INTEGRATED EFFECT OF RHIZOBIUM INOCULATION AND PHOSPHORUS APPLICATION ON SOYBEAN GROWTH AND YIELD

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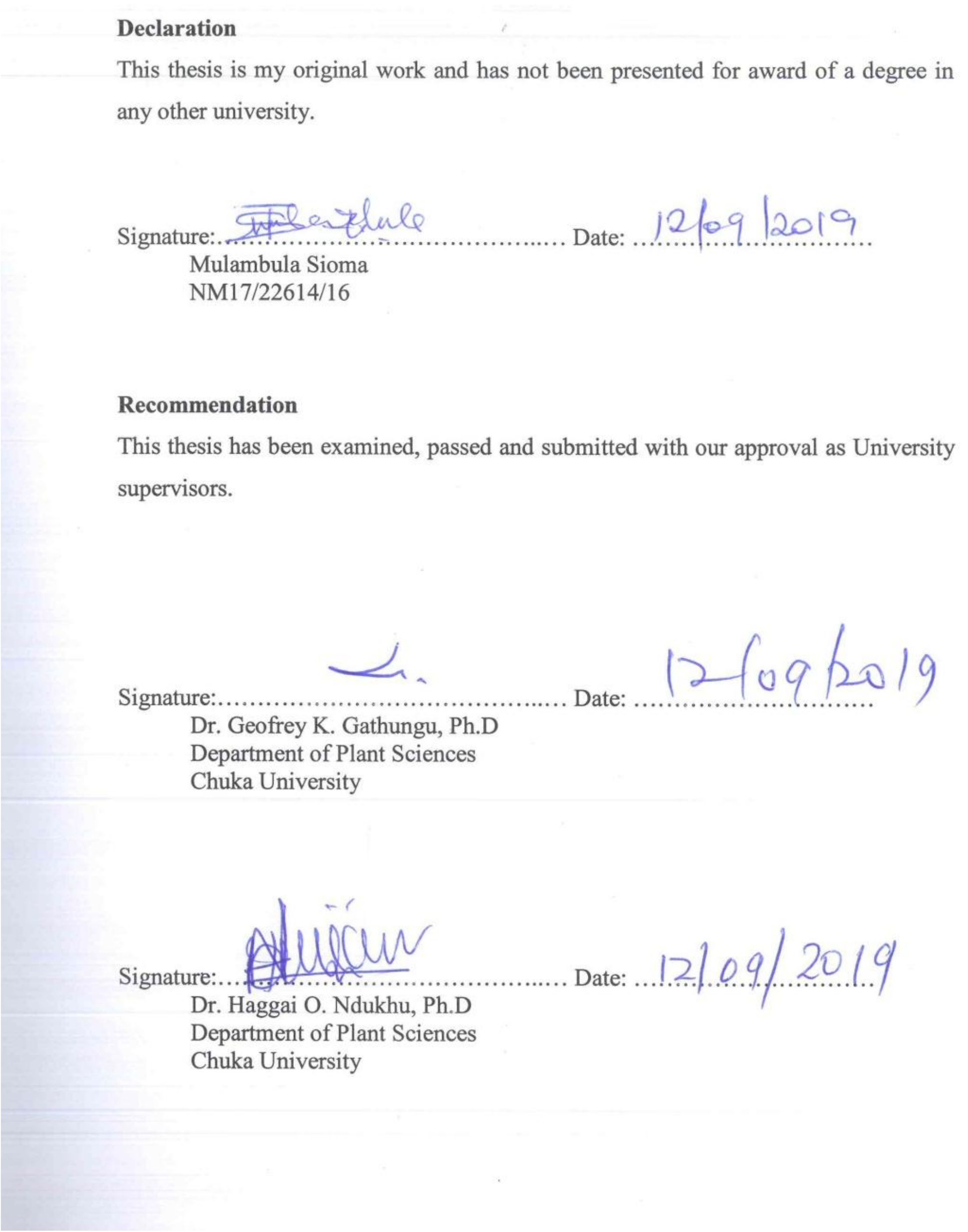
DECLARATION AND RECOMMENDATION



Declaration

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

This Thesis is dedicated to my beloved sons Collins Juma Mulambula, Elikanah Mulamba Mulambula and Abel Kasiwa Apuya.

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ABSTRACT

There has been a decline in soybean production in many parts of Kenya due to limited soil fertility, especially nitrogen and phosphorus contents. A field experiment was conducted at Chuka University Demonstration farm to determine the effect of integration of rhizobium inoculation (R) and phosphorus (P) on growth, nodulation and yields of soybeans in Meru South Sub County, Tharaka Nithi County. The experiment was laid out in a randomized complete block design (RCBD) in a split-split plot arrangement with each treatment replicated three times. The first cultivation (Trial I) was done and repeated in second cultivation (Trial II) in 2018. The aim of the experiment was to assess integration effect of R and P for sustainable soybean production in the study area. Treatments included; three rates of P (0, 20 and 30 Kg ha^{-1}), three rates of rhizobia (0, 100 and 200 g ha^{-1}) either applied alone or integrated and two soybean genotypes (SB19 and SB24). Triple superphosphate (0:46:0) was used as the source of the phosphorus. The soybean genotypes were assigned to the main plot with rhizobia strain in the sub-plot and phosphorus in the sub-subplots which was repeated once. Data was collected on plant height, number of pods, nodules and branches, fresh and dry nodule weight, fresh and dry shoot weight, length of root and seed yield. The data collected was subjected to analysis of variance (ANOVA) using the statistical analysis software (SAS) and significantly different means separated using Tukeys test at ($p \leq 0.05$). The results showed statistically significant difference in growth, nodulation, yield components and yields within SB19 and SB24 genotypes in both Trials at ($p \leq 0.05$). Integration of R and P at the rate of 200 g and 30 Kg ha^{-1} showed highest growth characteristics compared to other treatments applied. For instance, soybean plant height increased by 9.82 cm and 9.81 cm, and 10.99 cm and 11 cm at integration of 200 g and 30 Kg ha^{-1} compared to control for SB19 and SB24, in Trial I and II, respectively. Similarly, at integration of R and P at the rate of 200 g and 30 Kg ha^{-1}, the dry nodule weight increased from the control treatment (0 g R and 0 Kg P per ha) to 0.81 g and 2.54 g, and 0.81 g and 2.59 g per plant for SB19 and SB24 genotypes in Trial I and II, respectively. Integration of R and P at the rate of 200 g and 30 Kg ha^{-1} increased grain yield by 101% and 98%, and 158% and 138%. This earned a net economic benefit of ksh. 239,496 and 192,730, and ksh. 297,930 and 239,330 for SB19 and SB24 in both Trials, respectively. Both soybean genotypes performed well in all evaluated parameters. Adoption of the integration of R and P at 200 g and 30 kg P per ha and use of either of the genotypes by farmers show greater potential of enhancing soybean productivity in Meru South Sub County.

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LIST OF ABBREVIATIONS AND ACRYNOMS

AGRA:	Alliance for a Green Revolution in Africa
ANOVA:	Analysis of variance.
BNF:	Biological Nitrogen Fixation
FOASTAT:	Food and Agriculture Organization Statistics
FAO:	Food and Agriculture Organization of the United Nations
KALRO:	Kenya Agricultural and Livestock Research Organization.
MT:	Metric tonnes.
NACOSTI:	National Commission for Science Technology and Innovation
P:	Phosphorous
R:	Rhizobia
RCBD:	Randomized Complete Block Design
SDW:	Shoot Dry Weight
SSA:	Sub-Saharan Africa
USDA:	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Soybean (*Glycine max*) is produced on about 6% of the world's arable land, representing an estimated total area of more than 92.5 million ha, giving 217.6 million tonnes of production each year (Murithiab *et al.*, 2016). Area under soybean production has had the highest percentage increase compared to any other major crop worldwide (Hartman *et al.,* 2011). Soybean contains about 17-24% oil on dry matter basis and 40% protein (Ali *et al*., 2015). It has superior amino acid profile and its protein has great potential as a major source of dietary protein and plays an important role in solving malnutrition problems. Further, is adaptable to a wide range of ecological conditions (Tran *et al.,* 2015).

The crop has become popular as human food, source of cash income and excellent quality feed for livestock enterprises (Thilakarathna, 2019). The crop can be eaten in many forms which include soy sauce, soy milk, bean sprouts and meat analogs. Global soybean consumption in 2017 was anticipated to grow faster than production as per [United States Department of Agriculture , (2017)]. Although global population is expected to increase by 29% by 2050, the rise will be much greater in sub-Saharan Africa (SSA) than in other regions and this is expected to be accompanied by demand for food (FAO, 2014).

In areas of high population, as in the case of most parts of Africa and particularly Kenya the potential of expansion of agricultural land is limited making sustainable intensification imperative (Cook *et al.*, 2015). Integration of grain legumes, particularly soybean in the cereal-based farming systems in Africa in the context of integrated soil fertility management, thus offers a potential pathway for sustainable intensification (Adjei-Nsiah *et al*., 2019). Soybean plays an important role in agricultural nitrogen cycles by facilitating biological nitrogen into plant-available nitrogen (Nasir *et al.*, 2017).

When soybean is rotated with cereals it has an advantage of reducing the need for synthetic nitrogen fertilizer to the subsequent crop grown in rotation reducing cost of productions (Vanlauwe *et al.,* 2014). Soybean contribution to soil fertility improvements is due to its N fixing abilities by root nodules and in addition to those that remain in the crop residues and returned to the soil after harvest. Soybean can fix atmospheric N in the soil with estimated amounts varying between 44 -300 Kg N per ha (Ntambo *et al.,* 2017; Giller *et al.,* 2013). Cereal crops that are intercropped with or grown after soybean benefit from this N-fixing and improvement of soil properties by soybean (Mwangi *et al.,* 2011).

Furthermore, benefits of inoculated soybean on cultivations of cereals grown in rotation include breaking of pest and disease cycles (Sagolshemcha *et al.,* 2017). Soybean is known to enhance P availability to plants through secretion of enzymes and acids in the legume rhizosphere (Adjei-Nsiah *et al.,* 2019). Soybean is becoming an important cash crop in Kenya, however, the yields have remained low, due to limited use of inputs by poor resource farmers (Mathenge *et al.,* 2019). Soybean low yield has been attributed to poor soil fertility particularly P, high costs, or limited availability certified seeds and P fertilizers, as per [African Center for Economic Transformation (ACET, 2013)]. In Kenya average yield of 0.8 tons per hectare of soybean has been recorded with annual average yield ranging from 0.56 tons per ha in Western region to 1.1 tons per hecare in Eastern region (Chianu *et al.,* 2008). However, it is possible to obtain soybean yields of 3.0–3.6 tons per ha from improved varieties and good management practices (Adeyeye *et al.,* 2017; Kaara *et al.,* 1998).

Western region is leading in soybean production in Kenya and accounts for 50% of total planted area and yield (Chianu and Vanlauwe, 2006). However, even if the production per unit area in Eastern region is high, the planted area is less than Western region which remains the highest producer in Kenya. The increasing population in Eastern Kenya particularly Meru South has led to fragmentation and intensive use of agriculturally productive land, hence exhaustion of essential nutrients, in particular N and P (Nithi, 2013). Each household in Eastern Kenya has an average of 0.5–1.0 hectare of agriculturally productive farm (Moni *et al.,* 2016).

According to Adeyeye *et al.* (2017) and Giller *et al.* (2013) grain legume yields, and the amount of N fixed, depend on legume genotype, the effectiveness of R applied and management practices especially P application. Furthermore, counties in Eastern region have adverse weather conditions which require adoption of soybean which does well in a wide range of ecological conditions (Moni *et al*., 2016). Many researches have observed that R, soybean genotype and P have positive effects on the productivity of soybean (Ronnera *et al.,* 2016; Ahiabor *et al.,* 2014). However, response of soybean genotypes to these inputs have remained highly variable (van Heerwaarden *et al.,* 2018; Ronner *et al.,* 2016).

To correct P deficiency in soils, P fertilizers such as superphosphates can be recommended, however, these fertilizers are either not readily available or very expensive to the poor resource farmers (Thilakarathna, 2019). These have caused the farmers in Meru South to apply sub-optimal or no mineral P fertilizers to the crops, consequently, leading to poor crop establishment and low yields (Abuli, 2016). Further, use of P-efficient genotypes is a sustainable P management strategy for enhancing yield and P use efficiency (Zhou *et al*., 2016). However, inadequate information is available on P-efficient soybean genotypes in Kenya, and in particular the study area.

1.2 Statement of the Problem

Soybean is becoming an important legume cash crop in Kenya and yet the yields are on decline. Nitrogen and P are the limiting nutrients attributed to the decline in soybean yields. Legume crops such as soybean can be rotated with cereals with the benefit of reducing the use of inorganic (N) fertilizer to the subsequent cereal crops in the context of integrated soil fertility management. Grain legume yields, and the amount of N fixed, depend on legume genotype, the effectiveness of R applied and agronomic management especially P application. Soybean requires effective R and adequate P in soils which are capable of enhancing biological nitrogen fixation. However inadequate information is documented on optimum rates of the R and P which can enhance growth, N-fixation, yield components and grain yields of soybean in the study area. Furthermore, scanty information is documented on P-efficient soybean genotypes, which are a sustainable P management strategy for enhancing yield and P use efficiency.

1.3 Broad Objective

Assessment of the effect of Integrated Application of Different Rates of Commercial Rhizobium and Phosphorus for Sustainable Soybean Production.

1.3.1 Specific Objectives

The specific objectives included;

i. To determine the effect of integrated application of different rates of rhizobium and phosphorus on growth, nodulation and yield components of soybean.
ii. To evaluate the effect of integrated application of different rates of rhizobium and phosphorus on tissue nutrient content, symbiotic efficiency and phosphorus use efficiency in soybean production.
iii. To perform the analyses on the effect of integrated application of different rates of rhizobium and phosphorus on grain yield and net economic benefit in Soybean enterprise.

1.4 Hypotheses

The hypothesis tested included:

H_{01} : There was no significant effect of integrated application of different rates of R and P on growth, nodulation and yield components of soybean.

H_{02} : There wase no significant effect of integrated application of different rates of R and P on tissue content, symbiotic efficiency, and phosphorus use efficiency in soybean enterprise.

H_{03} : There was no significant effect of integrated application of different rates of R and P on grain yield and net economic benefit in soybean enterprise.

1.5 Justification of Study

Low soil fertility in Sub-saharan Africa in particular Kenya is often characterized by low available P, N and ineffective native rhizobia (Ndusha *et al.*, 2017; Singh and Ryan, 2015). Such parameters must be corrected as they are an integral part of the interaction of legumes, R strain and crop management for biological nitrogen fixation (BNF) and legume productivity (Adeyeye *et al.,* 2017; Giller *et al.,* 2013). Use of R as the source of N is a cheap alternative to inorganic fertilizers in enhancing crop yields (diCenzo *et al.,* 2019). Soybean plays a major role in improving soil N, and can fix atmospheric nitrogen of 44–300 Kg ha^{-1} per year (Murithiab *et al.,* 2016; Giller *et al*., 2013; Furseth *et al.,* 2012). Phosphorus is vital in rhizobia-soybean symbiosis, P provide energy to the rhizobium bacteria to convert atmospheric nitrogen into ammonium (NH_4), available form to the plants (Mathenge *et al.*, 2019). Inadequate P restricts root growth, the process of photosynthesis and translocation of sugars which influence BNF by legumes (Getachew *et al.*, 2017). Soybean on the other hand enhances P availability through secretion of enzymes and acids in the legume rhizosphere (Bargaz *et al.*, 2018). In addition to ascertaining the extent of microorganisms in enhancing P bioavailability, present trial provided evidence to showcase the advantages gained from the combinatory use of R and P in Meru South Sub County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Soybean Production and Utilization.

Soybean (*Glycine max*) is an important legume crop that is cultivated all over the world as a major source of livestock feed, food for human consumption, soil fertility improvement and industrial products such as candles and paints (Adjei-Nsiah *et al.,* 2019; Hartman *et al*., 2011). Soybean has a high protein content (40%) of good nutritional quality, and oil content (20%) which make soybean the crop of choice for improving the diets of people in developing countries (Murithiab *et al*., 2016). The crop is transformed through value addition into soybean meal and oil; used as an animal feed for its protein content and human food and biodiesel respectively (FAO, 2014).

Soybean is the world's largest source of animal protein feed, the second largest source of vegetable oil and the fourth leading crop produced globally (Tani *et al*., 2016). Fullfat soy flour is used in bakery and dietetic foods and in novel products, such as tofu-based ice cream and soybean yogurt [United States Department of Agriculture (2017)]. Due to its protein content it can help to reduce malnutrition among children and nursing mothers, hence enhancing nutrition in the developing world (USDA, 2016).

United States of America is the leading producer and exporter of soybean worldwide (USDA, 2016). The crop and its derivatives accounts for over 10% of the total value of global agricultural trade (Abuli, 2016). Global trade in soybeans and its products has risen rapidly with the highest percentage increase in area under its production compared to other major crops (Ndusha *et al*., 2017). From United States Department of Agriculture (USDA), factors driving global soybean trade include a rise in population and demand for livestock products (USDA, 2017).

Rise in income levels, and urbanization worldwide, also led to a shift to more diversified products, such as meat and other high-value agricultural products (Ndusha *et al*., 2017; USDA, 2016). These trend boosted demand for feed grains and protein meals, particularly from soybeans, for livestock and vegetable oils for food (Tani *et al*., 2016). Soybean has now been identified as the most preferred legume across eastern and southern Africa, as compared to common bean and cowpea, based on its preference (Rusike *et al*., 2013). According to USDA, (2017), Africa accounted for 0.4 – 1% of total world production of soybean with Nigeria, South Africa, Uganda, and Zimbabwe as the main producers in the continent. Nigeria contributes 50% of Africa's output, accounting for only 0.3% of the world soybean output (USDA, 2017).

According to FAOSTAT (2011) Uganda was the leading producer of soybean in East Africa, with an increase in production in 2005 from 158 000 to 213 300 tons in 2011. During the same period, the area under production increased by 6000 ha (FAOSTAT, 2011). According to FAOSTAT (2013) processing and cooking methods by non-governmental organizations in Uganda facilitated the adoption of soybean among smallholder households. This has led to an increase in the use of soymilk and soy flour among households in Uganda (USDA, 2017).

There is a substantial demand for soybean and soybean products, amounting to about 150 000 tonnes per year, in Kenya where production is dominated by smallholder farmers (Chianu *et al.*, 2009). This was mainly attributed to increasing demand for food and feed manufacturing industry (Rusike *et al.*, 2013). Production increased from 2000 tonnes in 2009 to about 4500 tonnes in 2012 (FAOSTAT, 2013). The potential for soybean production has not been maximized because cultivation takes place only in a few areas in the Western, Eastern regions and in the Rift Valley on a small scale (Chianu *et al*., 2009).

Kenya spent a total of US $27.54 million to import soybean and its products, which is a significant drain on her scarce foreign exchange (Abuli, 2016). Earlier FAO's records did not recognize Kenyan production in global soybean statistics (FAOSTAT, 2013). The yields in Kenya have remained under 2.0 tons per hectare below 3.0 tons realized in other Countries (Krause and Wasike, 1998). The yield of soybean has remained 1.0 tons per hectare on growers' farms compared to 3.0 tons per hectare realized in its research stations (Kamara, 2007). Soybean yields are determined by the effects of cultivars, the rhizobium strain(s) used, fertilizers used and their interactions (Adeyeye *et al.*, 2017; Giller *et al*., 2013). The use of R is the most profitable way to increase soybean production due to its low cost (Ronnera *et* *al*., 2016). Inoculation is aimed at providing a viable and effective rhizobia to induce colonization of the rhizosphere allowing nodulation to take place immediately after germination (Hartman *et al*., 2011). Soybean has the ability to provide all its N needs; influence the N balance of the soil and avail N to subsequent crops (Furseth *et al*., 2012). Microbial population density of about 10^3 *Bradyrhizobium japonicum* cells per a gram of soil is required for maximum nodulation and efficient BNF (Adjei-Nsiah *et al*., 2019; Nasir *et al*., 2017).

Phosphorus is known to be a major drawback hindering soybean yield in the producing countries in Africa (Kolawole, 2012). Inadequate phosphorus restricts root growth, the processes of photosynthesis and translocation of sugars which influence BNF in legumes (diCenzo *et al*., 2019; Fatima *et al*., 2007b). High fertilizer prices and scanty information on availability of soybean rhizobia (Ronnera *et al*., 2016; Ahiabor *et al*., 2014) have led to low yields of soybean. Soybean plays an important role in the global and agricultural N cycles by facilitating it into plant-available N (Nasir *et al*., 2017). Recent awareness of potential soil degradation and pollution of ground water by the inorganic nitrates, much attention has been given to BNF (Ouma *et al*., 2016; Palaniappan, 2010). Biological nitrogen fixation is an agriculturally and ecologically crucial and efficient process in terms of supplying N to the plants which is worthy to be embraced (diCenzo *et al*., 2019).

Application of P to soybean enhances the amount of nitrates derived from the atmosphere by the soybean-rhizobium symbiotic system (Zhou *et al*., 2016). Phosphorus is also an essential ingredient for R bacteria which is known to provide energy to convert atmospheric nitrogen (N_2) into an ammonium (NH_4) form readily available to plants (Fatima *et al*., 2007a). Soybean can fix N at the range of 44-300 Kg N per ha per year leading to a substantial savings in fertilizer costs (Murithiab *et al*., 2016; Giller *et al*., 2013; Furseth *et al*., 2012) especially to subsequent crops in crop rotation farming systems.

2.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Growth, Nodulation and Yield components of Soybean

Response of different soybean genotypes to the R and P has been highly variable (Ronnera *et al*., 2016; van Heerwaarden *et al*., 2018). Observations have revealed R and P increased plant height considerably, with highest at integration rates of the two (Leggett *et al*., 2015). Elsewhere, experiments have recorded a significant increase in height of crop legumes with increase in rhizobia and phosphorus application (Walangululu *et al*., 2013; Shahid *et al*., 2009). Soybean genotype SB24 has been reported to exhibit a higher plant height compared to SB19 (Mudibu *et al*., 2018). Differences in plant height of studied soybean accessions by most authors have been attributed to their differences in growth habit and adaptation (Adjei-Nsiah *et al.,* 2019). Furthermore, among many experiments done, observations revealed that most soybean genotypes are adapted to specific agro-ecological regions leading to differences in their performance (Monyo and Laxmipathi, 2014).

Tropical soils are known to be inadequate in N element and often rich in less effective native rhizobia (Ndusha *et al*., 2017). Effective nodulation has been suggested to be crucial for a functioning legume–rhizobium symbiosis to enhance BNF (Adjei-Nsiah *et al*., 2019). Plants most susceptible to infection by the bacteria strain and consequently producing highly effective nodules would have the utmost capacities to fix higher atmospheric nitrogen (Nasir *et al*., 2017; Kellman, 2008). Elsewhere, there was a significant increase in the number of nodules per plant when crop legumes were treated with rhizobia and P (Kawaka *et al*., 2018; Lamptey *et al*., 2014; Waluyo *et al*., 2004). Number of nodules increased at integration of R and P, with a maximum of 183 nodules per plant in lowly fertile soils (Abbasi *et al*., 2010). This was associated with improved soil nutrient as a result of the optimum application of R and P (Menge, 2016; Walangululu *et al*., 2014; Gicharu *et al*., 2013). In a study where P was applied, the number and size of nodules increased, consequently improving the density of R bacteria in the rhizoshere (Nasir *et al*., 2017; Bashir *et al*., 2011).

Similarly Mohamed and Hassan (2015) in their experiment oberved a higher nodule number and dry weight in chickpea due to the integration of R and P compared to control. Among cultivated soybean genotypes, differences in nodule number and dry weight observed, were attributed to variations in their ability to tolerate varied soil nutrients (Adjei-Nsiah *et al*., 2019). Increased seed yields were associated with N compounds contained in the seeds, resulting from R, consequently, enhancing the formation of nodules to fulfill N requirement (Masresha, 2017; Bashir *et al*., 2011).

Number of pods significantly increased in plants inoculated with R compared to uninoculated (Morad *et al.*, 2013). Soybean genotype SB24 remained significantly higher in number of pods and branches per plant among many soybean accessions studied (Mudibu *et al.*, 2018). Effective nodulation by R increased N fixation and consequently enhanced vegetative and dry matter yield of soybean compared to uninoculated (Kawaka *et al.*, 2018). In greenhouse and field studies done, P was observed to play a vital role in enhancing cell division during the growth of plants, leading to a higher fresh and dry shoot biomass (Kawaka *et al.*, 2018). Increased P rates of application resulted to a higher fresh and dry shoot weight which was attributed to enhanced vegetative growth due to BNF by increased nodules (Turuko and Mohammed, 2014). Elsewhere, inoculation significantly influenced biomass of soybean with rhizobium-inoculated seeds and maximum dry shoot weight per plant were recorded when R was integrated with P (Salih *et al.*, 2015; Balemi and Negisho, 2012). Phosphorus deficiency in the soil is well known to restrict the development of a free-living R population in the rhizosphere, to limit the growth of the host plant, restrict nodulation and impaired nodule function (diCenzo *et al.*, 2019; Getachew *et al.*, 2017).

2.3 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Tissue Content, Symbiotic and Phosphorus Use Efficiency in Soybean Production

The rhizobium inoculation and phosphorus application improved the uptake of N and P in different organs of the plant of soybean (Shish *et al.,* 2018). Intercrop of Soybean/maize resulted to a higher N content in maize grain from intercropping compared to sole planting (Kolawole, 2012). This indicated that soybean used more P for nodulation and in turn, secreted N compounds that enhanced the performance of maize. And hence, maize showed higher N uptake efficiency in the soybean intercrop (Vanlauwe *et al*., 2014).

Elsewhere, studies showed that P increased the percent and total amount of nitrogen in the harvested portion of the host legume (Bashir *et al*., 2011). Efficiency across P rates, 47 Kg grain yield was produced with the accumulation of 1 Kg P in the grain and straw (Abbasi *et al*., 2010). Phosphorus content in grain and straw was reported to be significantly influenced by R and P application (Adjei-Nsiah *et al*., 2019).

Furthermore, increased plant growth and plant N concentration in response to increased soil P supply was observed in soybean including several other legumes (Nasir *et al.*, 2017; Masresha, 2017).

The P content in grain, increased significantly while P content both in grain and straw was highest in the integration of R and P compared to control (Nasir *et al.*, 2017). High yields obtained from soybean and consequent profits, were related to symbiotic efficiency (SEF) of soybean with BNF bacteria (Barbosa, *et al.*, 2017). Nitrogen fixation is very sensitive to P deficiency due to reduced nodule mass and decreased ureide production (Shish *et al.*, 2018). Symbiotic N-fixation has a high P demand because the process consumes large amounts of energy and energy generating metabolism strongly depends upon the availability of P (Tairo and Ndakidemi, 2014).

Elsewhere, P application increased plant growth and yields by increasing the efficiency of BNF and enhancing the availability of other macronutrients in legumes (Makoi *et al*., 2013). The level of BNF observed varied among R isolates in Embu sub county with SEF of between 27 and 112% (Mwendaa *et al.*, 2011). Symbiotic efficiency range of between 67 and 170% when common beans were inoculated with R in Western Kenya was observed (Kawaka *et al.*, 2014). Findings from research works confirmed that R isolated from common beans from Njoro, Kenya, had higher SEF compared to the commercial inoculants (Mungai and Karubiu, 2011).

Native isolates varied and exhibited superior BNF compared to the local commercial inoculants (CIAT 899 and Strain 446) [Kawaka *et al.*, 2018]. Koskey *et al*. (2017) used plant shoot dry weight to evaluate the SEF in common beans which ranged between 86.7 and 123.72%. Studies on BNF in soybean revealed that soybean shows a strong demand for N of upto 80 Kg N per 1000 Kg of soybean grain for optimal development and productivity (Mathenge, 2019)

Improved crop genotypes that acquire and use P more efficiently are a sustainable solution to increase in crop yields (Jeannette *et al.*, 2014). In seed potato tuber production, phosphorus use efficiency PUE increased from 0 Kg/Kg observed with 0 Kg P per ha and 0 Kg N per ha to a range of 75.9 Kg/Kg to 186.6 Kg/Kg when application of P and N were combined at different rates (Gathungu *et al.*, 2014). Across different P rates applied, it was observed that a 5.2 Kg soybean grain yield was produced with the application of 1 Kg P representing the PUE. In addition apparent recovery efficiency was observed to be 11.2%, and utilization efficiency was 16.5 Kg of grain yield with the utilization of 1 Kg of P (Abbassi *et al*., 2010).

2.4 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield and Net Economic Benefit of Soybean Enterprise

2.4.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield

Rhizobium strains and P supply improves productivity of soybean, which is attributed to better nodulation, BNF and crop growth. The use of R and P were effective way of enhancing the nodulation attributes, available soil N and P, subsequently, yields of soybean (Shish *et al*., 2018). Grain yields of legume crops depend on legume genotype, the effectiveness of R strain, the biophysical environment and agronomic management (Giller *et al*., 2013).

Integration of R and P in legume plants significantly increased nodulation, pod formation and development, and a subsequent grain yield comparatively to the single use of R or P (Akpalu *et al*., 2014). Low yields in soybean has been attributed to the poor soil fertility (low P), high costs and limited certified seeds, P fertilizers, and inoculants (ACET, 2013). An average of 1,254 Kg per ha of soybean yield in Africa was reported, which was 50% of the global average of 2,475 Kg per ha in the world (FAOSTAT, 2013).

Eastern region had an average annual yield of 540 Kg to 1100 Kg per ha, however it has the potential of producing 3000 Kg to 3600 Kg per ha (Chianu *et al*., 2008). Korir *et al*. (2017) reported that R and P whether applied alone or in integration had a pronounced effect on common bean grain yield. Ronnera *et al*. (2016) observed that integration of native inoculant and P resulted in higher soybean yields compared to un-inoculated. The maximum grain yield of 2335 Kg per ha was observed when integration of R and P was applied compared with control of 1800 Kg per ha (Abbasi *et al*., 2010). In a field research, yields of 541.8 Kg per ha and 585.5 Kg per ha for soybean genotype SB19 and SB24 was recorded respectively (Mudibu *et al*., 2018). While in another trial yield in the control was 861 Kg per ha that significantly increased to a weight of between 1450–2072 Kg per ha with different rates of *Bradyrhizobium* application (Nasir *et al*., 2016).

2.4.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Net Economic Benefit of Sobean Enterprise

Kenya spent a total of US $27.54 million to import soybean and its products, which is a significant drain on her scarce foreign exchange (Abuli, 2016). Agriculture in recent times has embraced sustainable agricultural production through efficient use of productive resources in order to guarantee enhanced income and food security (Awotide *et al*., 2015). Agriculture development is considered the engine for economic growth in Sub Saharan Africa (SSA) and a key determinant in the region's efforts to reduce poverty in the years ahead (Kansiime *et al*., 2018).

Agriculture has moved from the traditional means of planting and harvesting to sustainable agricultural production through efficient use of productive resources in order to ensure food security, and eradicate poverty (Awotide *et al*., 2015). However, productivity of SSA in the sector lags considerably behind that of other continents, as well as the region's potential (AGRA, 2013). Much research done, has depicted that the marginal value products of all the resources used are less than their prices (MVP<MFC), indicating underutilization of resources (Omonona *et al*., 2010).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The experiment was conducted at Chuka University Research farm, Meru South Sub-County, Tharaka Nithi County in two cultivation (Trial I and II) in 2018. Chuka University lies at an altitude of (approx): 1399m above sea level. It lies at latitude of (lat): $0^{\circ}20'0''$S and longititude of (lon): $37^{\circ}39'0''$E (Figure 1). Had temperature range of 20.97 ^{o}C to 27.25 ^{o}C, average rainfall of 1178 mm with nitisol type of soils (Moni *et al.*, 2016). Major crops in the area are; *Phaseolus vulgaris, Zea mays, Vigna unguiculate, Manihot esculenta, Cajanus cajan, Glycine max, Sorghum spp, Eleusine coracana, Musa spp, Mangifera indica, Coffea arabica* and *Camellia sinensis* (Abuli, 2016).

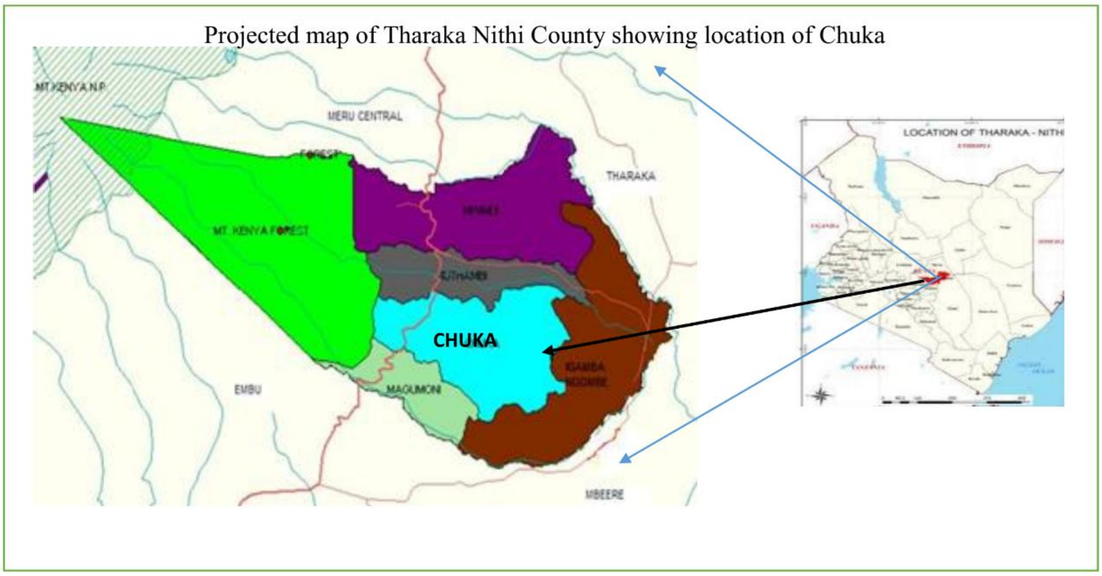


Figure 1: Location of Chuka in Tharaka Nithi County in Kenya

Source: (Google) [Modified]

3.2 Experimental Design

The experiment was laid out in a randomized complete block design (RBD) in a split-split plot arrangement with each treatment replicated thrice. Treatments included; three rates of phosphorus (0, 20 and 30 Kg^{-} ha^{-1}), and three rates of rhizobia (0, 100 and 200 g ha^{-1}) either applied alone or integrated and two soybean genotypes (SB19 and SB24). The triple superphosphate (0:46:0) was used as the source of phosphorus. The SB19 and SB24 soybean genotypes were assigned the main plot, P rates the sub-plot and R rates to sub-subplots, giving a total of nine treatments. The size of experimental plot was 1.5 x 1.3 m. Path between main plots was 1 m while between subplots and sub-subplots was 0.5 m**.**

3.3 Soil Sampling and Analysis

Soil sampling was carried out in the two sites before planting. The soil was sampled across and diagonally from 10 points in each site at a depth of 1-30 cm using a soil auger. A kilogram of a homogeneous composite soil sample was made from each site and packed independently into sterile bags for laboratory analysis. Soil samples were air dried and sieved through a 2 mm diameter sieve for physical and chemical analysis. Soil analysis was done at Kenya Agricultural Research and Livestock Organization (KALRO)–Embu according to the procedures described by Bremner (1986).

3.4 Planting Materials, Planting and Crop Management

Certified soybean seeds and inoculant was obtained from KALRO-Kakamega and MEA Limited-Nakuru respectively. The inoculation was done in Plant Science Laboratory of Chuka University according to Ahiabor *et al.* (2014), where soybean seeds were moistened with 4% Gum Arabica solution in a basin and the inoculant was added at the rates of 10 g per Kg and 20 g per Kg of soybean seeds. The mixture was stirred thoroughly and uniformly until even coating was attained. The seeds were then spread on flat plywood under a shade and allowed to air dry for 30 minutes to enable the inoculant to stick well enough onto the surface of the seeds before planting. The inoculated seeds were sown early in the morning to avoid its exposure to direct sun rays that could affect the efficacy of the inoculant. After these treatments, the uninoculated seeds were sown before the inoculated ones to avoid cross contamination.

A basal application of phosphorus at the rate of 0, 20, and 30 Kg P per ha which was equivalent to 0, 3.6, and 5.4 g per plot was done during planting to the assigned plots. Two seeds were sown at inter and intra row spacing of 0.5 m and 0.1 m respectively in a plot measuring 1.2 x 1.5 m. Seedlings were thinned to one per hill one week after emergence giving a plant population of 200,000 plants per ha or 39 plants per plot

(Plate 1). Weeding was done manually using the hoe. However, all cultural practices recommended (weeding, spraying against pests and diseases) for growing soybean were done equally to all the plots to curb on variation as a result of these practices.

Plate 1: Field layout after emergence and at physiological maturity

3.5 Data Collection

The data recording was done on quantitative parameters. Data on plant height, number of pods, nodules and branches, fresh and dry nodule and shoot weight, length of root and seed yield was taken from the middle plants of the rows from all the plots. The first and last rows including the first and last plants per row formed the guard rows. The net plot was the two middle rows of each plot.

3.5.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus Application on Growth, Nodulation, and Yield of Soybean

3.5.1.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Plant Height

Four plants were randomly selected from two inner rows after the border rows from each plot and tagged for data collection on plant height (PH). These selected plants per treatment were measured using a meter rule on 7, 14 ,21, 28, 35, 42, 49, 56, 63, 70, 77 and 84 days after emergence (DAE) to determine the treatment effects starting 7 days after emergence. Height was measured using a meter rule from the ground level to the apex of each tagged plant in all plots and recorded.

3.5.1.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Number and Weight of Nodules

Four plants were randomly selected from two inner rows after the border rows from each plot for data collection on number and nodule weight. The selected plants were uprooted 40 days after emergence from each treatment to determine number of nodules, fresh and dry nodule weight. Roots of uprooted plants per treatment were washed and the nodules detached, number ascertained and recorded. The detached nodules per plot were put in labelled khaki envelopes, fresh nodule weight ascertained and recorded. The nodules were then oven dried at 60 °C for 48 hours and their dry weight recorded.

3.5.1.3 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Number of Branches

Four plants were randomly selected for the determination of the number of branches per plot to ascertain treatment effect. Branches were counted from the selected plants and recorded per plant 40 days after emergence in both cultivations (Trial I and II) to ascertain treatment effect.

3.5.1.4 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Number of Pods, Fresh and Dry Shoot Weight

Four plants from each plot were randomly selected for determination of the number of pods, fresh shoot and dry shoot weight. These selected plants were uprooted 40 days after emergence. Number of the pods per plant were counted and recorded. The dry mass was determined using four randomly selected plants from the middle rows in each plot. Four plants from the two inner rows were uprooted from each plot, put in "khaki" papers, and weighed using an electronic balance when still fresh and later oven dried at 60 °C for 48 hours and then reweighed. Shoot dry weight per plant was ascertained and recorded per treatment.

3.5.1.5 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Root Length

Four plants from each plot were randomly selected for determination of the root length. These selected plants were uprooted 40 days after emergence. The length of the root of the uprooted plants was measured using a meter rule and recorded.

3.6 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Tissue Content, Symbiotic Efficiency and Phosphorus Use Efficiency in Soybean Production

3.6.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Shoot and Grain Nitrogen and Phosphorus Determination

Shoots and grain weighing 20 g from experimental plants were randomnly taken from every plot. The shoots and grains taken per plot were placed in khaki papers and dried in the oven at 60 ^{o}C for 72 hours. After oven drying the dry shoots and grain were ground into powder using a blender. The powder was then sieved using a laboratory test sieve and 15 g each packed in khaki paper bags ready for laboratory analysis. The plant shoots and grain powder were analyzed for N (%) and P (ppm) content according to Kjeldahl and Bremner (1996).

3.6.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Symbiotic Efficiency

The plant shoot dry weight (SDW) was used in the present study to evaluate the symbiotic nitrogen-fixing efficiency (SEF%) of the commercial R strain. Symbiotic efficiency in this study was determined according to (Koskey *et al.*, 2017) using formula below:

$$SEF = 100 \times \left[\frac{(SDW\ of\ inoculated\ (Kg)]}{SDW\ of\ non\ inoculated\ (Kg)}\right]$$

3.6.3 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Phosphorus Use Efficiency

The phosphorus use efficiency (PUE) was computed according to Belete *et al*. (2018) and Syers *et al*. (2008). Where phosphorus use efficiency in Kg/Kg was calculated according to Gathungu *et al*. (2014) using the formula below:

$$PUE = \left[\frac{(Seed\ \ yield\ (kg)\ of\ plots\ with\ Fert. - yield\ (kg) control}{Quantity\ of\ phosphorus\ (P)\ applied\ in\ kg\ per\ plot}\right]$$

3.7 Integrated Application of Different Rates of Rhizobium and Phosphorus Fertilizer on Grain Yield and Net Economic Benefit of Soybean Enterprise

3.7.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield

The soybean yield was determined at full maturity in Trial I and II. Where ten plants were randomly selected from the middle rows in each plot. Then harvested per plot, dried, threshed and then seeds cleaned and put in labeled paper bags. The threshed grains were used to determine the yield per plant, plot and hectare. The grain yield for the ten randomly selected experimental plants was added together and put in a paper bag and weighed with a spring balance in order to get the total yield in Kg per plot. Yield per plant within the treatment was determined by dividing the total yield per plot by the number of plants harvested. The resulting weights, in g per plant, were then extrapolated to Kg per ha basis to get the average grain yield per hectare. The grain yield collected was transformed into kilograms by multiplying weight per plant by plant population of 200,000 per hectare.

3.7.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Net Economic Analysis

Net economic benefit (NEB) of the soybean production was performed after harvest. It was calculated by deducting the (variable cost) gross production cost from (revenue) gross soybean output, according to (Reckling *et al.*, 2016). The gross soybean output was determined by multiplying the weight of harvested soybeans in kilograms by the prevailing market price. The gross benefit was the gross income derived from sale of the grain. The gross production cost included cost of; phosphorus, rhizobia, seeds and labour cost in man days which included ploughing, planting, weeding, crop protection, harvesting and post-harvest handling. The gross benefit per plot was translated to gross economic benefit per hectare.

The amount of elemental P applied was 0 g, 20 Kg and 30 Kg per ha. Before analysis of net aconomic benefit these figures were transformed into oxide. The elemental phosphorus was converted into oxide according to Bremner (1996) to ascertain quantity of triple superphosphate required per ha (Kg) because the P is taken in the form of P_2O_5. From the conversion 20 Kg and 30 Kg per ha was equivalent to 95 Kg and 143 Kg per ha, which was translated to 2 bags and 3 bgs of P respectively.

Net economic benefit of soybean grain was performed after harvest. It was calculated by deducting the gross production cost from the gross field benefit per treatment, according to Berche *et al*. (2013). The gross grain output (benefit) was determined by multiplying the weight of grain by the prevailing grain market price at Chuka municipal market. Market price of soybean was rather difficult due to fluctuating prices, and it was considered safe to use minimum market price at Chuka municipal market. The minimum grain price of soybean per Kg at Chuka municipal market was KSh. 100. This was translated to KSh. 5,000 for a 50 Kg bag of soybean grain. These prices were adopted for economic analysis. The gross benefit was the gross income derived from sale of the grain seed and the gross production costs were as indicated (Table 1)

Table 1: Gross Cost of Soybean Production per Hectare

Variables	No. of units	Unit Cost(Kshs)/ha	Total
Land preparations			
1st Ploughing	1 Ha	7,500	7,500
2nd ploughing	1 Ha	7,500	7,500
Planting (1 ha)	2 Man-days	20 mandays@ 379.30	18,950
1st Weeding(1 ha x2)	5 Man-days	10 mandays@ 379.30	37,900
Harvesting (1 Ha)	3 Man-days	10 mandays@ 379.30	11,370
Threshing/packaging	5 Man-days	10 mandays@ 379.30	18,950
Iputs			
TSP 20 Kg/ha	2 bags	4,600	9,200
TSP 30 Kg/ha	3 bags	4,600	14,400
Rhizobia 100 g	20 g x 5 pcs	100	500
Rhizobia 200 g	20 g x10 pcs	100	1,000
Seeds	15 Kg	600	9,000
Duduthrin	1 litre	1,500	1,500
Total			137,770

3.8 Ethical Consideration

The research permit was acquired from the National Commission of Science, Technology and Innovation (NACOSTI) and permission was sort from County Director of education, Tharaka Nithi County, where the research was done (Appendix 1). The research was done in an ethical manner by ensuring confidentiality and security of collected data. The data was collected and analyses done as per laid down rules and procedures. All the data collected was used solely for the purpose of this research. Conclusions and recommendations were published for easy of dissemination of the information. Further the research ensured that the laid down policies were followed. Should there be need for use of the research results for policy matters, the information will be released to requesting institution in consultation with Chuka University.

3.9 Data Analysis

The data collected was subjected to analysis of variance (ANOVA) using the statistical analysis software (SAS) system for windows V8 1999-2001 by SAS Institute Inc., Cary, NC, USA (SAS, 2001) and significantly different means were separated using Tukeys test at ($p \leq 0.05$).

CHAPTER FOUR

RESULTS

4.1 Climatic data and Soil Analysis

After analysis of the soil at KALRO-Embu the pH was 5.31 and 4.31, total nitrogen was 0.23% and 0.60% and the organic carbon content was 2.54% and 2.50% while the available P was 27 ppm and 29 ppm for Trial I and II, respectively (Table 2). The experimental site had a mean temperature that ranged from 20.9 to 24.6 ^{o}C and a total of 1178 mm of rainfall was received (Table 3).

Table 2: Soil Analysis Results of the Site

Soil properties	Trial I	Trial II
pH	5.31	4.31
Nitrogen (N) %	0.23	0.6
Organic Carbon (OC) %	2.54	2.5
Potassium (K) (cmol/ Kg)	0.88	0.91
Magnesium (Mg) (cmol/Kg)	1.28	1.3
Calcium (Ca) (cmol/Kg)	3	2.89
Aluminium (Al) (cmol/Kg)	2.45	2.22
Manganese (Mn) (ppm)	73.15	71.01
Phosphorus (P) (ppm)	27	29
Sand %	14.01	16.1
Clay %	55.77	60.55

4.2 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Growth, Nodulation and Yield Components of Soybean

4.2.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Plant Height

There was no significant difference in plant height between genotype SB19 and SB24 within and between Trial I and II ($p \leq 0.05$). However, there was significant influence of the integration of R and P in plant height within individual genotypes at ($p \leq 0.05$) in both Trial I and II (Appendix 2). Rhizobia application significantly increased soybean plant height for SB19 and SB24 genotypes in Trial I and II. For example, R application at the rate of 100 g per ha increased plant height from 24.22cm and 23.25cm, and 21.07 cm and 20.14 cm in the control treatment (0 g R and 0 Kg P per ha) to 27.35 cm and 26.36 cm, and 25.21 cm and 24.27 cm for SB19 and SB24 genotypes in Trial I and II, respectively (Table 4).

Table 3: Climatic Data Showing Rainfall and Temperatures from Jan-Aug 2018 at Chuka University

Month	Rainfall (mm)	Mean Temperature (^{o}C)
Mar	246.2	24.61
Apr	494.4	23.63
May	377.5	22.84
June	30	21.1
July	19.8	20.97
Aug	10	22.1
Total	1177.9	

Compared to the control, R at the rate of 200 g per ha increased plant height by 5.47 cm and 5.53 cm, and 6.3 cm and 6.33 cm per plant for SB19 and SB24 genotypes in Trial I and II, respectively (Table 4). Phosphorus at the rate of 20 Kg per ha significantly increased soybean height from 24.22 cm and 23.25 cm, and 21.07 cm and 20.14 cm per plant in the control treatment (0 g R and 0 Kg P per ha) to 26.29 cm and 25.28 cm, and 23.79 cm and 22.39 cm per plant for SB19 and SB24 genotypes in Trial I and II, respectively.

When P was applied at the rate of 30 Kg per ha soybean height significantly increased to 28.40 cm and 27.38 cm, and 23.85 cm and 24.92 cm per plant for SB19 and SB24 soybean genotypes in both Trial I and II, respectively. Compared to the control treatment, integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased plant height per plant from 24.22 cm and 23.25 cm, and 21.07 cm and 20.14 cm in the control treatment (0 g R and 0 Kg P per ha) to 29.79 cm and 28.8 cm, and 27.12 cm and 26.16 cm for SB19 and SB24 in Trial I and II, respectively. For example when 100 g and 30 Kg per ha was used, the height per plant significantly increased to 32.28 cm and 31.24 cm, and 29.30cm and 28.46 cm for SB19 and SB24 genotypes in both Trial I and II, respectively. Similarly, increase in R application rate led to an increase in soybean plant height. Application of 200 g R and 20 Kg P per ha significantly increased the height per plant to 32.10 cm and 31.07 cm, and 29.41 cm and 28.44 cm compared to 24.22 cm and 23.25 cm, and 21.07 cm and 20.14 cm observed with the control in both Trial I and II respectively.

Table 4: Effect of Rhizobia and Phosphorus on Soybean Height, Nodule Number and Fresh Weight per Plant

Variety		Trial I			Trial II		
	Trt	Height (cm)	No. of Nodule	FN Wt (g)	Height (cm)	No. of Nodule	FN Wt (g)
SB19	T1	24.22^{c*}	9^{e}	0.23^{e}	23.25^{f}	9^{e}	0.7^{e}
	T2	26.29^{c}	18^{fe}	0.29^{e}	25.28^{fe}	14^{e}	1.13^{e}
	T3	28.40^{b}	26^{d}	0.36^{d}	27.38^{edc}	23^{fe}	3.05^{d}
	T4	27.35^{c}	16^{e}	0.34^{d}	26.36^{fed}	29^{e}	2.30^{d}
	T5	29.79^{b}	38^{c}	0.49^{c}	28.8^{bedc}	42^{d}	3.15^{c}
	T6	32.28^{a}	69^{b}	0.79^{b}	31.24^{ba}	65^{b}	4.3^{b}
	T7	29.69^{b}	25^{d}	0.39^{c}	28.78^{bdc}	37^{ef}	2.49^{c}
	T8	32.10^{a}	57^{b}	0.65^{b}	31.07^{bac}	53^{c}	3.71^{b}
	T9	34.04^{a}	90^{a}	1.04^{a}	33.06^{a}	83^{a}	5.04^{a}
SB24	T1	21.07^{c}	9^{e}	0.23^{e}	20.14^{f}	9^{f}	0.61^{e}
	T2	23.79^{c}	18^{d}	0.27^{e}	22.39^{fe}	11^{f}	1.27^{e}
	T3	25.85^{b}	25^{c}	0.35^{d}	24.92^{edc}	23^{e}	2.09^{d}
	T4	25.21^{c}	14^{e}	0.32^{d}	24.27^{fed}	29^{e}	2.40^{d}
	T5	27.12^{b}	34^{c}	0.48^{c}	26.16^{bedc}	40^{d}	3.37^{c}
	T6	29.30^{a}	55^{b}	0.73^{b}	28.46^{ba}	61^{b}	4.20^{b}
	T7	27.37^{b}	23^{d}	0.49^{c}	26.47^{bdc}	35^{d}	2.75^{d}
	T8	29.41^{a}	56^{b}	0.68^{b}	28.44^{bac}	53^{c}	4.21^{b}
	T9	32.06^{a}	82^{a}	1.0^{a}	31.14^{a}	79^{a}	4.95^{a}
MSD		3.67	12.56	5.87	3.72	1.33	0.1474
CV %		50	37.49	49	46	11.7	36.00

*Means with the same letter along the column for the same variety are not significantly different at ($p \leq 0.05$); MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; FN Wt= Fresh nodule weight; R=Rhizobia; P=Phosphorus.

This was equivalent to an increase of plant height by 7.88 cm and 7.82, and 8.34 and 8.3 cm at integration of 200 g R and 30 Kg P per ha applied compared to the control for SB19 and SB24 genotypes in Trial I and II respectively (Table 4).

4.2.2 Effect of Different Rates of Rhizobia and Phosphorus on Number, Fresh and Dry Nodule Weight

There were no significant difference in the number of nodules, fresh and dry nodule weight per plant between genotype SB19 and SB24 within and between Trial I and II ($p \leq 0.05$). However, there were significant influence of the integration of R and P in number of nodules, fresh and dry nodule weight per plant within individual genotypes at ($p \leq 0.05$) in both Trial I and II (Appendix 3,4 and 5). Application of R significantly increased nodule number from 9 observed with the control treatment (0 g R and 0 Kg P per ha) to 25 and 23, and 37 and 35 per plant observed with the higher rate of 200 g R per ha for SB19 and SB24 genotypes in Trials I and II, respectively (Table 4). This was an equivalent increase by 16 and 14, and 28 and 26 nodules per plant when 0 g of R was applied compared to 200 g of R for SB19 and SB24 in Trial I and II, respectively.

When P was applied alone, it significantly increased nodule number to 26 and 25, and 22 and 23 per plant at 30 Kg P per ha from 9 per plant observed with the control treatment for SB19 and SB24 in Trial I and II, respectively (Table 4). This is equivalent to an increase in nodules by 17 and 16, and 13 and 14 per plant when application of 30 Kg P per ha was compared to the control treatment for SB19 and SB24 in Trial I and II, respectively (Table 4).

Integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased nodule number per plant to 37 and 42, and 34 and 40 compared to 9 observed with the control treatment for SB19 and SB24 in Trial I and II repectively. Further, when 100 g R and 30 Kg P per ha was applied, the number of nodules per plant increased to 69 and 65, and 55 and 61 for SB19 and SB24 in Trial I and II. Similarly, the integration at the rate of 200 g R and 20 Kg P per ha significantly increased nodule number per plant to 57 and 53, and 56 and 53 for SB19 and SB24 in Trial I and II. Furthermore, integration of 200 g R and 30 Kg P per ha significantly increased the nodule number to 90 and 83, and 82 and 79 for SB19 and SB24 in Trial I and II, respectively (Table 4).

There was significant increase in nodule fresh weight with increase in the application of R and P, whether they were applied alone or they were integrated (Table 4). When no rhizobia (control) application was compared with R application alone at the rate of 100 g per ha the nodule fresh weight per plant significantly increased from 0.23 g and 0.7 g, and 0.51 g and 2.76 g to 0.34 g and 2.3 g, and 0.32 g and 2.4 g for soybean genotypes SB19 and SB24 in Trial I and II, respectively. Further, increasing R application to 200 g per ha significantly increased nodule fresh weight per plant to

0.39 g and 2.49 g, and 0.49 g and 2.75 g for SB19 and SB24 soybean genotypes in Trial I and II, respectively (Table 4).

When P was applied at the rate of 20 Kg per ha nodule fresh weight plant^{-1} significantly increased to 0.29 g and 1.13 g, and 0.27 g and 1.27 g while 30 Kg per ha increased the nodule fresh weight plant^{-1} to 0.36 g and 3.05 g, and 0.35 g and 2.09 g for SB19 and SB24 genotypes in Trial I and II, respectively (Table 4). Integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased nodule fresh weight per plant to 0.49 g and 3.15 g, and 0.48 g and 3.37 g while integration of 100 g R and 30 Kg P per ha significantly increased the nodule fresh weight plant^{-1} to 0.79 g and 4.3 g, and 0.73 g and 4.20 g for genotypes SB19 and SB24 in Trial I and II, respectively. Furthermore, increasing the amount of P to a similar rate of R application led to an increase in nodule fresh weight per plant. For example, when the integration rate of 200 g R and 20 Kg P per ha was compared with integration rate of 200 g R and 30 Kg P per ha the nodule fresh weight per plant significantly increased from 0.65 g and 3.71 g, and 0.69 g and 4.21 g to 1.04 g and 5.04 g, and 1.0 g and 4.95 g for SB19 and SB24 genotypes in Trial I and II, respectively (Table 4).

When R was applied at the rate of 100 g per ha, nodule dry weight (NDW) per plant significantly increased from 0.12 g and 0.36 g, and 0.11 g and 0.31 g observed with the control treatment (0 g R and 0 Kg P per ha) to 0.22 g and 1.2 g, and 0.22 g, 1.25 g for SB19 and SB24 in both Trial I and II, respectively. Similarly, NDW per plant significantly increased to 0.27 g and 1.26 g, and 0.41 g and 1.48 g observed with the control treatment (0 g R and 0 Kg P per ha) at the application rate of 200 g rhizobia per ha for SB19 and SB24 genotypes in Trial I and II, respectively (Table 5).

When P was applied at the rate of 20 Kg per ha dry nodule weight per plant increased to 0.16 g and 0.60 g, and 0.14 g and 0.31 g while 30 Kg per ha increased the NDW per plant to 0.25 g and 1.05 g, and 0.23 g and 1.13 g for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 5). Integration of R with P at the rate of 100 g R and 20 Kg P per ha significantly increased nodule dry weight per plant to 0.37 g and 1.57 g, and 0.36 g and 1.57 g observed with the control treatment for SB19 and SB24 genotypes in Trial I and II, repectively.

Table 5: Effect of Rhizobia and Phosphorus on Soybean Nodule Dry Weight and Number of Branches Per Plant.

Variety		Trial I		Trial II	
	Trt	Nodule wt. (g)	No.of branches	Nodule wt.(g)	No. of Branches
SB19	T1	0.12^{f}*	3.75^{e}	0.36^{f}	2.92^{f}
	T2	0.16^{fe}	5.41^{cd}	0.60^{fe}	4.33^{de}
	T3	0.25^{ed}	5.5^{cd}	1.05^{ed}	4.58^{d}
	T4	0.22^{fe}	4.58^{d}	1.2^{de}	3.58^{ef}
	T5	0.37^{c}	5^{c}	1.57^{c}	4^{ef}
	T6	0.65^{b}	5.25^{bc}	2.23^{b}	4.42^{cd}
	T7	0.27^{dc}	4.83^{dc}	1.26^{dc}	4.08^{ef}
	T8	0.53^{b}	5.66^{dc}	1.87^{b}	4.83^{b}
	T9	0.81^{a}	6.33^{a}	2.54^{a}	5.42^{a}
SB24	T1	0.11^{f}	8.33^{e}	0.31^{f}	7.17^{f}
	T2	0.14^{fe}	11.33^{cd}	0.65^{e}	9.9^{ef}
	T3	0.23^{ed}	11.35^{cd}	1.13^{d}	9.92^{ef}
	T4	0.22^{fe}	11.5^{d}	1.25^{d}	10.17^{e}
	T5	0.36^{c}	13.5^{c}	1.66^{c}	12^{c}
	T6	0.61^{b}	13.58^{bc}	2.98^{b}	11.46^{d}
	T7	0.41^{dc}	12.33^{dc}	1.48^{c}	11.17^{de}
	T8	0.54^{b}	14.25^{bc}	2.15^{b}	12.67^{b}
	T9	0.81^{a}	16.66^{a}	2.59^{a}	15.08^{a}
MSD		13.9	1.22	13.7	1.23
CV(%)		24.26	15.28	28.56	17

*Means with the same letter along the column for the same variety are not significantly different at ($p \leq 0.05$); MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha, respectively; T4 and T7=100 g R and 200 g R per ha, respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; ND Wt: Nodule Dry weight; R=Rhizobia; P=Phosphorus.

Furthermore, when 100 g R and 30 Kg P per ha was applied the NDW per plant increased to 0.65 g and 2.23 g, and 0.61 g and 2.98 g for SB19 and SB24 genotypes in Trial I and II. Similarly, the integration at the rate of 200 g R and 20 Kg P per ha significantly increased NDW per plant to 0.53 g and 1.8 g, and 0.54 g and 2.15 g for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, integration of 200 g R and 30 Kg P per ha significantly increased the NDW per plant to 0.81 g and 2.54 g, and 0.81 g and 2.59 g for SB19 and SB24 genotypes in Trial I and II, respectively (Table 5).

4.2.3 Effect of Different Rates of Rhizobia and Phosphorus on Number of Branches

There were no significant difference in the number of branches between genotype SB19 and SB24 within and between Trial I and II (*p≤0.05*). However, there were significant effect of the integration of R and P in number of branches per plant within individual genotypes at (*P≤0.05*) in both Trial I and II (Appendix 6). Rhizobia application at the rate of 100 g per ha, significantly increased branch number per plant from 3.75 and 2.92, and 8.33 and 7.17 observed with the control treatment (0 g R and 0 Kg P per ha) to 4.58 and 3.58, and 11.50 and 10.17 for genotypes SB19 and SB24 in both Trial I and II, respectively. Similarly, number of branches per plant increased from the control treatment (0 g R and 0 Kg P per ha) to 4.83 and 4.08, and 12.33 and 11.17 at the application rate of 200 g R per ha for genotypes, SB19 and SB24 in Trial I and II, repectively (Table 5).

Phosphorus application at the rate of 20 Kg per ha, increased number of branches per plant from 3.75 and 2.92, and 8.33 and 7.17 observed with the control treatment (0 g R and 0 Kg P per ha) to 5.41 and 4.33, and 11.33 and 9.9 for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, number of branches per plant increased from the control treatment (0 g R and 0 Kg P per ha) to 5.5 and 4.58, and 11.35 and 9.92 at the application rate of 30 Kg P per ha for SB19 and SB24 soybean genotypes in both Trial I and II, respectively (Table 5).

Number of branches per plant of soybean increased with increase in integration rates of R and P per ha. For example, number of branches per plant increased to 5.0 and 4.0, and 13.50 and 12.0 at the integration rate of 100 g R and 20 Kg P per ha, while to 5.25 and 4.42, and 13.58 and 11.46 at the rate of 100 g R and 30 Kg P per ha for SB19 and SB24 genotypes in both Trial I and II, respectively. Similarly, number of branches per plant increased from 3.75 and 2.92, and 8.33 and 7.17 observed with the control treatment (0 g R and 0 Kg P per ha) to 5.66 and 4.83, and 14.25 and 12.67 at the integration rate of 200 g R and 20 Kg P per ha for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, number of branches per plant significantly increased by 2.58 and 2.5, and 8.33 and 7.91 compared with the control treatment (0 g

R and 0 Kg P per ha) at the integration of R and P at the rate of 200 g and 30 Kg per ha for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 5).

4.2.4 Effect of Different Rates of Rhizobia and Phosphorus on Number of Pods, Fresh and Dry Shoot Weight

There were no significant difference in the number of pods, fresh and dry shoot weight between genotype SB19 and SB24 within and between the two Trials ($p \leq 0.05$). However, there were significant respond of the integration of R and P in number of pods, fresh and dry shoot weight per plant within SB19 and SB24 at ($p \leq 0.05$) in Trial I and II (Appendix 7, 8 and 9). Rhizobia applied at the rate of 100 g per ha, significantly increased pod number per plant from 29.85 and 25.0, and 43.17 and 38.92 the control treatment (0 g R and 0 Kg P per ha) to 30.08 and 33.92, and 50.17 and 45.83 for SB19 and SB24 genotypes in both Trials, respectively.

Number of pods per plant significantly increased by 14.23 and 14.92, and 8.83 and 7.25 at the application rate of 200 g R per ha compared to the control treatment (0 g R and 0 Kg P per ha) for SB19 and SB24 genotypes in both Trials, repectively (Table 6). When P was applied at the rate of 20 Kg per ha, soybean pod number per plant significantly increased from 29.85 and 25, and 43.17 and 38.92 observed with the control treatment (0 g R and 0 Kg P per ha) to 30.83 and 25.92, and 49.5 and 44.42 for SB19 and SB24 genotypes in both Trials, respectively. Furthermore, number of pods per plant significantly increased from the control treatment (0 g R and 0 Kg P per ha) to 40.08 and 35.17, and 54.83 and 49.25 at the rate of 30 Kg P per ha for SB19 and SB24 soybean genotypes in Trial I and II, respectively (Table 6).

Integration of R and P at the rates of 100 g and 20 Kg per ha significantly increased number of pods per plant from 29.85 and 25, and 43.17 and 38.92 the control treatment (0 g R and 0 Kg P per ha) to 52.92 and 47.33, and 55.17 and 49.75 for SB19 and SB24 soybean genotypes both in Trial I and II, respectively. This was a significant increase in pod number per plant from the control treatment (0 g R and 0 Kg P per ha) to 66.0 and 61, and 75.33 and 46.17 at the integration of R and P at the rates of 100 g and 30 Kg per ha for SB19 and SB24 genotypes in both Trial, respectively.

Table 6: Effect of Rhizobia and phosphorus on Soybean Number of Pod, Fresh Weight (g) and Dry Shoot Weight (g) Per Plant

Variety	Trial 1				Trial 2		
	Trt	NP	FS wt(g)	DS wt (g)	NP	FS wt (g)	DS wt (g)
SB19	T1	29.85^{f}*	61.52^{f}	39.38^{d}	25^{f}	56.17^{f}	26.92^{d}
	T2	30.83^{ef}	63.26^{f}	42.12^{d}	25.92^{f}	58.08^{f}	32.00^{d}
	T3	40.08^{cde}	75.62^{cde}	52.53^{cd}	35.17^{e}	70.33^{cde}	42.42^{cd}
	T4	39.08^{de}	69.25^{ef}	54.56^{cd}	33.92^{e}	64.50^{ef}	44.58^{cd}
	T5	52.92^{c}	82.55^{bcd}	59.33^{bc}	47.33^{d}	77.25^{ab}	49.17^{bc}
	T6	66.00^{b}	90.85^{ab}	68.59^{a}	61.00^{b}	85.92^{ab}	58.17^{a}
	T7	44.08^{cd}	70.73^{def}	50.80^{cd}	39.92^{e}	65.58^{def}	40.92^{cd}
	T8	63.25^{b}	84.25^{abc}	65.00^{ab}	58.25^{c}	79.17^{abc}	54.08^{ab}
	T9	76.33^{a}	100.72^{a}	80.57^{a}	71.42^{a}	95.42^{a}	70.50^{a}
SB24	T1	43.17^{f}	73.17^{f}	49.15^{d}	38.92^{d}	65.42^{f}	38.92^{d}
	T2	49.5^{ef}	92.00^{f}	50.65^{d}	44.42^{cd}	67.92^{f}	40.42^{d}
	T3	54.83^{cde}	75.85^{cde}	61.21^{cd}	49.25^{c}	86.75^{cde}	51.17^{cd}
	T4	50.17^{de}	92.25^{ef}	55.87^{cd}	45.83^{c}	71.00^{ef}	45.42^{cd}
	T5	55.17^{c}	108.03^{bcd}	70.80^{bc}	49.75^{c}	87.08^{bcd}	60.42^{bc}
	T6	75.33^{b}	111.55^{ab}	91.60^{a}	70.91^{a}	97.72^{ab}	82.45^{a}
	T7	52.00^{cd}	78.55^{def}	58.51^{cd}	46.17^{c}	73.25^{def}	47.58^{cd}
	T8	69.67^{b}	108.03^{abc}	87.58^{ab}	64.50^{b}	102.75^{abc}	77.58^{b}
	T9	82.75^{a}	116.17^{a}	98.59^{a}	77.75^{a}	111.08^{a}	88.50^{a}
MSD		7.79	13.95	13.9	7.65	15.11	28.56
CV%		15.8	18.23	24.26	17.15	21.18	13.7

Means with the same letter along the column for the same variety are not significantly different at ($p \leq 0.05$*); MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; NP=Number of Pods; FS wt=Fresh shoot weight; DS wt=Dry shoot weight; R=Rhizobia; P=Phosphorus.

Similarly, pod number per plant significantly increased by 33.4 and 33.25, and 26.5 and 25.58 at the integration of R and P at the rates of 200 g and 20 Kg per ha compared to the control treatment (0 g R and 0 Kg P per ha) for SB19 and SB24 genotypes both in Trial, respectively. Furthermore, number of pods per plant significantly increased from the control treatment (0 g R and 0 Kg P per ha) to 76.33 and 71.42, and 82.75 and 77.75 at the integration of R and P at the rate of 200 g and 30 Kg per ha for SB19 and SB24 genotypes in both Trials, respectively. This observed the highest mean difference of 46.48 and 46.42, and 39.58 and 38.83 compared to the control treatment (0 g R and 0 Kg P per ha) for SB19 and SB24 soybean genotypes for Trial I and II, respectively.

Increase in application of R alone significantly increased the soybean fresh shoot weight (FSW). Application of R at the rate of 100 g per ha, significantly increased FSW per plant from 61.52 g and 56.17 g, and 73.17 g and 65.42 g the control treatment to 69.25 g and 77.25 g, and 92.25 g and 71.00 g SB19 and SB24 genotypes in both Trials, respectively. Similarly, FSW per plant increased by 9.21 g and 14.56 g, and 5.38 g 7.83 g at the application rate of 200 g R per ha compared to the control treatment for SB19 and SB24 genotypes in both Trial I and II, repectively (Table 6).

Phosphorus application significantly increased FSW of soybean plants in the present study. Phosphorus, at the rate of 20 Kg P per ha, fresh shoot weight per plant significantly increased by 1.74 g and 1.91 g, and 18.83 g and 2.5 g compared to the control treatment for SB19 and SB24 genotypes in both Trials, respectively. Similarly, FSW per plant increased from 61.52 g and 56.17 g, and 73.17 g and 65.42 g the control treatment to 72.62 g and 70.33 g, and 75.85 g and 86.75 g at the rate of 30 Kg P per ha for SB19 and SB24 genotypes in both Trials, respectively (Table 6).

Integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased FSW plant^{-1} to 82.55 g and 77.25 g, and 108.03 g and 87.08 g from the control treatment (0 g R and 0 Kg P per ha) for SB19 and SB24 genotypes in both Trials, respectively. Furthermore, integration of R and P at the rate of 100 g and 30 Kg per ha significantly increased FSW per plant from 61.52 g and 56.17 g, and 73.17 g and 65.42 g the control treatment to 90.85 g and 85.92 g, and 111.55 g and 97.72 g for SB19 and SB24 genotypes in both Trials, respectively. Similarly, integration of R and P at the rate of 200 g and 20 Kg per ha, increased FSW per plant from the control treatment to 84.3 g and 79.2 g, and 108 g and 102.8 g for SB19 and SB24 genotypes in both Trials, respectively. Compared to the control treatment FSW per plant significantly increased by 39.2 g and 39.3 g, and 43 g and 45.7 g at the integration of R and P at the rate of 200 g and 30 Kg per ha for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 6).

Rhizobia application increased dry shoot weight (DSW) plant^{-1} in soybean. Rhizobia, at the rate of 100 g per ha, significantly increased DSW per plant from 39.38 g and 26.92 g, and 49.15 g and 38.92 g observed with the control treatment (0 g R and 0 Kg

P per ha) to 54.56 g and 44.58 g, and 55.87 g and 45.42 g for SB19 and SB24 genotypes in both Trials, respectively. Resulting to a mean difference of 15.18 g and 17.66 g, and 6.72 and 6.5 g for SB19 and SB24 genotypes in both Trial I and II, respectively. Similarly, DSW per plant increased from the control treatment to 50.80 g and 40.92 g, and 58.51 g and 47.58 g at the application of R at 200 g per ha for SB19 and SB24 genotypes in both Trials, repectively (Table 6).

When P was applied at the rate of 20 Kg per ha it significantly increased DSW per plant from 39.38 g and 26.92 g, and 49.15 g and 38.92 g observed with the control treatment (0 g R and 0 Kg P per ha) to 42.12 g and 32.00 g, and 50.65 g and 40.42 g for SB19 and SB24 genotypes in both Trial I and II, respectively. Compared to control DSW per plant significantly increased by 13.15 g and 15.5 g, and 12.06 g and 12.25 g at the application of P at the rate of 30 Kg per ha for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 6).

Integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased DSW per plant from 39.38 g and 26.92 g, and 49.15 g and 38.92 g observed with the control treatment (0 g R and 0 Kg P per ha) to 59.33 g and 49.17 g, and 70.80 g and 60.42 g for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, at the integration of R and P at rate of 100 g and 30 Kg per ha significantly increased DSW per plant from the control treatment to 68.59 g and 58.17 g, and 91.60 g and 82.45 g for SB19 and SB24 in both Trials, respectively. Similarly, at the integration of R and P at the rate of 200 g and 20 Kg per ha, significantly increased DSW per plant from the control treatment (0 g R and 0 Kg P per ha) to 65.00 g and 54.08 g, and 87.58 g and 77.58 g for SB19 and SB24 genotype in both Trial I and II, respectively. Compared to control dry shoot weight DSW per plant significantly increased by 41.19 g and 43.58 g, and 49.44 g and 49.58 g at the integration of R and P at the rate of 200 g and 30 Kg per ha for SB19 and SB24 in both Trials, respectively (Table 6).

4.2.5 Effect of Different Rates of Rhizobium and Phosphorus on Soybean Root Length and Seed Weight

There were no significant difference in root length and seed weight between genotype SB19 and SB24 within and between Trial I and II (*p≤0.05*). However, there were significant influence of the integration of R and P in root length and seed weight per plant within individual genotypes at (*p≤0.05*) in both Trials (Appendix 10 and 11). Rhizobia applied at the rate of 100 g per ha, significantly increased the root length per plant from 12.33 cm and 11.33 cm, and 15.25 cm and 14.42 cm observed with the control treatment (0 g R and 0 Kg P per ha) to 12.50 cm and 11.50 cm, and 21.17 cm and 20.75 cm for SB19 and SB24 genotypes in both Trials, respectively. Similarly, at the application of R at the rate of 200 g per ha, the root length per plant increased from the control treatment to 15.17 cm and 14.17 cm, and 25.58 cm and 24.5 cm for SB19 and SB24 genotypes in Trial I and II, repectively (Table 7).

Table 7: Effect of Rhizobia and Phosphorus on Soybean Root Length (cm) and Seed weight (g) per Plant

Variety		Trial 1		Trial 2	
	Trt	RL (cm)	Seedwt(g)	RL (cm)	Seed wt. (g)
SB19	T1	12.33^{e}*	6.14^{f}	11.33^{e}	4.13^{e}
	T2	12.62^{de}	8.49^{de}	11.67^{de}	6.55^{cd}
	T3	15.5^{cd}	9.08^{d}	14.50^{cd}	7.08^{c}
	T4	12.5^{de}	7.64^{e}	11.50^{de}	5.64^{d}
	T5	17.58^{bc}	10.21^{c}	16.58^{bc}	8.21^{b}
	T6	18.75^{ab}	11.01^{b}	17.75^{ab}	9.01^{b}
	T7	15.17^{bcd}	8.55^{de}	14.17^{bcd}	6.55^{cd}
	T8	20.79^{ab}	10.61^{bc}	19.75^{ad}	8.61^{b}
	T9	23.17a	12.36^{a}	22.16^{a}	10.36^{a}
SB24	T1	15.25^{e}	7.17^{f}	14.42^{e}	5.13^{e}
	T2	21.75^{de}	9.28^{de}	20.75^{de}	7.27^{cd}
	T3	22.96 ^{cd}	9.86^{d}	21.92^{cd}	7.86^{c}
	T4	21.17^{de}	9.30^{e}	20.17^{ed}	7.30^{d}
	T5	26.67^{bc}	11.08^{c}	25.67^{bc}	9.15^{b}
	T6	29.68^{ab}	12.29^{b}	27.82^{ab}	10.29^{b}
	T7	25.58^{bcd}	10.22^{de}	24.50^{bcd}	8.25^{cd}
	T8	28.00^{ab}	11.79^{bc}	27.00^{ab}	9.72^{b}
	T9	31.21^{a}	14.20^{a}	31.50^{a}	12.24^{a}
MSD		4.25	0.98	4.21	0.98
CV(%)		22.78	17.4	23.8	21.82

*Means with the same letter along the column for the same variety are not significantly different at (*p≤0.05*); MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively;

T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; RL=Root Length; R=Rhizobia; P=Phosphorus.

Phosphorus application significantly increased the soybean root length per plant. Application of P at the rate of 20 Kg per ha, significantly increased root length per plant from 12.33 cm and 11.33 cm, and 15.25 cm and 14.42 cm observed with the control treatment (0 g R and 0 Kg P per ha) to 12.62 cm and 11.67 cm, and 21.75 cm and 20.75 cm for SB19 and SB24 genotypes in both Trials, respectively. Further, application of P at the rate of 30 Kg per ha, significantly increased the root length per plant from the control treatment to 15.5 cm and 14.5 cm, and 22.96 cm and 21.92 cm for SB19 and SB24 soybean genotypes in Trial I and II, respectively (Table 7).

Integration of R and P significantly increased soybean root length per plant. Application of R and P at the rate of 100 g and 20 Kg per ha, significantly increased the root length per plant from 12.33 cm and 11.33 cm, and 15.25 cm and 14.42 cm observed with the control treatment (0 g R and 0 Kg P per ha) to 17.58 cm and 16.58 cm, and 26.67 cm and 25.67 cm for SB19 and SB24 genotypes in both Trials, respectively. This resulted to a mean difference of 5.25 cm and 11.42 cm, and 11.25 cm for SB19 and SB24 soybean genotypes in Trial I and II, respectively. Compared to control, the root length per plant significantly increased by 6.42 cm, and and 14.43 cm and 13.40 cm at the integration application of R and P at the rate of 100 g and 30 Kg per ha for SB19 and SB24 soybean genotypes in both Trial, respectively. Similarly, the root length per plant significantly increased from the control treatment (0 g R and 0 Kg P per ha) to 20.79 cm and 19.75 cm, and 28 cm and 27 cm at the integration application of R and P at the rate of 200 g and 20 Kg per ha for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased the root length per plant from control to 23.17 cm and 22.16 cm, and 31.21 cm and 31.5 cm for SB19 and SB24 genotypes in Trial I and II, respectively (Table 7).

Rhizobia application significantly increased soybean seed weight per plant in Trial I and II. Rhizobia application at the rate of 100 g per ha, significantly increased soybean seed weight per plant from 6.14 g and 4.13 g, and 9.08 g and 7.08 g observed with the control treatment (0 g R and 0 Kg P per ha) to 7.64 g and 5.64 g, and 9.3 g and 7.3 g for SB19 and SB24 genotypes in both Trials, respectively. Rhizobia at the rate of 200 g per ha, significant increased seed weight per plant from the control treatment to 8.55 g and 6.55 g, and 10.22 g and 8.25 g for SB19 and SB24 genotypes in both Trials, respectively (Table 7). Phosphorus application significantly increased the seed weight per plant. Application of P at the rate of 20 Kg per ha, significantly increased seed weight per plant from 6.14 g and 4.13 g, and 9.08 g and 7.08 g observed with the control treatment (0 g R and 0 Kg P per ha) to 8.49 g and 6.55 g, and 9.28 g and 7.27 g for SB19 and SB24 genotypes in both Trials, respectively. At the rate of 30 kg P per ha, significantly increased the seed weight per plant from the control treatment to 9.08 g and 7.08, and 9.86 g and 7.86 for SB19 and SB24 genotypes in Trial I and II, respectively (Table 7).

Integration of R and P application at the rate of 100 g and 30 Kg per ha, significantly increased seed weight per plant from the control treatment (0 g R and 0 Kg P per ha) to 11.01 g and 9.01 g, and 12.29 g and 10.29 g for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, integration of R and P at the rate of 200 g and 20 Kg per ha, significantly increased seed weight per plant from the control treatment to 10.61 g and 8.61 g, and 11.79 g and 9.72 g for SB19 and SB24 genotypes in both Trials, respectively. Similarly, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased seed weight per plant from the control treatment (0 g R and 0 Kg P per ha) to 12.36 g and 10.36 g, and 14.2 g and 12.24 g for SB19 and SB24 genotypes in both Trials, respectively (Table 7).

4.3 Effect of Different Rates of Rhizobium and Phosphorus on Tissue Content, Symbiotic and Phosphorus Use Efficiency in Soybean Production

4.3.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Shoot and Grain Nitrogen Content

There were no significant difference in shoot and grain N content between genotype SB19 and SB24 within and between Trial I and II ($p \leq 0.05$). However, there were significant respond of the integration of R and P in shoot and grain N content within genotypes SB19 and SB24 at ($p \leq 0.05$) in both Trials (Appendix 12 and 13). Rhizobia application significantly increased shoot N content. For instance, application of R at the rate of 100 g per ha, significantly increased shoot N content from 0.81% and

0.7%, and 0.78% and 0.71% observed with the control treatment (0 g R and 0 Kg P per ha) to 0.98% and 0.92%, and 0.98% and 0.96% for SB19 and SB24 genotypes in Trial I and II, respectively. Similarly, application of R at the rate of 200 g per ha, increased the shoot N content from the control treatment to 1.4% and 1.03%, and 1.46% and 1.09% for SB19 and SB24 genotypes in both Trials, respectively (Table 8).

Table 8: Effect of Rhizobia and Phosphorus on Soybean Shoot and Grain N Content.

Variety		Trial 1		Trial 2	
	Trt	Shoot N (%)	Grain N (%)	Shoot (N %)	Grain N (%)
SB19	T1	0.81^{g}*	5.12^{g}	0.7^{g}	4.4^{f}
	T2	0.88^{gf}	5.54^{f}	0.8^{fg}	4.5^{f}
	T3	0.94^{f}	5.69^{fe}	0.83^{fe}	4.73^{e}
	T4	0.98^{f}	5.8^{e}	0.92^{e}	4.83^{e}
	T5	1.53^{d}	6.8^{c}	1.06^{d}	5.20^{c}
	T6	2.2^{b}	7.69^{b}	1.6^{b}	5.41^{b}
	T7	1.4^{e}	5.97^{d}	1.03^{d}	5.11^{d}
	T8	2.15^{c}	6.82^{c}	1.44^{c}	5.31^{b}
	T9	2.98^{a}	8.93^{a}	1.73^{a}	6.51^{a}
SB24	T1	0.78^{g}	5.57^{g}	0.71^{g}	4.64^{f}
	T2	0.92^{gf}	5.62^{f}	0.81^{fg}	4.62^{f}
	T3	0.96^{f}	5.83^{fe}	0.86^{fe}	4.84^{e}
	T4	0.98^{f}	5.80^{e}	0.96^{e}	4.88^{e}
	T5	1.63^{d}	6.80^{c}	1.07^{d}	5.29^{c}
	T6	2.46^{b}	7.74^{b}	1.6^{b}	5.61^{b}
	T7	1.46^{e}	6.02^{d}	1.09^{d}	5.07^{d}
	T8	2.10^{c}	6.98^{c}	1.5^{c}	5.50^{b}
	T9	3.09^{a}	9.10^{a}	1.73^{a}	6.57^{a}
MSD		0.11	0.19	0.11	0.14
C.V.		6.75	2.78	9.16	2.65

*Means with the same letter along the column for the same variety are not significantly different at $p \leq 0.05$; MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; R=Rhizobia; P=Phosporus.

When P was applied at the rate of 20 Kg per ha, it significantly increased shoot N content from 0.81% and 0.7%, and 0.78% and 0.71% observed with the control treatment (0 g R and 0 Kg P per ha) to 0.88% and 0.80%, and 0.92% and 0.81% for SB19 and SB24 soybean genotypes in Trial I and II, respectively. At the application of P at the rate 30 Kg per ha, shoot N content increased from the control treatment to

0.94% and 0.83%, and 0.96% and 0.86% for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 8).

Integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased shoot N content from 0.81% and 0.7%, and 0.78 and 0.71% observed with the control treatment (0 g R and 0 Kg P per ha) to 1.53% and 1.06%, and 1.63% and 1.07% for SB19 and SB24 genotypes for Trial I and II, respectively. Compared to control, integration of R and P at the rate of 100 g and 30 Kg per ha, significantly increased shoot N content by 1.39% and 0.9%, and 1.68% and 0.89% for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, integration at the rate of 200 g and 20 Kg per ha, increased shoot N content to 2.15% and 1.44%, and 2.1% and 1.5% for SB19 and SB24 genotypes in both Trial I and II, respectively. Similarly, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased shoot N content to 2.98% and 1.73%, and 3.09% and 1.73% for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 8).

When P was applied at the rate of 20 Kg per ha, it significantly increased shoot N content from 0.81% and 0.7%, and 0.78% and 0.71% observed with the control treatment (0 g R and 0 Kg P per ha) to 0.88% and 0.80%, and 0.92% and 0.81% for SB19 and SB24 genotypes in Trial I and II, respectively. Phosphorus at the rate of 30 Kg per ha, increased shoot N content from the control treatment to 0.94% and 0.83%, and 0.96% and 0.86% for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 8).

Integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased shoot N content from 0.81% and 0.7%, and 0.78 and 0.71% observed with the control treatment (0 g R and 0 Kg P per ha) to 1.53% and 1.06%, and 1.63% and 1.07% for SB19 and SB24 genotypes in both Trials, respectively. Compared to control, application of R and P at the rate of 100 g and 30 Kg per ha, significantly increased shoot N content by 1.39% and 0.9%, and 1.68% and 0.89% for SB19 and SB24 genotypes in both Trials, respectively. Furthermore, integration of R and P at the rate of 200 g and 20 Kg per ha, increased shoot N content to 2.15% and 1.44%, and 2.1% and 1.5% for SB19 and SB24 genotypes in both Trials, respectively. Similarly, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased shoot N content to 2.98% and 1.73%, and 3.09% and 1.73% for SB19 and SB24 genotypes in both Trials, respectively (Table 9).

Rhizobia application significantly increased grain N content for SB19 and SB24 genotypes in both Trial I and II. For example, rhizobia application at the rate of 100 g per ha, increased grain N content from 5.12% and 4.4%, and 5.57% and 4.64% observed with the control treatment (0 g R and 0 Kg P per ha) to 5.8% and 4.83%, and 5.8% and 4.88% for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, R application at the rate of 200 g per ha, significantly increased grain N content to 5.97% and 5.11%, and 6.02% and 5.07% for SB19 and SB24 genotypes in both Trial I and II, respectively.

Integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased grain N content from 5.12% and 4.4%, and 5.57% and 4.64% observed with the control treatment (0 g R and 0 Kg P per ha) to 6.8% and 5.2%, and 6.8% and 5.29% for SB19 and SB24 genotypes in both Trials, respectively. Compared to the control, treatment application of R and P at the rate of 100 g and 30 Kg per ha, increased grain N content by 2.57% and 1.01%, and 2.17% and 0.97% for SB19 and SB24 genotypes in Trial I and II, respectively. Similarly, integration of R and P application at the rate of 200 g and 20 Kg per ha, increased grain N content from the control treatment to 6.82% and 5.31%, and 6.98% and 5.5% for SB19 and SB24 genotypes in Trial I and II, respectively. Compared to control, integration of R and P application at the rate of 200 g and 30 Kg per ha, increased grain N content by 3.81% and 2.11%, and 3.53% and 1.93% for SB19 and SB24 genotypes in both Trial, respectively (Table 8).

4.3.2 Effect of Integration of Different Rates of Rhizobium and Phosphorus on Shoot and Grain Phosphorus Content

There was no significant difference in shoot and grain P content between genotype SB19 and SB24 within and between the two Trials ($p \leq 0.05$). However, there was significant effect of the integration of R and P in shoot and grain P content within genotypes SB19 and SB24 at ($p \leq 0.05$) in Trials I and II (Appendix 14 and 15). Rhizobia application increased shoot P content in SB19 and SB24 genotypes in both Trial I and II. For instance, application of R at the rate of 100 g per ha, significantly increased the Shoot P content from 253.1 ppm and 248.2 ppm, and 256.9 ppm and 251.8 ppm observed with the control treatment (0 g R and 0 Kg P per ha) to 334.3

ppm and 328.4 ppm, and 337.4 ppm and 332.1 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 9).

Similarly, the Shoot P content increased from the control treatment (0 g R and 0 Kg P per ha) to 361.7 ppm and 385.4 ppm, and 366.0 ppm and 383.0 ppm at the application of R at the rate of 200 g per ha for SB19 and SB24 genotypes in Trial I and II, repectively (Table 9). Phosphorus application at the rate of 20 Kg per ha significantly increased the Shoot P content to 290.2 ppm and 285 ppm, and 294 ppm and 289 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, application of P at the rate of 30 Kg per ha increased the Shoot P content from 253.1 ppm and 248.2 ppm, and 256.9 ppm and 251.8 ppm observed with the control treatment (0 g R and 0 Kg P per ha) to 326.1 and 320.6 ppm, and 333.6 and 327.8 ppm for SB19 and SB24 genotypes in Trial I and II, respectively (Table 9).

Table 9: Effect of Rhizobia and Phosphorus on Soybean Shoot and Grain P Content.

Variety		Trial 1		Trial 2	
	Trt	Shoot P (ppm)	Grain P (ppm)	Shoot P (ppm)	Grain P (ppm)
SB19	T1	253.1^{h*}	225.6^{i}	248.2^{h}	235.6^{i}
	T2	290.2^{g}	323.3^{h}	285.0^{g}	333.3^{h}
	T3	326.1^{f}	340.6^{g}	320.6^{f}	350.8^{g}
	T4	334.3^{f}	509.9^{e}	328.4^{f}	519.6^{f}
	T5	488.4^{d}	579.8^{c}	497.9^{d}	589.8^{d}
	T6	671.6^{b}	734.4^{b}	737.2^{b}	834.3^{b}
	T7	361.7^{e}	430.1^{f}	385.4^{e}	529.6^{e}
	T8	542.0^{c}	524.6^{d}	649.9^{c}	624.6^{c}
	T9	849.6^{a}	852.4^{a}	906.0^{a}	950.0^{a}
SB24	T1	256.9^{h}	241.7^{i}	251.8^{h}	240.6^{i}
	T2	294.0^{g}	328.4	289.0^{g}	338.4^{h}
	T3	333.6^{f}	346.4^{g}	327.8^{f}	356.4^{g}
	T4	337.4^{f}	514.1^{e}	332.1^{f}	524.56^{f}
	T5	490.4^{d}	584.4^{c}	510.6^{d}	594.7^{d}
	T6	672.2^{b}	739.4^{b}	738.4^{b}	839.3^{b}
	T7	366.0^{e}	434.2	383.0^{e}	534.6^{e}
	T8	535.7^{c}	529.7^{d}	660.2^{c}	629.7^{c}
	T9	849.6^{a}	853.3^{a}	913.8^{a}	955.0^{a}
MSD		9.7	0.19	6.73	0.14
C.V.		2.01	1.8	1.31	0.85

*Means with the same letter along the column for the same variety are not significantly different at ($p \leq 0.05$); MSD=Mean Significant Difference; Treatments: T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; R=Rhizobia; P=Phosphorus.

Integration of R and P application rate increased shoot P content in SB19 and SB24 genotypes. For instance, integration of R and P application at the rate of 100 g and 20 Kg per ha, significantly increased shoot P content from 253.1 ppm and 248.2 ppm, and 256.9 ppm and 251.8 ppm observed with the control treatment (0 g R and 0 Kg P per ha) to 488.4 ppm and 497.9 ppm, and 490.4 ppm and 510.6 ppm for SB19 and SB24 genotypes in Trial I and II, respectively. Similarly, at the integration application of R and P at the rate of 100 g and 30 Kg per ha, shoot P content significantly increased from the control treatment (0 g R and 0 Kg P per ha) to 671.6 ppm and 737.2 ppm, and 672.2 ppm and 738.4 ppm for SB19 and SB24 soybean genotypes in Trial I and II, respectively.

Compared to control, integration of R and P at the rate of 200 g and 20 Kg per ha, significantly increased shoot P content by 288.9 ppm and 401.7 ppm, and 278.8ppm and 408.4 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, integration of R and P application at the rate of 200 g and 30 Kg per ha, significantly increased shoot P content to 849.6 ppm and 906 ppm, and 849.6 ppm and 913.8 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 9).

Rhizobia application increased grain P content in SB19 and SB24 genotypes in both Trial I and II. For example, R application at the rate of 100 g per ha, significantly increased the grain P content from 225.6 ppm and 235.6 ppm, and 241.7 ppm and 240.6 ppm observed with the control treatment (0 g R and 0 Kg P per ha) to 509.9 ppm and 519.6 ppm, and 514.1 ppm and 524.5 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively. Compared to control, application of R at the rate of 200 g per ha significantly increased the grain P content from the control treatment to 430.1 ppm and 529.6 ppm and 434.2 and 534.6 ppm for SB19 and SB24 genotypes in both Trial I and II, repectively (Table 9).

Phosphorus application at the rate of 20 Kg per ha, significantly increased the grain P content from the control treatment (0 g R and 0 Kg P per ha) to 323.3 ppm and 333.3 ppm, and 328.4 ppm and 338.4 ppm. While at the application of P at the rate of 30 Kg per ha, increased grain P content from the control treatment to 340.6 ppm and 350.8

ppm, and 346.4 ppm and 356.4 ppm for SB19 and SB24 genotypes in Trial I and II, respectively (Table 9). Integration of R and P application increased grain P content in SB19 and SB24 genotypes in both Trials. For instance, integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased grain P content from the control treatment to 579.8 ppm and 589.8 ppm, and 584.4 and 594.7 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively.

At the integration of R and P at the rate of 100 g and 30 Kg per ha, grain P content significantly increased grain P content to 734.4 ppm and 8 34.4 ppm, and 739.4 ppm and 839.3 ppm for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, integration of R and P at the rate of 200 g and 20 Kg per ha, significantly increased grain P content to 524.6 ppm and 624.6 ppm and 535.7 ppm and 629.7 ppm for SB19 and SB24 genotypes in both Trial I and II, respectively. Similarly, integration of R and P application at the rate of 200 g and 30 Kg per ha, significantly increased grain P content to 852.4 ppm and 950 ppm, and 853.3 ppm and 955 ppm for SB19 and SB24 genotypes in both Trials, respectively (Table 9).

4.3.3 Effect of Different Rates of Rhizobium and Phosphorus on Rhizobium Symbiosis and Use Efficiency

4.3.3.1 Effect of Different Rates of Rhizobium and Phosphorus on Symbiotic Efficiency

There was no significant difference in symbiotic effeciency between genotype SB19 and SB24 within and between Trials I and II ($p \leq 0.05$). However, there was significant influence of the integration of R and P in symbiotic effeciency within genotypes SB19 and SB24 at ($p \leq 0.05$) in Trials I and II (Appendix 16). Rhizobia application increased symbiotic efficiency in genotypes in both Trials. For example, application of R at the rate of 100 g, increased symbiotic efficiency (SEF) from 101% and 107%, and 101% and 100% observed with the control treatment (0 g R and 0 Kg P per ha) to 129% and 165%, and 114% and 116% for SB19 and SB24 genotypes in Trial I and II, respectively (Table 10).

Similarly, R application at the rate of 200 g per ha, increased the SEF from the control treatment (0 g R and 0 Kg P per ha) to 130 and 152%, and 119 and 122% for SB19 and SB24 genotypes in Trial I and II, repectively (Table 10). Compared to control, P application at the rate of 20 Kg per ha, significantly increased the SEF by 7% and 12%, and 1% and 4% for SB19 and SB24 genotypes in Trial I and II, respectively. When P was applied at the rate of 30 Kg per ha, increased the SEF from the control treatment to 135% and 157%, and 126% and 131%. Resulting to a mean difference of 34% and 50%, and 25% and 31% for SB19 and SB24 genotypes in Trial I and II, respectively (Table 10).

Table10: Effect of Rhizobia and Phosphorus on Symbiotic Efficiency (%), Phosphorus (Kg/Kg) and Rhizobium (Kg/Kg)

Variety		Trial 1		Trial II	
	Trt	SEF (%)	PUE (Kg/Kg)	SEF(%)	PUE (Kg/Kg)
SB19	T1	101^{d*}	0^{d}	107^{d}	0^{d}
	T2	108^{d}	4.65^{c}	119^{d}	4.8^{c}
	T3	135^{cd}	3.9^{c}	157^{cd}	3.9^{c}
	T4	129^{cd}	0^{d}	165^{cd}	0^{d}
	T5	153^{bc}	8.15^{a}	182^{bc}	8.15^{b}
	T6	176^{ab}	6.49^{b}	149^{bc}	3.78^{c}
	T7	130^{cd}	0^{d}	152^{cd}	0^{d}
	T8	167^{ab}	8.6^{a}	200^{ab}	8.96^{a}
	T9	207^{a}	6.9^{a}	261^{a}	8.75^{a}
SB24	T1	101^{d}	0^{d}	100^{d}	0
	T2	103^{d}	4.2^{c}	104^{d}	4.3^{b}
	T3	126^{cd}	3.6^{c}	131^{cd}	3.6^{c}
	T4	114^{cd}	0^{d}	116^{cd}	0^{d}
	T5	145^{bc}	7.8^{a}	155^{bc}	3.8^{c}
	T6	187^{ab}	6.6^{bc}	209^{bc}	4.2^{b}
	T7	119^{cd}	0^{d}	122^{cd}	0^{d}
	T8	179^{ab}	8.9^{a}	199^{ab}	9^{a}
	T9	201^{a}	9.4^{a}	227^{a}	9.5^{a}
MSD		31	1.3	46	1.4
CV (%)		25	58	31	59

Means with the same letter along the column for the same variety are not significantly different at ($p \leq 0.05$*); MSD=Mean Significant Difference; Treatments: T1 =Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8 =200 g R and 20 Kg P per ha and T9 =200 g R and 30 Kg P per ha; PUE=Phosphorus Use Efficiency; SEF=Symbiosis efficiency

Integration of R and P applicaton at the rate of 100 g and 20 Kg per ha, significantly increased SEF from the control treatment (0 g and 0 Kg per ha) to 153% and 182%, and 145 and 155% for SB19 and SB24 genotypes in Trial I and II, respectively. Compared to control, integration of R and P application at the rate of 100 g and 20 Kg per ha, significantly increased SEF by 153% and 182%, and 145 and 155% for SB19 and SB24 genotypes in both Trial I and II, respectively.

Furthermore, the integration of R and P at the rate of 100 g and 30 Kg per ha, significantly increased SEF to 176 and 149%, and 187 and 209% for SB19 and SB24 genotypes in Trial I and II, respectively. Furthermore, integration of R and P at the rate of 200 g and 20 Kg per ha, significantly increased SEF from 101% and 107%, and 101% and 100% observed with the control treatment (0 g R and 0 Kg P per ha) to 167% and 200%, and 179 and 199% for SB19 and SB24 genotypes in Trial I and II, respectively. Compared to control, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased SEF by 106% and 154%, and 101 and 127% for SB19 and SB24 genotypes in Trial I and II, respectively (Table 10).

4.3.4 Effect of Different Rates of Rhizobium and Phosphorus on Phosphorus Use Efficiency

There were no significant difference in phosphorus use effeciency (PUE) between genotype SB19 and SB24 within and between Trials I and II ($p \leq 0.05$). However, there were significant respond of the integration of R and P in PUE within genotypes SB19 and SB24 at ($p \leq 0.05$) in Trials I and II (Appendix 18). When P was applied at the rate of 20 Kg per ha, the soybean grain yield obtained per unit of P applied increased to 4.65 Kg/Kg and 4.8 Kg/Kg, and 4.2 Kg/Kg and 4.28 Kg/Kg for SB19 and SB24 soybean genotypes in Trial I and II, respectively. Furthermore, when P was applied at the rate of 30 Kg per ha the soybean grain yields obtained per unit of P applied increased from the control treatment (0 g and 0 Kg per ha) to 3.93 Kg/Kg and 3.9 Kg/Kg, and 3.58 Kg/Kg and 3.6 Kg/Kg for SB19 and SB24 genotypes in Trial I and II, respectively.

Integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased soybean grain yield obtained per unit of P applied from the control treatment (0 g and 0 Kg per ha) to 8.15 Kg/Kg and 7.8 Kg/Kg, and 3.95 Kg/Kg for SB19 and SB24 soybean genotypes in Trial I and II, respectively. Similarly, integration of R and P at the rate of 100 g and 30 Kg per ha, increased soybean grain yield obtained per unit of

P applied from the control treatment to 6.49 Kg/Kg and 3.78 Kg/Kg, and 6.6 Kg/Kg and 4.16 Kg/Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Integration of R and P at the rate of 200 g and 20 Kg per ha, increased grain yield obtained per unit of P applied from the control treatment (0 g and 0 Kg per ha) to 8.6 Kg/Kg and 8.96 Kg/Kg, and 8.9 Kg/Kg and 9.18 Kg/Kg for SB19 and SB24 genotypes in Trial I and II, respectively.

Furthermore, integration of R and P at the rate of 200 g and 30 Kg per ha increased grain yield obtained per unit of P applied from the control treatment (0 g and 0 Kg per ha) to 6.9 Kg/Kg and 8.75 Kg/Kg, and 9.37 Kg/Kg and 9.48 Kg/Kg for SB19 and SB24 genotypes in Trial I and II, respectively (Table 10).

4.4 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield and Net Economic Benefit of Soybean Enterprise

4.4.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield

There were significant influence of the integration of R and P in grain yields within genotypes SB19 and SB24 at ($p \leq 0.05$) in Trials I and II (Appendix 19) at ($p \leq 0.05$). Rhizobia application increased grain yields of SB19 and SB24 genotypes in both Trial I and II. For example, R application at the rate of 100 g per ha, significantly increased the grain yield per ha from 1227 Kg and 826 Kg, and 1434 Kg and 1024 Kg observed with the control treatment (0 g and 0 Kg per ha) to 1529.3 Kg and 1129 Kg, and 1859 Kg and 1459 Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Similarly, R application at the rate of 200 g per ha, increased the grain yields from the control treatment (0 g and 0 Kg per ha) to 1709.9 Kg and 1303 Kg, and 2044 Kg and 1650.7 Kg for SB19 and SB24 genotypes in Trial I and II, repectively (Table 11).

Phosphorus application at the rate of 20 Kg per, ha significantly increased the grain yields per ha, from 1227 Kg and 826 Kg, and 1434 Kg and 1024 Kg observed with the control treatment (0 g and 0 Kg per ha) to 1692 Kg and 1313 Kg, and 1856 Kg and 1455 Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Compared to control, application of P at the rate of 30 Kg per ha, significantly increased the grain yields per ha by 589.7 Kg and 590 Kg, and 537 Kg and 547 Kg for SB19 and SB24 genotypes in Trial I and II respectively (Table 11).

Integration of R and P significantly increased grain yield of SB19 and SB24 genotypes. For instance, integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased grain yields per ha from 1227 Kg and 826 Kg, and 1434 Kg and 1024 Kg observed with the control treatment (0 g and 0 Kg per ha) to 2042.7 Kg and 1641 Kg, and 2217 Kg and 1829 Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Integration of R and P significantly increased grain yield of SB19 and SB24 genotypes. For example, integration of R and P at the rate of 100 g and 20 Kg per ha, significantly increased grain yields per ha from 1227 Kg and 826 Kg, and 1434 Kg and 1024 Kg the control treatment (0 g and 0 Kg per ha) to 2042.7 Kg and 1641 Kg, and 2217 Kg and 1829 Kg for SB19 and SB24 genotypes in Trial I and II, respectively.

Table 11: Effect of Rhizobia and Phosphorus on Grain yield and Net Income

Variety		Trial I		Trial II	
	Trt	GY/ha (Kg)	NEB/Ha (Kshs)	GY/ha (Kg)	NEB/Ha (Kshs)
SB19	T1	1227^{e}*	70722^{e}	826^{e}	11238^{d}
	T2	1692^{cd}	133030^{d}	1312^{cd}	70750^{c}
	T3	1816^{c}	145430^{cd}	1416^{c}	84030^{c}
	T4	1529^{d}	116223^{d}	1128^{d}	56120^{c}
	T5	2042^{b}	184012^{bc}	1641^{b}	127496^{b}
	T6	2201^{b}	199663^{b}	1794^{b}	141630^{b}
	T7	1709^{cd}	142796^{bc}	1302^{cd}	81763^{c}
	T8	2089^{b}	190830^{b}	1722^{b}	135430^{b}
	T9	2472^{a}	239496^{a}	2138^{a}	192730^{a}
SB24	T1	1434^{e}	109296^{e}	1026^{e}	41230^{d}
	T2	1855^{cd}	156520^{d}	1454^{cd}	96330^{c}
	T3	1971^{c}	168663^{cd}	1571^{c}	108630^{c}
	T4	1859^{d}	165730^{d}	1459^{d}	105730^{c}
	T5	2216^{b}	210730^{bc}	1829^{b}	163696^{b}
	T6	2431^{b}	240963^{b}	2058^{b}	184930^{b}
	T7	2044^{cd}	237563^{bc}	1650^{cd}	134080^{c}
	T8	2324^{b}	225780^{b}	1944^{d}	173630^{b}
	T9	2840^{a}	297930^{a}	2449^{a}	239330^{a}
MSD		194.36	45373	199.25	29750
CV (%)		17.19	17.2	21.9	21.7

*Means with the same letter along the column for the same variety are not significantly different at (*p≤0.05*) MSD=Mean Significant Difference; Treatments:

T1= Control (0 g R and 0 Kg P per ha); T2 and T3=20 Kg and 30 Kg P per ha respectively; T4 and T7=100 g R and 200 g R per ha respectively; T5=100 g R and 20 Kg P per ha, T6=100 g R and 30 Kg P per ha; T8= 200 g R and 20 Kg P per ha and T9= 200 g R and 30 Kg P per ha; R=Rhizobia; P=Phosphorus; GY: Grain yield; NEB: Net Economic Benefit.

Furthermore, at the integration of R and P application at the rate of 100 g and 30 Kg per ha, significantly increased grain yields from the control treatment (0 g and 0 Kg per ha) to 2201.3 Kg and 1794 Kg, and 2431 Kg and 2058 Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Similarly, with integration of R and P at the rate of 200 g and 20 Kg per ha, grain yields per ha significantly increased to 2089 Kg and 1722 Kg, and 2324 Kg and 1944 Kg for SB19 and SB24 genotypes in Trial I and II, respectively. Compared to control, integration of R and P at the rate of 200 g and 30 Kg per ha, significantly increased grain yields per ha by 1246 Kg and 1313 Kg, and 1406 Kg and 1425 Kg for SB19 and SB24 genotypes in Trial I and II, respectively (Table 11).

4.4.2 Effect of Different Rates of Rhizobium and Phosphorus on Net Economic Benefit of Soybean Enterprise

The net economic benefit (NEB) of soybean grain enterprise depended on rhizobia, P rates and soybean genotypes which significantly varied among the treatments applied (Appendix 20) at ($p \leq 0.05$). Rhizobia application significantly increased the NEB of soybean grain enterprise per ha for SB19 and SB24 soybean genotypes in both Trial I and II. Application of R at the rate of 100 g per ha, significantly increased the NEB of the soybean grain enterprise per ha from Kshs.70,722.66 and Kshs. 11,232.70, and Kshs.109,296.60 and Kshs. 41,230 observed with the control treatment (0 g and 0 Kg per ha) to Kshs.116,223.30 and Kshs. 56,120, and Kshs. 168,663.30 and Kshs. 108,630 for SB19 and SB24 soybean genotypes in Trial I and II, respectively. Similarly, R application at the rate of 200 g per ha, significantly increased the NEB of the grain enterprise per ha from the control treatment to Kshs.142,796.70 and Kshs. 81,763.30, and Kshs. 237,563.30 and Kshs. 134,080 for SB19 and SB24 genotypes in both Trial I and II, repectively (Table 11).

Phosphorus application at the rate of 20 Kg per ha, increased net economic benefit in SB19 and SB24 genotypes grain enterprise. For example, P application at the rate of 20 Kg per ha, significantly increased the NEB per ha from Kshs. 70,722.66 and Kshs.

11,232.70, and Kshs. 109,296.60 and Kshs. 41,230 observed with the control treatment (0 g and 0 Kg per ha) to Kshs. 133,030 and Kshs. 70,750, and Kshs. 156,520 and Kshs. 96,330 for SB19 and SB24 genotypes grain enterprise in Trial I and II, respectively. Compared to the control, application of P at the rate of 30 Kg per ha, significantly increased the NEB per ha by Kshs. 74,707.34 and Kshs. 72,797.30, and Kshs. 59,366.70 and Kshs. 67,400 for SB19 and SB24 genotypes grain enterprise in Trial I and II, respectively (Table 11).

Integration of R and P application increased NEB per ha of SB19 and SB24 genotypes grain enterprise in both Trial I and II. Integration of R and P at the rate of 100 g and 20 Kg per ha significantly increased NEB per ha from Kshs. 70,722.66 and Kshs. 11,232.70, and Kshs. 109,296.60 and Kshs. 41,230 per ha observed with the control treatment (0 g and 0 Kg per ha) to Kshs. 184,012.60 and Kshs. 127496.60, and Kshs. 210,730.00 and Kshs. 163,696.60 per ha for SB19 and SB24 genotypes in both Trial I and II, respectively. Furthermore, integration of R and P application at the rate of 100 g and 30 Kg per ha significantly increased NEB from the control treatment (0 g and 0 Kg per ha) to Kshs. 199,663.30 and Kshs. 141,630, and Kshs. 240,963.30 and Kshs. 184,930 per ha for SB19 and SB24 genotypes grain enterprise in both Trial I and II, respectively.

Compared to control, integration of R and P at the rate of 200 g and 20 Kg per ha significantly increased NEB per ha by Kshs. 120,107.34 and Kshs. 124,197.30, and Kshs. 116,483.40 and Kshs. 132,400 per ha for SB19 and SB24 genotypes grain enterprise in both Trial I and II, respectively. Similarly, integration of R and P at the rate of 200 g and 30 Kg per ha significantly increased NEB per ha from the control treatment (0 g and 0 Kg per ha) to Kshs. 239,496 and Kshs. 192,730, and Kshs. 297,930 and Kshs. 239,330 per ha for SB19 and SB24 genotypes in both Trial I and II, respectively (Table 11).

CHAPTER FIVE

DISCUSSION

5.1 Soil Analysis

The soil used was slightly acidic with pH of 5.31 and 4.31 for Trial I and II respectively. Soybean does well in soils of pH between 4.5 and 8 (Dugje *et al.,* 2009) and hence soil acidity could not constrain production since the soil pH was within pH range sufficient for soybean production. However the acidity could constrain the available P to the plants which is known to fix it at pH below 6.

5.2 Integration of Different Rates of Rhizobium and Phosphorus Application on Growth, Nodulation and Yield of Soybean

In the present study the soybean genotypes SB19 and SB24 used, exhibited differences in growth, nodulation, and yield and yield components in both Trials. The fact that there was significant ($P \leq .05$) differences in the variables measured, is evident that application of rhizobia and phosphorus affected the plant height. Similarly, to nodule number, fresh and dry weights, number of branches and pods, fresh and dry shoot weight of SB19 and SB24 soybean genotypes.

Integration of R and P showed higher performance compared to where rhizobia and phosphorus was applied alone and the control. This was probably because of the adequacy in plant nutrient resulting from R and P application which positively enhanced the growth, nodulation yield components and yields of SB19 and SB24 soybean genotypes. Progressive increase in the soybean plant height with increased inoculant and phosphorus levels were recorded. The application of R and P probably, potentially improved soil fertility. Further, by enhancing availability of N and P which significantly increased biochemical reaction and root formation, leading to increase in the plant height. This concurs with Getachew *et al.* (2017) who reported that N and P availability play a very vital role in biochemical processes, which include; chlorophyll formation and root development respectively.

These results were in agreement with Walangululu *et al.* (2013) and Shahid *et al.* (2009) who reported that there was a significant increase in height of crop legumes with increase in R and P application. Further, this findings was in conformity with Leggett *et al.* (2015) who reported that P increased plant height considerably but the values for integration of R and P were higher than the control and when R and P treatments were used alone. There were no significant difference in plant height between the two genotypes. Which was contrary to Mudibu *et al*. (2018) who observed soybean genotype SB24 being higher in plant height compared to soybean genotype SB19. This is also contrary to Adjei-Nsiah *et al.* (2019) and Monyo and Laxmipathi (2014), who observed that most soybean varieties are adapted to specific agro-ecological regions.

Effective nodulation has been suggested to be crucial for a functioning legume–rhizobium symbiosis and so plants inoculated by highly effective nodules have the capacities to fix higher BNF (Kellman, 2008). There was low number of nodules, fresh and dry weight of nodules in plots with low levels of R and P application. The interaction between the R inoculation and the P supply on the nodulation may have probably occurred since P is essential for nodule development. Therefore, more P was available for the complete development of the nodule, whereas only a portion of these nodules were able to develop in lower P.

These concurs with Mohamed and Hassan (2015) who reported a similar trend in their observations in nodule number which increased higher than the control in chickpea production in inoculated plots. This concurs with Getachew *et al*. (2017) who observed that P deficiencies in the soil restricted the development of a population of free-living R in the rhizosphere. And also limited the growth of the host plant, restricted nodulation and caused an impaired nodule function. Furthermore, this was in agreement with Tsvetkova and Georgiev (2003) who reported that soils with deffiency in P supply significantly decreased nodule fresh and dry weight by almost 50%, in N and P defficiency soils.

However, maximum number of nodules, fresh and dry nodule weight per plant was higher when maximum integration of R and P was applied. This was attributed to an increase in levels of R and P in the integration which probably, led to increased availability of N and P in the soils inducing more nodule formation. This is in agreement with Menge (2016) who reported that in Eastern region, inoculated bean plants produced a significantly higher nodule number and dry nodule weight than non-inoculated bean plants. Similarly, this findings concurs with Masresha (2017) who observed that R significantly increased nodule weight while when integrated with P, the weight significantly increased with maximum specific nitrogenase activity compared with control.

Furthermore, increase in nodule number and nodule mass with application of phosphorus could probably, be associated with major functions of P in legumes. Phosphorus stimulated nodulation through energy provision for biochemical reactions in plants. Consequently, this might have enhanced growth and development of more nodules in integration of R and P plots compared to control. This is similar to Bashir *et al.* (2011) who reported that R and P significantly increased the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules. Hence improving the density of rhizobia bacteria in the soil surrounding the root. This study is in agreement with Abassi *et al.* (2010) and Solaiman and Habibullah (1990) who reported that integration of R and P significantly influenced nodule formation and N fixation in crop legumes.

Similar findings have been reported by Kawaka *et al.* (2018), Lamptey *et al.* (2014) and Waluyo *et al.* (2004) who observed that increase in R and P increased number of nodules, nodule fresh and dry nodule weight per plant. This concurs with Walangululu *et al*. (2014) who observed that number of nodules, fresh and dry nodule weight significantly increased because of improved soil nutrient as a result of the optimal application of R and P. Branches significantly increased with increased levels of R and P. In this Trials probably, application of R and P resulted to increased photosynthetic activity as a result of optimal availability of plant nutrients. Subsequently, increasing the availability of photosynthates for branch expansion and consequently greater branch numbers.

This research observed that the significant increase in number of branches probably, was associated with adequate availability of N and P as a result of R and P, which consequently enhanced pronounced vegetative growth and development. This is in conformity with Lamptey *et al.* (2014) who reported that increase in integration of rhizobia and phosphorus enhanced vegetative development, subsequently, resulting to more number of branches. Number of branches ranged between 4 and 11 genotype

SB19 and SB24 in both Trials. Which were contrary to (Mudibu *et al.*, (2018) and Li and Nelson (2001) who reported a range of 3-5 in both genotypes. The higher pod number per plant was recorded at higher R and P levels. This might have resulted because of enhanced vegetative development due to increased N in the soil, fixed by rhizobia with enhanced energy from phosphorus provided by P. Enhanced vegetative development resulted to a subsequently increase in the number of branches. Many branches in turn, probably, provided more space for higher pod attachment and development. This study is in agreement with Morad *et al.* (2013) who reported that number of pods significantly increased in inoculated plots compared to control.

In the present research it was observed that ntegration of R and P produced the highest fresh and dry shoot weight compared to control. Probably, this could have resulted from the presence of optimal N in the soils through rhizobial fixation which consequently enhanced biomass development. This was in conformity with Kawaka *et al.* (2018) who reported that uninoculated plants produced lower dry matter than inoculated by P enhancing plant cell division hence high fresh and dry shoot weight. This concurs with Lamptey *et al.* (2014) who reported enhanced nodulation led to higher N fixation and consequently increased vegetative and dry matter yield of soybean compared to uninoculated. This was supported by Turuko and Mohammed, (2014) who inferred that biomass per plant were significantly increased by different phosphorus levels.

Further, this concurs with findings by Nasir *et al.* (2016) who reported that increased P resulted to higher fresh and dry shoot weight. High fresh and dry shoot weight probably, associated with enhanced vegetative growth that could have been supported by the immediate release of N from the nodules. This is in agreement with Turuko and Mohammed, (2014) who reported that total shoot and plant biomass always increase in response to added soil N.

This concurs with findings by Balemi and Negisho (2012) who reported a significant increase in shoot dry weight of crop legumes in soils with adequate amount of P. A higher nodule dry matter recorded by increase in application of R and P reflects a more efficient symbiotic nitrogen fixation that could probably, lead to increased shoot biomass. These findings are in agreement with observations by Alam (2015) who reported that inoculation significantly influenced biological yield (biomass) of soybean with rhizobium-inoculated seeds.

5.3 Integration of Different Rates of Rhizobium and Phosphorus on Tissue Content, Symbiotic and Phosphorus Use Efficiency in Soybean Production

Rhizobium and P application alone or in ntegration significantly increased shoot and grain N uptake in the soybean genotypes. Positive shoot and grain N uptake probably, could be associated with R and P. Which enhanced N fixation, root length and root mass. Consequently, resulting to absorption of higher concentration of mineral nutrients from the soil, particularly available N. Similarly, significant increase in root nodules due to integration of R and P, probably, increased N_2 fixation. This in turn led to increase in N uptake by soybean plants. This is in agreement with Bargaz *et al.* (2018) and Abbasi *et al.* (2010) who observed that, P plays a vital role in physiological and developmental process in plant life. These favorable influence of this nutrient accelerated the growth process that increased N uptake in plants. Similarly, significant increase in root nodulation due to integration of R inoculation and P increased N_2 fixation that led to increase in N uptake by shoot and grain of soybean.

Shoot and grain P content in was significantly affected by R and P for SB19 and SB24. Higher P content in shoot and grain due to R and P application can probably, be attributed to the root length of soybean. A longer root system in the present research might have created a greater root-soil contact. Leading to a significant increase in P uptake hence high P content in soybean shoot and grain. These findings are in agreement with Mathenge (2019) who observed that a larger root system enhanced by P provided greater root-soil contact hence higher uptake. A higher presence of soluble P in the vicinity of the roots coupled with larger root soil contact was especially necessary for uptake of low mobility nutrients the P.

Furthermore, a significant increase in the shoot and grain P content can be attributed to the presence of R applied which enhanced the solubilization of the precipitated P components in the soil. Thereby increasing available P for uptake by soybean plants. This is in agreement with Adjei-Nsiah *et al.* (2019) and Fatima *et al.* (2007a) who observed that strains of rhizobia have the ability to solubilize precipitated P components thereby increased P uptake in plants. This concurs with Abbasi *et al.* (2010) who repoted that soybean grain/straw P uptake was quadratically increased with increasing P and R. The control in the present research had the lowest shoot P content compared to all the treatments, this is supported by Koskey *et al. (* 2017) who observed that shoot P content was high where commercial strain was used compared to control.

In the present study control had significantly high SEF in the trails. These findings probably, suggest that native isolates (control) were active and effective. Hence enhancing nitrogen fixation, which consequently increased SDW. Further, the good performance of control compared to commercial strains, probably, could be associated with native strain adaptation to the ecological conditions of the study area. These results are in agreement with the findings by Kawaka *et al.* (2014) who reported SEF ranging between 67 and 170% when common beans were inoculated with native rhizobia in Western Kenya.

However, in the present study, commercial R seemed superior in performance to native strains where applied alone owing to their higher performance compared to the control. This probably, could be associated with the commercial strains being equally more adapted to the study area compared to the native strains. Consequently, leading to higher performance in SEF. This is contrary to Mungai and Karubiu, (2011) who observed that native rhizobia isolated from common beans from Njoro, Kenya, had higher symbiosis efficiency (SEF) compared to commercial inoculants Biofix and USDA 9030. Integration application rates of R and P had the highest SEF compared to control and where either of them was applied alone. These findings in the present Trials, could probably, be associated with enhanced energy provision by P which improved the performance of both native (control) and commercial R in SEF. This concurs with the findings by Bargaz *et al.* (2018) and Meghvansi *et al*. (2010) who reported that BNF has a high P demand because the process consumes large amounts of energy.

Exept where integration of R and P, PUE decreased with increase in P rates in plots that received P applications alone. The low phosphorus use efficiency could probably, be associated with higher removal of P from the soil by the current soybean genotypes with less achievement in yields of grain obtained. This is contrary with findings by Abbasi *et al.* (2010) who reported that crop that would remove less P from soil, thereby reducing the cost of production of each ton of grain obtained, increases PUE.

Alternatively, low PUE in the present study, probably, may be associated with P fixation in the soil. This could be due to presence of either Ca compounds or Fe/Al oxides (beyond scope of this study) making P less available to the plants. Consequently, leading to low PUE. This concurs with findings by Fageria and Barbosa (2007) and Singh *et al.* (2005) who observed that higher P fixation due to presence of calcium or aluminium/ iron oxides. These decreased PUE with increase in P rates in lentil and rice enterprise respectively. Overall, the present study observed that a 4.3 and 4.2 Kg, and 4.5 and 3.85 Kg soybean grain was produced with application of 1 Kg of P for soybean genotype SB19 and SB24 in trial I and II respectively. This economic production was below findings by Abbasi *et al.* (2010) who reported a 5.2 Kg soybean grain yield produced with the application of 1 Kg phosphorus.

5.4 Integration Effects of Different Rates of Rhizobium and Phosphorus on Grain Yield and Net Economic Benefit of Soybean Enterprise

5.4.1 Integration Effects of Different Rates of Rhizobium and Phosphorus on Grain Yield

Low yields in grain resulted in soybeans that received low rates of R and P whether used alone or in integration. This could probably, be attributed to low soil fertility and particularly due to sub-optimal application of R and P. Consequently, resulting into inadequate availability of plant nutrient. Hence reducing grain yields of soybean in the study area. This is in agreement with ACET (2013) who reported low yields in soybean as a result of low soil fertility, and particularly P levels.

Response of soybean with variations in application rates of R and P was observed within individual genotypes . This concurs with Giller *et al.* (2013) who observed that grain legumes depended on the effectiveness of rhizobium strain, the biophysical environment and agronomic management. However there were no variations of yields between the genotypes. Which can be attributed to both genotypes being adapted to the study area. Contrary to van Heerwaarden *et al.* (2018) who reported response of soybean genotypes to application of different rates of R and phosphorus being highly variable.

The highest yield increment was noted with the maximum integration of R and P for soybean genotypes SB19 and SB24 in both trial I and II. This could probably, be attributed to rates of R and P used, which might have been optimal hence providing adequate plant nutrient. Subsequently, enhancing soybean grain yields. This is in agreement with Nasir *et al.* (2016) who reported that maximum legume grain yields was recorded with optimal integration of R and P. Integration of R and P, probably, played the role of enhancing the number of nodules and subsequently their functions. Resulting to higher amount of N compounds available in the rhizosphere which was absorbed and translocated to the seeds. Therefore leading to increase in seed weight. This concurs with Shish *et al.* (2018) and Fatima *et al.* (2007b) whose findings observed that grain yields directly correlated with nodulation because seed contain nitrogenous compounds that are influenced by formation of nodules on plant root to fulfil nitrogen requirements.

5.4.2 Integration Effects of Different Rates of Rhizobium and Phosphorus on Net Economic Benefit of Soybean Enterprise

Net economic benefit (NEB) increased with increase in application levels of R and P. Lowest net economic return was observed at control while highest was recorded at the highest rate of integrated application of R and P. This higher return on investment could probably, be associated with integration application of cheap input, that is use of R and complementarity by P where each enhanced their use efficiency.

This was contrary with findings by Omonona *et al.* (2010) who observed that the marginal value products (MVP) of all the resources used by poor-resource smallholder farmers was less than marginal financial cost indicating underutilization of resources. The use of 200 g of R per ha was equivalent to 3 bags of urea to cover 1 ha which costs kshs. 9,000, which probably, reduced cost of inputs resulting to higher returns on investment. This concurs with Singh *et al.* (2016) who observed that crop production using inoculants could be cheaper and more affordable to the poor resource smallholder farmers. Overall, the present Trials showed that use of both SB19 and SB24 genotype and integration of R and P at the rate of 200 g and 30 Kg resulted to the highest returns on investment, hence favorable for adoption by poor-resource smallholder farmers in Meru South Sub County.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of the Findings

6.1.1 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Growth, Nodulation and Yield Components of Soybean

Rhizobia and phosphorus significantly influenced the soybean growth, nodulation and yield components of soybean at ($p \leq 0.05$) in both trial I and II. Both genotypes showed positive response towards increase in R and P whether applied alone or in integration. Integration of R and P at 200 g R and 30 Kg P per ha proved optimum owing to the response of number of nodules and pods fresh and dry nodule and shoot weight and root length. Same trend was observed with response of the genotypes in number of branches and seed weight.

6.1.2 Effects of Integrated Application of Different Rates of Rhizobium and Phosphorus on Tissue Content, Symbiotic and Phosphorus Use Efficiency in Soybean Production.

Lowest shoot and grain N was observed at control while highest was observed with the optimum integration rate of 200 g R and 30 Kg P per ha. There were no significant difference within and between the Trials for SB19 and SB24 genotypes. Same trend was depicted with Shoot P and grain P for SB19 and SB24 in both Trials. Both genotypes perfomed well in symbiotic and phosphorus use efficiency in Trial I and II.

Integration of R and P had the highest overall SEF of 209% at the application rate of 100 g and 30 Kg per ha. This showed that optimum rate for SEF was 100 g Rand 30 Kg P for SB19 and SB24 soybean genotypes in both Trials. Phosphorus use efficiency PUE was significantly influenced by rhizobia and phosphorus rates, whether applied alone or in integration in both Trials at ($p \leq 0.05$). With integration of R and P at the rate of 200 g and 20 Kg and 200 g and 30 Kg observed PUE per ha at the range of 6.9 Kg/Kg and 9.48 Kg/Kg for SB19 and SB24 soybean genotypes in Trial I and II.

6.1.3 Effect of Integrated Application of Different Rates of Rhizobium and Phosphorus on Grain Yield and Net Economic benefit in Soybean Enterprise.

Grain yields and net economic benefit (NEB) were significantly affected by rhizobia and phosphorus rates whether applied alone or in integration for soybean genotype SB19 and SB24 in both tria I and II at ($p \leq 0.05$). At the rate of 100 g and 30 Kg, and 200 g and 30 Kg per ha, observed yield range of between 1722 Kg and 2324 Kg per ha. Highest yields observed with the application rate of 200 g and 30 Kg per ha for SB19 and SB24 soybean genotypes in both Trials. Integration of R and P at the rate of 200 g and 30 Kg per ha had significantly highest increase of NEB per ha from the control treatment (0 g and 0 Kg per ha) to ksh.239,496 and 192,730, and ksh.297,930 and 239,330 per ha for SB19 and SB24 soybean genotypes in both Trial I and II respectively.

6.2 Conclusions

Following the findings of this study, the following conclusions can be made;

i. There were positive response on integration application of R and P on Growth, Nodulation and Yield Components of Soybean. Integration of R and P at the rate of 200 g and 30 Kg per ha was the optimum rate of application for SB19 and SB24. Further, both genotypes perfomed well in trial I and II.
ii. There were significant effect of integration application of R and P on tissue nutrient content, symbiotic and phosphorus use efficiency in soybean enterprise. Optimum rate remained at integrated rateof 200 g R and 30 Kg P per ha.
iii. There were significant response of integrated application of different rates of rhizobium and phosphorus on grain yield and net economic benefit in Soybean Enterprise. The highest grain yield was 2840 Kg per ha, with highest NEB of ksh. 297930 at integration of P and R at the rate of 200 g and 30 Kg per ha.

6.3 Recommendations

i. The research recommends integration of R and P at the rate of 200 g and 30 Kg per ha and use of SB19 and SB24 genotypes for cultivation to be adopted for sustainable growth, nodulation and yield components.
ii. Present research recommends integrated application of R and P at the rate of 200 g and 30 Kg per ha. And use of both genotypes in enhancing tissue content, symbiotic efficiency and phosphorus use efficiency in the study area.
iii. Present research recommends integrated application of R and P at the rate of 200 g and 30 Kg per ha. With adoption of either of SB19 and SB24 genotype for enhanced grain yield and net economic benefit in soybean.

6.4 Suggestions for Further Research

Based on the findings of this study there exist a gap in the following areas;

i. Research with other higher yielding soybean accessions in order to ascertain a genotype that is higher in growth, nodulation and yield components compared to the two used.
ii. Use of other sources of P such as phosphorus solubilizing bacteria to enhance symbiotic and phosphorus efficiency.
iii. Isolation of native rhizobia in the study area which might be more effective and compatible with the local conditions. That will improve on BNF enhancing soil fertility which subsequently will increase on soybean yields.

REFERENCES

Abaidoo, R. C. and Sanginga, N. (2007). Population size, distribution, and symbiotic characteristics of indigenous Bradyrhizobium spp. that nodulate TGx soybean genotypes in Africa. *Applied Soil Ecology, 35*(1), 57-67.

Abbasi, M. K., Manzoor, M. and Tahir, M. M. (2010). Efficiency of rhizobium inoculation and P fertilization in enhancing nodulation, seed yield, and phosphorus use efficiency by field grown soybean under hilly region of Rawalakot Azad Jammu and Kashmir. *Journal of plant nutrition, 33*(7), 1080-1102.

Abuli, S. (2016). A brief history of soybean production in Kenya. *Research Journal of Agriculture and Environmental Management, 5*(4), 058-064.

[African Center for Economic Transformation (2013)]. *Africa's soybean agroprocessing opportunity.* Accra:.

Adeyeye, A., Togun, A., Olaniyan, A. and Akanbi, W. (2017). Effect of Fertilizer and Rhizobium Inoculation on Growth and Yield of Soyabean Variety (Glycine max L. Merrill). *Advances in Crop Science and Technology, 5*(1), 255.

Adjei-Nsiah, S., Kumah, J., Owusu-Bennoah, E. and Kanampiu, F. (2019). Influence of P sources and rhizobium inoculation on growth and yield of soybean genotypes on Ferric Lixisols of Northern Guinea savanna zone of Ghana. *Communication in Soil Science and Plant Analysis,* 1532-2416.

[Alliance for a Green Revolution in Africa (2013)]. Focus on Staple Crops.

AGRA. (2016). Going beyond demos to transform African agriculture. *Alliance for a Green Revolution in Africa*.

Ahiabor, B. D., Lamptey, S., Yeboah, S. and Bahari, V. 2. (2014). Application of phosphorus fertilizer on soybean [(Glycine max L. (Merril)] inoculated with rhizobium and its economic implication to farmers. *American Journal of Experimental Agriculture* (4), 1420–34.

Akpalu, M. M., Siewobr, H., Oppong-Sekyere, D. and Akpalu, S. E. (2014). Phosphorus application and Rhizobia inoculation on growth and yield of soybean (Glycine max L. Merrill). *American Journal of Experimental Agriculture*, *4*(6), 674-685.

Alam, F. M., Bhuiyan, A. H., Alam, S. S., Waghmode, T. R., Kim, P. J. and Lee, Y. B. (2015). Effect of Rhizobium sp. BARIRGm901 inoculation on nodulation, nitrogen fixation and yield of soybean (Glycinmax) genotypes in gray terrace soil. *Bioscience, Biotechnology and Biochemistry, 79*, 1660-1668.

Ali, A., Khan, S., Khan, E., Ali, N., Hussain, I. and F., A. (2015). Genetic studies among diverse soybean (Glycine max L. Merrill) genotypes for variability and correlation at Swat. *International Journal of Biosciences, 6*(4), 165-169.

Awotide, O. D., 1, I. J., Ajala, O. S. and Kaltungo, H. J. (2015). *Input Use and Profitability of Arable Crops Production in Nigeria.* Olabisi Onabanjo University, Department of Agricultural Economics and Farm Management. Yewa: Canadian Center of Science and Education.

Balemi, T. and Negisho, K. (2012). Balem Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *Journal of Soil Science and Plant Nutrition, 12*(3), 547–62.

Barbosa, L. P., Costa, P., Ribeiro, P. R., Rufini, M., Guimarães, A. A. and Moreira, F. M. (2017). Symbiotic Efficiency and Genotypic Characterization of Variants of Bradyrhizobium spp. in Commercial Inoculants for Soybeans. *Rev Bras Cienc Solo, 14*, 1-15.

Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y. and Dhiba, D. (2018). Soil Microbial Resources for Improving Fertilizers Efficiency in an Integrated Plant Nutrient Management System. *Frontier Microbiology. 9:1606., 9*, 1606.

Bashir, K., Ali, S. and Umair, A. (2011). Effect of different phosphorus levels on xylem sap components and their correlation with growth variables of mash bean. *Sarhad Journal of Agriculture, 27*, 1-6.

Belete, F., Dechassa, N., Molla, A. and Tamado Tana, T. (2018). Effect of nitrogen fertilizer rates on grain yield and nitrogen uptake and use efficiency of bread wheat (Triticum aestivum L.) varieties on the Vertisols of central highlands of Ethiopia. *Agriculture and Food Security, 7*(78), 1-12.

Berche, J., Asumadu, H., Yeboah, S., Agyeman, K. and Acheampong, P. (2013). An Evaluation of the Effects of Yara Fertilizers on the Growth and Yield Performance of Maize (Zea-mays and its Economic Implications to Farmers in Ghana. *International Journal of Science and Advanced Technology, 3*(8), 1-12.

Bremner, J. M. (1996). *Soil pH and Lime Requirement. Methods of Soil Analysis Part 3—Chemical Methods* (Vol. 3).

Chianu Jonas, N., and Vanlauwe, B.V. (2006). “Soybean: a new role in western Kenya”. *Highlights CIAT in Africa, 35.*

Chianu, J. N., Ohiokpehai, O., Vanlauwe, B., Adesina, A., De Groote, H. and Sanginga, N. (2009). Promoting a versatile but yet minor crop: soybean in the farming systems of Kenya. *Journal of Sustainable Development in Africa, 10*, 324–44.

Chianu, J. N., Vanlauwe, B., Mahasi, J., Katungi, E., Akech, C. and Mairura, F. (2008). Soybean situation and outlook analysis: The case for Kenya.

Cook, S., Silici, L., Adolph, B. and Walker, S. (2015). Sustainable intensification revisited. *IIED`s Natural Resources.*

diCenzo, G. C., Zamani, M., Checcucci, A., Fondi, M., Griffitts, J. S., Finan, T. M. and Mengoni, A. (2019). Multidisciplinary approaches for studying rhizobium–legume symbioses. *Canadian Journal of Microbiology, 65,* 1-33.

Dugje, I., Omoigui, L., Ekeleme, A., Kamara, A. and Ajeigbe, H. (2009). Farmers' Guide to Cowpea Production in West Africa. *IITA*, 1-25.

Fageria, N. K. and Barbosa, F. M. P. (2007). Dry-matter and grain yield, nutrient uptake, and phosphorus use-efficiency of low land rice as influenced by phosphorus fertilization. *CommunicationsinSoilScience and Plant Analysis, 38,* 1289-1297.

[Food and Agriculture Organization of the United Nations (2014)]. *Sustainable Crop Production Intensification.* Rome. Italy

[Food and Agricultural Organization of Statistics database, (2011)]. FAO, Rome. Italy

FAOSTAT. (2013). Food and Agricultural Organization Statistics database, FAO, Rome. Italy

Fatima, Z., Zia, M. and Chaudhary, M. F. (2007a). Interactive effect of Rhizobium strains and P on soybeanyield, nitrogen fixation and soil fertility. *Pakistan Journal of Botany, 39,* 255-264.

Fatima, Z., Zia, M. and Chaudhary, M. F. (2007b). Effect of Rhizobium strains and phosphorus on growth of soybean (Glycine max) and survival of Rhizobium and P solubilizing bacteria. *Pakistan Journal of Botany, 38,* 459–464.

Furseth, B., Conley, S. P. and Ané, J. M. (2012). Soybean response to rhizobia and seed applied rhizobia inoculants in Wisconsin. *Crop Science, 52,* 339-344.

Gathungu, G. K., Aguyo, J. N. and Isutsa, D. K., (2014). Effects of Irrigation Water and Mineral Nutrients Application Rates on Tissue Contents and Use Efficiencies in Seed Potato Tuber Production. *International Journal of Plant and Soil Science, 3*(9), 1153-1166.

Getachew, Z., Abera, G. and Beyene, S. (2017). Rhizobium inoculation and sulphur fertilizer improved yield, nutrients uptake and protein quality of soybean (Glysine max L.) varieties on Nitisols of Assosa area, Western Ethiopia. *African Journal of Plant Science, 11*(5), 123-132.

Gicharu, G., Gitonga, N., Boga, H., Cheruiyot, R. and Maingi, J. (2013). Effect of inoculating selected climbing bean cultivars with different rhizobia strains on nitrogen fixation. *American Journal of Plant Science, 1,* 25–31.

Giller, K. E., Franke, A. C., Baijukya, F., Bala, A., Boahen, S., Dashiell, K., Sanginga, J. (2013). N2AfricaPutting nitrogen fixation to work for smallholder farmers in Africa. (B. Vanlauwe, P. Van Asten, and G. Blomme, Eds.) *In Agroecological Intensification of agricultural systems in the African highlands*, 156-174.

Hartman, G. L., West, E. D. and Herman, T. K. (2011). Crops that feed the World 2. Soybean—worldwide production, use, and constraints caused by pathogens and pests. *Food Security, 3,* 5-17.

Hungria, M., Araujo, R. S., Silva Júnior, E. B. and Zilli, J. (2017). Inoculum Rate Effects on the Soybean Symbiosis in New or Old Fields under Tropical Conditions. *109*(3), pp. 1106-1112.

Jeannette, S., Buyuelo-Jimanez and Ochoa-Cadavid, I. (2014). Phosphorus acquisition and internal utilization efficiency among maize landraces from the central Mexican highlands. *Science Directorate, 156*(1), 123-134.

Kaara, J., Werner, J. and Wasike, V. (1998). *Soybean Impact study: A case study on the small scale soyabean production, cottage processing and consumption in selected areas of Kenya.* GTZ Soyabean.

Kamara *et al.* (2007). Influence of phosphorus application on growth and yield of soybean genotypes in the tropical savannas of northeast Nigeria. *Archives of Agronomy and Soil Science*, *53*(5), 539-552.

Kansiime, K. M., van Asten, P. and Sneyersd, K. (2018). Farm diversity and resource use efficiency: Targeting agricultural policy interventions in East Africa farming systems. *Wageningen Journal of Life Sciences, 82*, 31-41.

Kawaka F. (2018). Genetic diversity of symbiotic bacteria nodulating common bean (Phaseolusvulgaris) in western Kenya. Thesis., PLoS ONE,13(11), 1-13. doi:10.1371

Kawaka, F., Dida, M., Opala, P., Ombori, O., John Maingi, J., Amoding, A. and Muoma, J. (2018). Effect of nitrogen sources on the yield of common bean (Phaseolus vulgaris) in western Kenya. *Journal of Plant Nutrition, 41*(13), 1652-1661.

Kellman, A. W. (2008). *Effective nodulation has been suggested to be crucial for a functioning legume–rhizobium symbiosis of common bean (Phaseolus vulgaris l.).* PhD Thesis, Lincoln University Canterbury New.

Kolawole, G. O. (2012). Effect of phosphorus fertilizer application on the performance of maize/soybean intercrop in the southern Guinea savanna of Nigeria. *Archives of Agronomy and Soil Science, 58*(2), 189-198.

Korir, H., Mungai, N. W., Thuita, M., Y., H. and Masso, C. (2017). Co-inoculation Effect of Rhizobia and Plant Growth Promoting Rhizobacteria on Common Bean Growth in a Low Phosphorus Soil. *Frontiers in Plant Science, 8*(141).

Koskey, G., Mburu, S. and Njeru, E. (2017). Potential of Native Rhizobia in Enhancing Nitrogen Fixation and Yields of Climbing Beans (Phaseolus Vulgaris L.) in Contrasting Environments of Eastern Kenya. *Frontiers in Plant Science, 8*(443), 1-2.

Krause, G., & Wasike, V. (1998). Soyabean project Kenya: Soyabean Seed Supply Survey. *LUSO CONSULT GmbH.*

Lamptey, S., Ahiabor, B. D., Yeboah, S., Akech, C. and Asamoah. (2014). Response ofSybean (Glycine max) to rhizobial inoculation and Phosphorus Application. *Journal of Experimental Biology and Agricultural Sciences, 2*(1), 73-77.

Leggett, M. M., Newlands, M. K., Greenshields, D., West, L., Inman, S. and Koivunen, M. E. (2015). Maize yield response to a phosphorus- solubilizing microbial inoculant in field trials. *Journal of Experimental Biology and Agricultural Sciences 153*(8), 1464-1478.

Leggett, M., Diaz-Zorita, M., Koivunen, M., Bowman, R., Pesek, R., Stevenson, C. and Leister, T. (2017). Soybean Response to Inoculation with Bradyrhizobium japonicum in the United States and Argentina. *American Society of Agronomy, 109*(3), 1031–1038.

Li, Z. and Nelson, R. 2. (2001). Genetic diversity among soybean accessions from three countries measured by RAPDS. *Journal of Crop Sciences, Vol. 41*, 1337–1347.

Makoi, J. H., Bambara, R. S. and Ndakidemi, P. A. (2013). Rhizobium Inoculation and the Supply of Molybdenum and Lime Affect the Uptake of Macronutrients in Common Bean (P. vulgaris L.). *Australian Journal of Crop Science, 7*(6), 784-793.

Masresha, A. T. (2017). *Effects of Rhizobium, Nitrogen and Phosphorus Fertilizers on Growth, Nodulation, Yield and Yield Attributes of Soybean at Pawe Northwestern Ethiopia.* Retrieved November 16, 2017, from World Scientific News: www.worldscientificnews.com

Mathenge, (2019). Variability of soybean response to rhizobia inoculant, Vermicompost, and a legume-specific fertilizer blend in Siaya County of Kenya. *Thesis*. Republic of Congo. *International Journal of Research in Plant Science, 8*(1), 1-5.

Meghvansi, M., Prasad, K. and Mahna, S. (2010). Symbiotic potential, competitiveness and compatibility of indigenous Bradyrhizobium japonicum isolates to three soybean genotypes of two distinct agro-climatic regions of Rajasthan. *Saudi Journal of Biological Science, 17*, 303-310.

Menge, E. M (2016). Improving biological nitrogen fixation in common bean (phaseolus vulgaris) varieties grown within eastern Kenya (Masters Thesis). *Kenyatta University*.

Mohamed, A. A. and Hassan, M. A. (2015). Evaluation of two chickpea (Cicer arientinun L.) cultivars in response to three Rhizobium strains at River Nile State, Sudan. *Merit Research Journal of Agricultural Science and Soil Science, 3*(5), 062-069.

Moni, A., Mulwa, R., & Lutta, M. (2016). Eliciting farmers' willingness to pay and adopt improved seed varieties in semi-arid counties of Machakos, Makueni and Tharaka-Nithi in Eastern Kenya. *International Journal of Agricultural Sciences, 6*(11), 1183-1199.

Monyo, E. S. and Laxmipathi, G. C. (2014). *Grain Legumes Strategies and Seed Roadmaps for Select Countries in Sub-Saharan Africa and South Asia.* Tropical Institute for the Semi-Arid Tropics. Andhra Pradesh: International Crops Research.

Morad, M., Sara, S., Alireza, E. and Chaichi, M. R. (2013). Effects of seed inoculation by Rhizobium strains on yield and yield components in common bean cultivars (Phaseolus vulgaris L.). *International Journal of Bioscience, 3*, 134–141.

Mudibu, J., Lukombo, J. C., Lunkamba, Y., Mangunga, Bueso, Tshilenge-Lukanda, L. and Kalonji, M. (2018). Evaluation of agronomic performance of soybean accessions (Glycine max) in east periphery of Kinshasa in Democratic

Mungai, N. W. and Karubiu, N. M. (2011). Effectiveness of rhizobia isolates from Njoro soils (Kenya) and commercial inoculants in nodulation of common beans (Phaseolus vulgaris). *Journal Agricultural Science Technology, 12,* 47–59.

Murithiab, H. M., Beedc, F., Tukamuhabwad, P., Thommab, B. P. and Joosten, M. H. (2016). Soybean production in eastern and southern Africa and threat of yield loss due to soybean rust caused by Phakopsora pachyrhizi. *Plant Pathology,* 65, 176–188.

Mwangi, S. N. (2011). Genetic diversity and symbiotic efficiency of legume nodulating bacteria from different land use systems in Taita Taveta, Kenya. *Tropical and Subtropical Agroecosystem, 13,* 109-118.

Mwendaa, G. M., Karanja, N. K., Bogaa, H., Kahindib, J. H., Muigaia, A. and Odeed, D. (2011). Abundance and Diversity of Legume Nodulating Rhizobia in Soils of Embu District, Kenya. *Tropical and Subtropical Agroecosystems, 13*, 1-10.

Nasir, R., Abbasi, M. K. and Hameed, S. (2017). Variability in the growth and nodulation of soybean in response to elevation and soil properties in the Himalayan region of of Kashmir-Pakistan. *Pakistan Journal of Botany, 49*(1), 237-247.

Nasir, R., Abbasia, M. K. and Hameedb, S. (2016). Nodulation, nutrient accumulation and yield of rainfed soybean in response to indigenous soybean-nodulating Bradyrhizobia in the Himalayan region of Kashmir-Pakistan. *International Journal of Plant Production, 10*(4), 1735-8043.

Ndakidemi, P. A., Dakora, D. F., Nkonya, E. M., Ringo, D. & Mansoor, H. (2006). Yield and economic benefits of common bean (Phaseolus vulgaris) and soybean (Glycine max) inoculation in northern Tanzania. *Australian Journal of Experimental Agriculture, 46*, 571-577.

Ndusha, B. N., Karanja, N. K., Woomer, P. L., Walangululu, J., Mushagalusa, G. N. and Sanginga, J. M. (2017). Effectiveness of rhizobia strains isolated from South Kivu soils (Eastern D.R. Congo) on nodulation and. *African Journal of Soil Science, 5* (3), 367-377.

Njeru, P. N., Mugwe, J., Maina, I., Mucheru-Muna, M., Mugendi, D., Lekase, J. K., . . . Mugendi, D. (2013). Integrating scientific and farmers' perception towards evaluation of rainfed agricultural technologies for sorghum and cowpea productivity in Central Kenya . *Journal of Soil Science and Environmental Management, 4*, 123-131.

Ntambo, M. S., Chilinda, I. S., Taruvinga, A., Hafeez, S., Anwar, T., Sharif, R., . . . Kies, L. (2017). The effect of rhizobium inoculation with nitrogen fertilizer on growth and yield of soybeans (Glycine max L.). *International Journal of Biosciences, 10*(3), 163-172.

Nwoke, O. C., Diels, J., Abaidoo, R. and Sanginga, N. (2005). Low phosphorus availability in West African moist savanna soils: Effect of sparing soluble P sources on growth of soybean, cowpea and maize. *African Crop Science, 7*, 1157–61.

Omonona, T. B., Egbetokun, A. O. and Akanbi, T. A. (2010). Farmers Resource – Use and Technical Efficiency in Cowpea Production in Nigeria. *Economic Analysis and Policy, 40*(1), 87-95.

Ouma, E. W., Asango, A. M., Maingi, J. and Njeru, E. M. (2016). Elucidating the potential of native rhizobial isolates to improve biological nitrogen fixation and growth of common bean and soybean in smallholder farming systems of Kenya. *International Journal of Agronomy doi: 10.1155/2016/4569241*, 1-7.

Palaniappan, S. P. (2010). *Organic farming: theory and practice.* Jodphur, Indian: Scientific Publishers.

Reckling et al., (2016). Trade-Offs between Economic and Environmental Impacts of Introducing Legumes into Cropping Systems. *Frontiers in Plant Sciences, 7*, 669.

Ronnera, E., Frankea, A., Vanlauwe, B., Diandad, C. M., Edehe, E., Ukeme, B., . . . K.E. Gillera, K. E. (2016). Understanding variability in soybean yield and response to P-fertilizerand rhizobium inoculants on farmers' fields in northern Nigeria. *International Institute of Tropical Agriculture, 186*, 133-144.

Rusike, J., Van den Brand, G. and Boahen, S. (2013). Value chain analyses of grain legumes in N2Africa: Kenya, Rwanda, eastern DRC, Ghana, Nigeria, Mozambique, Malawi and Zimbabwe. Wageningen, Netherlands: N2Africa.

SAS Institute Inc. 2001. The SAS system for Windows. SAS Institute Inc., Cary, NC, USA

Sagolshemcha, R., Devi, Y. N. and Singh, W. R. (2017). Plant Growth Promoting Effect and Biocontrol Potential of Rhizobium spp. against Macrophomina phaseolina. *International Journal of Current Microbiology and Applied Sciences, 6*(6), 2695-2701.

Salih, S. H., Hamd, S. A. and Dagash, Y. M. (2015). The effects of rhizobium, mycorrhizal inoculations and diammonium phosphate (DAP) on nodulation, growth and yield of soybean. *Universal Journal of Agricultural Research, 3*(1), 11-14.

Shahid, M. Q., Saleem, M. F., Khan, H. and Anjum, S. A. (2009). Performance of soybean (glycine max l.) under different phosphorus levels and inoculation. *Pakistan Journal Agricultural Science, 46*(4).

Shish, R. J., Vinod, K., Mitra, N. G. and Ompal, S. (2018). Effect of Soybean (Glycine max) Seed Inoculation with Liquid and Carrier Based Rhizobium cultures and Phosphorus Levels on Productivity and Physico-Chemical Properties of Soil. *International Journal of Microbiological Applied Science, 7*(6), 1807-1814.

Singh, B. and Ryan, J. (2015). *Managing fertilizers to enhance soil health.* Paris: International Fertilizer Industry Association (IFA).

Singh, J. S., Koushal, S., Kumar, A., Vimal, S. R. and Gupta, V. K. (2016). *Microbial inoculants in sustainable agricultural productivity-functional application* (Vol. 7).

Singh, K. K., Srinivasarao, C. and Ali, M. (2005). Root growth, nodulation, grain yield, and phosphorus use efficiency of lentil as influenced by phosphorus, irrigation, and inoculation. *Communications in Soil Science and Plant Analysis, 36*, 1919-1929.

Syers, J., Johnston, A. and Curtin, D. (2008). *Efficiency of soil and fertilizer phosphorus use : reconciling changing concepts of soil phosphorus behaviour with agronomic information.* Rome: FAO.

Tairo, E. V. and Ndakidemi, P. (2014). Macronutrients uptake in soybean as affected by Bradyrhizobium japonicum inoculation and phosphorus (P) supplements. *American Journal of Plant Science, 5*, 488-496.

Tani, L., Anh, T., James, Hansen. and Mark, A. (2016). Major Factors Affecting Global Soybean and Products Trade Projections. *Economic Research Service*.

Thilakarathna, S. M. (2019). Evaluating the Effectiveness of Rhizobium Inoculants and Micronutrients as Technologies for Nepalese Common Bean Smallholder Farmers in the Real-World Context of Highly Variable Hillside Environments and Indigenous Farming Practices. *Journal of Agriculture*, 9(20), 1-17; doi:10.3390

Tran, V. T., Lien, T. and Mau, C. H. (2015). Proteomic characterization of soybean leaf proteins from cultivar DT2000 with rust-resistant ability in Vietnam. *International Journal of Biosciences*, *6*(2), 468-477.

Tsvetkova, G. E. and Georgiev, G. I. (2003). Effects of Phosphorus Nutrition on the Nodulation, Nitrogen Fixation and Nutrient Use Efficiency of Bradyrhizobium Japonicum –Soybean (Glycine Max L. Merr.) Symbiosis. *J. Plant Physiol*(SPECIAL ISSUE), 331-335.

Turuko, M. and Mohammed, A. (2014). Effect of different phosphorus fertilizer rates on growth, dry matter yield and yield components of common bean (Phaseolus vulgaris L.). *World Journal of Agricultural Research, 2*(3), 88–92.

[United States Department of Agriculture. (2016)]. Agricultural Projections to 2025. *Economic Research Service*.

USDA. (2017). Soybeans and oil crops. *Economic Research Outlook*, 1.

Van Heerwaarden et al. (2018). Soyabean response to rhizobium inoculation across sub-Saharan Africa: Patterns of variation and the role of promiscuity. *Agriculture, Ecosystems and Environment*, 211-218.

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B. and Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, *155*, 10-13.

Walangululu, M., Shukuru, B., Bamuleke, K., Bashagaluke, B., Angelani, A. and Baijukya, F. (2014). Response of introduced soybean varieties to inoculation with rhizobium in Sud Kivu province, Democratic Republic of Congo. *Fourth RUFORUM Biennial Regional Conference, Maputo, Mozambique*, (pp. 273 - 279).

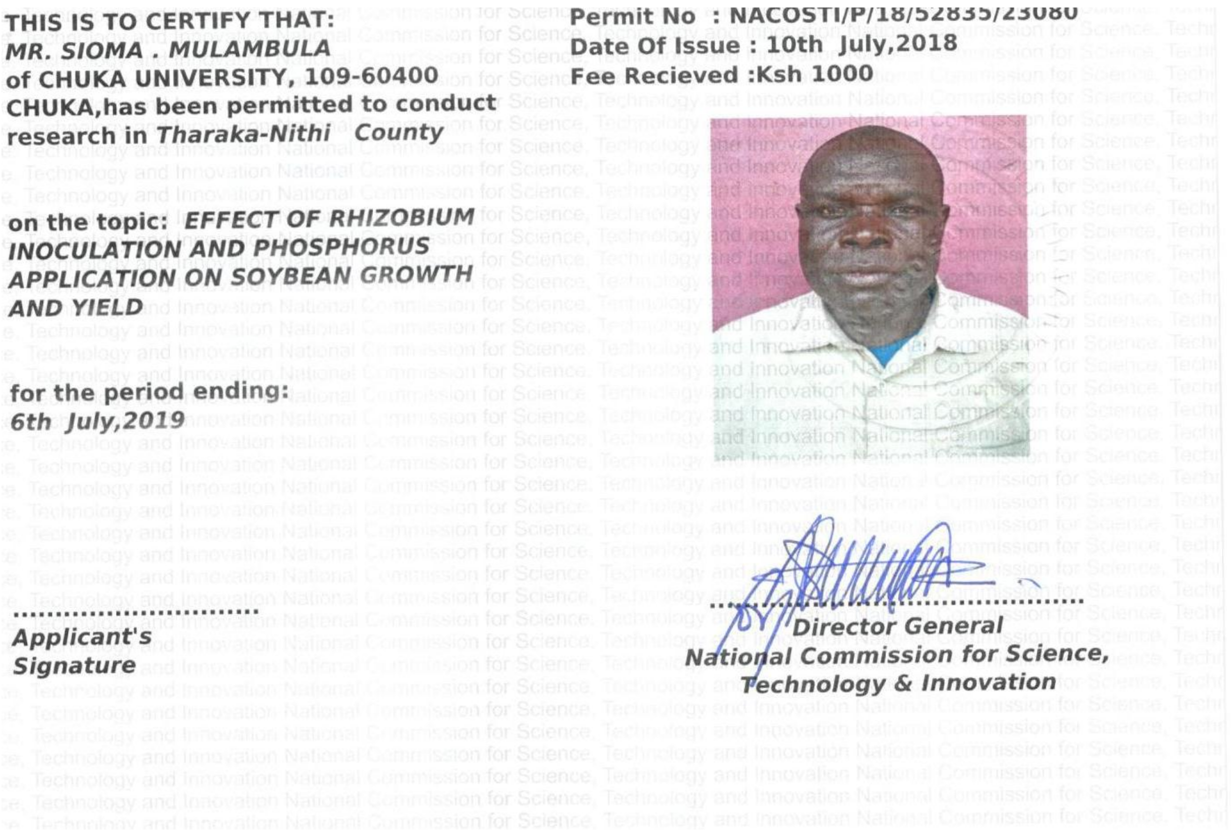
Walangululu, M., Sika, T., Cizungu, N., Mulumuna, L. and Baijukya, F. (2013). Field legume response to inoculation with Rhizobium in the Sud Kivu province, DR Congo. *Paper presented at ISFM Africa conference,* (p. 11).

Waluyo, S. H., Lie, T. A. and Mannetje, L. (2004). Effect of phosphate on nodule primordia of soybean (Glycine max Merrill) in acid soils in rhizotron experiment. *Indonesian Journal of Agricultural Science, 5*, 37-44.

Zhou, Q. H., Chen, Q., Y. Tong, Y. L. and Wang, Y. (2016). Light-induced ambient degradation of Few-layer black phosphorus: Mechanism and protection. *Angewandte Chemie* (128), 11609-11613.

APPENDICES

Appendix 1: National Commission of Science Technology and Innovations Permit



THIS IS TO CERTIFY THAT:
MR. SIOMA . MULAMBULA
of CHUKA UNIVERSITY, 109-60400
CHUKA,has been permitted to conduct
research in *Tharaka-Nithi County*

Permit No : NACOSTI/P/18/52835/23080
Date Of Issue : 10th July,2018
Fee Recieved :Ksh 1000

on the topic: *EFFECT OF RHIZOBIUM INOCULATION AND PHOSPHORUS APPLICATION ON SOYBEAN GROWTH AND YIELD*

for the period ending:
6th July,2019

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix 2: Analysis of Variance for Plant Height in Trail I and II

		Plant Height Trail I				Plant Height Trail II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	407.58731	203.79366	1.01	0.3639	373.97010	186.98505	0.93	0.3938
Variety	1	4243.76372	4243.76372	21.06	<.0001	4170.88889	4170.88889	20.80	<.0001
Rhizobia	8	23765.22646	2970.65331	14.74	<.0001	24182.60204	3022.82526	15.0	<.0001
Block*Variety	2	2760.82281	1380.41140	6.85	0.0011	2595.03299	1297.51649	6.47	0.0016
Variety*Rhizobia	8	78.64204	9.83026	0.05	0.9999	85.10937	10.63867	0.05	0.9999
Block*Variet*Rhizobi	32	1554.15807	48.56744	0.24	1.0000	1552.08025	48.50251	0.24	1.0000

Appendix 3: Analysis of Variance for Nodule Number in Trail I and II

		Nodule Number Trail I				Nodule Number Trail II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	29709.4815	14854.7407	77.47	<.0001	161.9441	80.9720	3.29	0.0398
Variety	1	689.7963	689.7963	3.60	0.0596	186.2929	186.2929	7.57	0.0066
Rhizobia	8	129018.1481	16127.2685	84.11	<.0001	107877.1560	13484.644	547.62	<.0001
Block*Variety	2	164.9259	82.4630	0.43	0.6512	56.2006	28.1003	1.14	0.3220
Variety*Rhizobia	8	1084.8704	135.6088	0.71	0.6849	187.9349	23.4919	0.95	0.4741
Block*Variet*Rhizobi	32	17031.5926	532.2373	2.78	<.0001	691.8250	21.6195	0.88	0.6576

Appendix 4: Analysis of Variance for Fresh Nodules in Trail I and II

		Fresh Nodules Trial I				Fresh Nodules Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	526.700436	263.350218	6.28	0.0024	0.3388254	0.1694127	1.56	0.2136
Variety	1	389.271300	389.271300	9.28	0.0027	0.4945673	0.4945673	4.55	0.0344
Rhizobia	8	2407.639475	300.954934	7.18	<.0001	392.0694085	49.0086761	450.90	<.0001
Block*Variety	2	509.045979	254.522989	6.07	0.0029	0.2504820	0.1252410	1.15	0.3185
Variety*Rhizobia	8	2283.451262	285.431408	6.81	<.0001	2.0128635	0.2516079	2.31	0.0224
Block*Variet*Rhizobi	32	9652.960685	301.655021	7.19	<.0001	1.7356169	0.0542380	0.50	0.9886

Appendix 5: Analysis of Variance for Dry Nodule in Trail I and II

		Dry Nodule Trial I				Dry Nodule Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.78061204	0.39030602	20.66	<.0001	0.3748672	0.1874336	0.63	0.5360
Variety	1	0.00026667	0.00026667	0.01	0.9056	1.3246185	1.3246185	4.42	0.0370
Rhizobia	8	10.64790926	1.33098866	70.46	<.0001	118.2813241	14.7851655	49.38	<.0001
Block*Variety	2	0.22346944	0.11173472	5.91	0.0033	0.1980791	0.0990396	0.33	0.7188
Variety*Rhizobia	8	0.11915000	0.01489375	0.79	0.6135	2.8834756	0.3604345	1.20	0.2999
Block*Variet*Rhizobi	32	0.11915000	0.01489375	0.79	0.6135	13.4935090	0.4216722	1.41	0.0877

Appendix 6: Analysis of Variance for Number of Banches in Trail I and II

		Number of Banches in Trail I				Number of Banches in Trail I			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	68.481481	34.240741	18.74	<.0001	24.878	12.439	5.61	0.0044
Variety	1	2948.166667	2948.166667	1613.52	<.0001	2496.56781	2496.56781	1125.38	<.0001
Rhizobia	8	426.148148	53.268519	29.15	<.0001	382.725716	47.840715	21.57	<.0001
Block*Variety	2	3.000000	3.000000	0.82	0.4418	12.868355	6.434177	2.90	0.0579
Variety*Rhizobia	8	149.500000	18.687500	10.23	<.0001	127.701303	15.962663	7.20	<.0001
Block*Variet*Rhizobi	32	83.351852	2.604745	1.43	0.0802	76.064250	2.377008	1.07	0.3766

Appendix 7: Analysis of Variance for Number of Pods in Trail I and II

		Number of Pods in Trail I				Number of Pods in Trail II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	4.73148	2.36574	0.03	0.9673	7.36749	3.68374	0.05	0.9496
Variety	1	5280.66667	5280.66667	74.23	<.0001	5158.22842	5158.22842	72.39	<.0001
Rhizobia	8	41570.06481	5196.25810	73.04	<.0001	41351.63615	5168.95452	72.54	<.0001
Block*Variety	2	9.69444	4.84722	0.07	0.9342	15.06549	7.53275	0.11	0.8997
Variety*Rhizobia	8	9.69444	4.84722	0.07	0.9342	1407.38060	175.92258	2.47	0.0150
Block*Variet*Rhizobi	32	514.90741	16.09086	0.23	1.0000	515.22611	16.10082	0.23	1.0000

Appendix 8: Analysis of Variance for Fresh Shoot in Trail I and II

		Fresh Shoot in Trail I				Fresh Shoot in Trail II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	77.18509	38.59255	0.16	0.8494	4.54181	2.27091	0.01	0.9918
Variety	1	9493.62963	9493.62963	40.19	<.0001	8024.94112	8024.94112	28.97	<.0001
Rhizobia	8	44195.31870	5524.41484	23.39	<.0001	40851.49918	5106.43740	18.44	<.0001
Block*Variety	2	154.14509	77.07255	0.33	0.7221	4.82438	2.41219	0.01	0.9913
Variety*Rhizobia	8	1778.94204	222.36775	0.94	0.4842	1522.73757	190.34220	0.69	0.7024
Block*Variet*Rhizobi	32	2353.27481	73.53984	0.31	0.9999	4409.73230	137.80413	0.50	0.9889

Appendix 9: Analysis of Variance for Dry Shoot in Trail I and II

		Dry Shoot in Trail I				Dry Shoot in Trail II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	1.17593	0.58796	0.00	0.9979	220.91756	110.45878	0.48	0.6180
Variety	1	8214.00000	8214.00000	29.64	<.0001	7992.01203	7992.01203	34.92	<.0001
Rhizobia	8	40851.49918	5106.43740	18.44	<.0001	47160.47087	5895.05886	25.76	<.0001
Block*Variety	2	11.08333	5.54167	0.02	0.9802	0.00000	0.00000	0.00	1.0000
Variety*Rhizobia	8	1361.50000	170.18750	0.61	0.7652	3165.63207	395.70401	1.73	0.0953
Block*Variet*Rhizobia	32	4097.24074	128.03877	0.46	0.9941	877.21372	27.41293	0.12	1.0000

Appendix 10: Analysis of Variance for Root Length in Trail I and II

		Root Length Trial I				Root Length Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	224.998633	112.499317	5.19	0.0065	215.000660	107.500330	4.97	0.0081
Variety	1	3577.838992	3577.838992	165.10	<.0001	3631.316149	3631.316149	167.79	<.0001
Rhizobia	8	3483.864746	435.483093	20.10	<.0001	3605.881741	450.735218	20.83	<.0001
Block*Variety	2	228.302759	114.151379	5.27	0.0061	233.432582	116.716291	5.39	0.0054
Variety*Rhizobia	8	288.930442	36.116305	1.67	0.1103	256.991328	32.123916	1.48	0.1666
Block*Variet*Rhizobi	32	488.459972	15.264374	0.70	0.8781	513.286455	16.040202	0.74	0.8397

Appendix 11: Analysis of Variance for Seed YieId per Plant in Trail I and II

		Seed YieId per Plant Trial I				Seed YieId per Plant Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.890368	0.445184	0.15	0.8623	0.978384	0.489192	0.16	0.8505
Variety	1	204.622978	204.622978	68.09	<.0001	203.946407	203.946407	67.51	<.0001
Rhizobia	8	1846.392803	230.799100	76.80	<.0001	1855.583040	231.947880	76.78	<.0001
Block*Variety	2	1.134011	0.567006	0.19	0.8281	1.278013	0.639007	0.21	0.8094
Variety*Rhizobia	8	19.722960	2.465370	0.82	0.5848	21.618003	2.702250	0.89	0.5208
Block*Variet*Rhizobi	32	27.408907	0.856528	0.29	1.0000	27.758843	0.867464	0.29	1.0000

Appendix 12: Analysis of Variance for Shoot N in Trail I and II

		Shoot N Trial I				Shoot N Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.15797037	0.07898519	7.02	0.0014	0.01245926	0.00622963	0.58	0.5633
Variety	1	0.11950617	0.11950617	10.63	0.0015	0.02444506	0.02444506	2.26	0.1353
Rhizobia	8	87.19973333	10.89996667	969.42	<.0001	19.87848889	2.48481111	230.13	<.0001
Block*Variety	2	0.05499753	0.02749877	2.45	0.0915	0.00326420	0.00163210	0.15	0.8599
Variety*Rhizobia	8	0.27751605	0.03468951	3.09	0.0036	0.01733827	0.00216728	0.20	0.9902
Block*Variet*Rhizobi	32	0.65892099	0.02059128	1.83	0.0114	0.15712099	0.00491003	0.45	0.9939

Appendix 13: Analysis of Variance for Grain N in Trail I and II

		Grain N Trial I				Grain N Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.2414815	0.1207407	3.65	0.0293	0.06567901	0.03283951	1.74	0.1797
Variety	1	0.6050000	0.6050000	18.29	<.0001	0.52246914	0.52246914	27.75	<.0001
Rhizobia	8	207.2111111	25.9013889	782.84	<.0001	55.64567901	6.95570988	369.45	<.0001
Block*Variety	2	0.0548148	0.0274074	0.83	0.4395	0.00641975	0.00320988	0.17	0.8435
Variety*Rhizobia	8	0.6666667	0.0833333	2.52	0.0150	0.27308642	0.03413580	1.81	0.0823
Block*Variet*Rhizobi	32	0.6303704	0.0196991	0.60	0.9531	0.21901235	0.00684414	0.36	0.9992

Appendix 14: Analysis of Variance for Shoot P in Trail I and II

		Shoot P Trial I				Shoot P Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	145.198	72.599	0.86	0.4273	296.148	148.074	3.64	0.0295
Variety	1	189.043	189.043	2.23	0.1381	1152.000	1152.000	28.33	<.0001
Rhizobia	8	5674635.716	709329.465	8373.63	<.0001	7705808.222	963226.028	23685.9	<.0001
Block*Variety	2	237.272	118.636	1.40	0.2509	31.259	15.630	0.38	0.6818
Variety*Rhizobia	8	519.346	64.918	0.77	0.6330	780.444	97.556	2.40	0.0202
Block*Variet*Rhizobi	32	2208.864	69.027	0.81	0.7425	765.704	23.928	0.59	0.9566

Appendix 15: Analysis of Variance for Grain P in Trail I and II

		Grain P Trial I				Grain P Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	227.568	113.784	1.35	0.2625	227.568	113.784	1.35	0.2625
Variety	1	1306.173	1306.173	15.54	0.0001	1306.173	1306.173	15.54	0.0001
Rhizobia	8	5731711.679	716463.960	8526.20	<.0001	5731711.679	716463.960	8526.20	<.0001
Block*Variety	2	185.346	92.673	1.10	0.3356	185.346	92.673	1.10	0.3356
Variety*Rhizobia	8	623.383	77.923	0.93	0.4971	623.383	77.923	0.93	0.4971
Block*Variet*Rhizobi	32	2197.531	68.673	0.82	0.7394	2197.531	68.673	0.82	0.7394

Appendix 16: Analysis of Variance for Symbiotic Efficiency in Trail I and II

		Symbiotic Efficiency Trial I				Symbiotic Efficiency Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	1596.4387	798.2193	0.61	0.5442	1766.0849	883.0425	0.35	0.7074
Variety	1	622.9611	622.9611	0.48	0.4910	11132.9096	11132.9096	4.37	0.0381
Rhizobia	8	245653.3076	30706.6634	23.49	<.0001	379171.7247	47396.4656	18.62	<.0001
Block*Variety	2	249.8487	124.9244	0.10	0.9089	212.3232	106.1616	0.04	0.9592
Variety*Rhizobia	8	4158.7440	519.8430	0.40	0.9206	46924.9896	5865.6237	2.30	0.0230
Block*Variet*Rhizobi	32	2366.5616	73.9550	0.06	1.0000	10316.9873	322.4059	0.13	1.0000

Appendix 17: Analysis of Variance for Rhizobium Use Efficiency in Trail I and II

		Rhizobium Use Efficiency I				Rhizobium Use Efficiency Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	4728990	2364495	0.36	0.6960	2805631	1402816	0.26	0.7696
Variety	1	85426756	85426756	13.10	0.0003	108469779	108469779	20.26	<.0001
Rhizobia	8	6808031790	851003974	130.52	<.0001	5213304547	651663068	121.74	<.0001
Block*Variety	2	933538	466769	0.07	0.9309	802179	401090	0.07	0.9278
Variety*Rhizobia	8	271664160	33958020	5.21	<.0001	380279361	47534920	8.88	<.0001
Block*Variet*Rhizobi	32	59329039	1854032	0.28	1.0000	32822483	1025703	0.19	1.0000

Appendix 18: Analysis of Variance for Phosphorus Use Efficiency in Trail I and II

		Phosphorus Use Efficiency I				Phosphorus Use Efficiency Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	3.148853	1.574426	0.30	0.7411	0.468198	0.234099	0.04	0.9595
Variety	1	5.237245	5.237245	1.00	0.3185	23.368107	23.368107	4.13	0.0426
Rhizobia	8	6552.362319	819.045290	155.96	<.0001	6268.698519	783.587315	138.53	<.0001
Block*Variety	2	0.130229	0.065114	0.01	0.9877	0.018387	0.009193	0.00	0.9984
Variety*Rhizobia	8	92.488732	11.561091	2.20	0.0261	258.614337	32.326792	5.71	<.0001
Block*Variet*Rhizobi	32	80.030116	2.500941	0.48	0.9939	52.477267	1.639915	0.29	1.0000

Appendix 19: Analysis of Variance for Grain Yield Per Ha in Trail I and II

		Grain Yield Per Ha I				Grain Yield Per Ha Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	225.298611	112.649306	5.14	0.0069	70007.64	35003.82	0.29	0.7519
Variety	1	3556.723380	3556.723380	162.21	<.0001	7774080.12	7774080.12	63.37	<.0001
Rhizobia	8	3469.000000	433.625000	19.78	<.0001	76896333.47	9612041.68	78.35	<.0001
Block*Variety	2	242.030093	121.015046	5.52	0.0048	8079.35	4039.67	0.03	0.9676
Variety*Rhizobia	8	239.287037	29.910880	1.36	0.2160	702929.61	87866.20	0.72	0.6773
Block*Variet*Rhizobi	32	497.337963	15.541811	0.71	0.8738	975962.61	30498.83	0.25	1.0000

Appendix 20: Analysis of Variance for Net Income in Trail I and II

		Net Income I				Net Income Trial II			
Source	DF	Anova SS	Mean Square	F Value	Pr > F	Anova SS	Mean Square	F Value	Pr > F
Block	2	12469548854	6234774427.2	0.98	0.3760	1629181324.1	814590662.06	0.30	0.7426
Variety	1	254764305814	254764305814	40.05	<.0001	199985918851	199985918851	73.12	<.0001
Rhizobia	8	1.325396E12	165674500422	26.04	<.0001	1.5175961E12	189699518526	69.36	<.0001
Block*Variety	2	5328143335.9	2664071668	0.42	0.6581	169176779.67	84588389.836	0.03	0.9695
Variety*Rhizobia	8	61234924499	7654365562.4	1.20	0.2950	12613433951	1576679243.8	0.58	0.7975
Block*Variet*Rhizobi	32	187070095976	5845940499.3	0.92	0.5976	22461348044	701917126.36	0.26	1.0000