nitrogen into other forms that can be easily absorbed by the symbiotic plants, which explains the variations among the inoculants (Gouda et al., 2018; Vejan et al., 2016). According to Muleta et al. (2017), inoculated soybeans had higher shoot % N and P compared to uninoculated control soybean plants which is supported by the current study. Commercial *Bradyrhizobium* inoculation significantly enhanced AMF root colonization and this can be associated to enhanced solubilization of phosphorus in the soil for plants uptake (Tamayo-Velez & Osorio, 2016; Wahid et al., 2016). In the work of Priyadharsini et al. (Priyadharsini & Muthukumar, 2016), effective nodulation and AMF root colonization promote the uptake of N and P from the soil by host plants depicting the importance of synergism.

Diversification of soybean varieties is advisable for sustainable agriculture. Even though the SB 19 soybean variety had relatively lower performance compared to SC Squire, agronomically the SB 19 variety has the potential to enhance the uptake of nitrogen from symbiotic association (Omondi et al., 2015) in low acidic soils of Kenya. On the other hand, the non-promiscuous Gazelle variety consistently scored lowly in all the parameters tested for shoot nutrients. According to Khojely
et al. (2018), promiscuous soybeans are the solution to low production for this crop in tropics for their compatibility with diverse bradyrhizobia population.

The shoots for soybeans planted in organic farms had a significantly higher amount of P and shoot % N compared to plants from the conventional farms. Organic farms maintain good soil properties in terms of pH and other physicochemical properties that support the effectiveness of symbiotic microorganisms. Seufert et al. (2019) further stress the importance of biofertilization in organic farming for sustainable crop production. According to Bhardwaj et al. (2014), organic farming is environmentally friendly and harbors diverse microbes useful for plant growth. The shoots of soybean plants from organic farms had a significantly higher amount of OC compared to shoots of plants from conventional farms. The significant interactive effects between the farm management system and inoculation show that the two farming systems responded differently to bradyrhizobia inoculation. Conventional farm management practice did not favor inoculation possibly due to harsh soil properties such as increased acidity and low phosphorus level.

Notably, the current study demonstrated a significant interactive effect between bradyrhizobia inoculation and soybean varieties on seeds % N. This interaction depicts an association where some variety responded to inoculation better than others. For instance, SC Squire soybean variety consistently responded well to bradyrhizobia inoculation in almost all the parameters tested compared to the other two soybean varieties SB 19 and Gazelle. Increased biological N fixation enhances plant growth, which may be the reason why plants inoculated with CB had seeds with higher amount of OC compared to uninoculated control (Sinclair & Nogueira, 2018). Interaction between bradyrhizobia and soybean varieties in enhancing nitrogen uptake helps the plants to withstand low soil fertility and amelioration of other plant minerals. In this study, a high concentration of seed P and N was recorded in soybeans inoculated with CB in all the farm management systems. This has demonstrated the effectiveness and consistency of commercial inoculant in biological N fixation. As in the study by Vance (2001), P is a crucial nutrient that determines the efficiency of biological N fixation process, and hence, soils deficient of P results to poor nitrogen fixation irrespective of the abundance of bradyrhizobia strains in the soil.

Seeds of soybean plants from organic farms had a significantly higher percentage of N and P compared to the conventional farms. This could be due to various factors such as good soil conditions for effective biological N fixation, climatic conditions and effectiveness of bradyrhizobia (Sinclair & Nogueira, 2018). Soil properties like high acidity in the conventional farms limit the effectiveness of bradyrhizobia and availability of important minerals such as phosphorus. The OC was also lowest for seeds from plants in the conventional farms. According to Altieri et al. (2018), conventional farming is not sustainable in developing countries where the majorities of farmers are smallholders, resource-constrained and depend on entire low input agriculture.

5. Conclusion
Our present results demonstrate the importance of organic farming and bradyrhizobia inoculation in enhancing biological soil fertility, production and yield quality, a key step towards sustainable production of healthy foods and maintenance of environmental quality. Therefore, compared to conventional system, organic farming that involves application of locally available organic manure that is cheaper than inorganic fertilizer is sustainable for majority of smallholder farmers who are resource-constrained and depend on low input agriculture. The results clearly show the potential of organic farm management practices to positively impact on the functional activity of bradyrhizobia species in promoting soybean growth and production. Organic farming enhanced the role of symbiotic microorganisms in soybean production due to increased biological nitrogen fixation, organic carbon; potassium and phosphorus as demonstrated from the soil, shoot and seed analyses. The consistent superior performance of promiscuous soybean varieties SC Squire and SB 19 over non-promiscuous Gazelle indicates that promiscuous soybeans could be more adaptable to the region and inoculation, hence, recommended to the farmers. Moreover, CB strain had effective biological N fixation and should be adopted and its use optimized as an alternative to
chemical fertilizers for agricultural sustainability and reduced cost of crop production. Further studies should focus on screening promiscuous soybean varieties on their compatibility with a diverse array of native bradyrhizobia due to the relatively low performance of NB in this study.

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