Original Research Article

Grain Yield and Economic Benefit of Soybean as affected by Integration of *Rhizobium* Inoculation and Phosphorus Application in Chuka sub-County, Kenya

ABSTRACT

Soybean (*Glycine max* [L.] Merrill) yields are far below the potential yield on most smallholder farms in Kenya. This necessitates suitable interventions to bridge this yield gap and result to profitable soybean production. An experiment was conducted in Chuka University demonstration farm, Chuka Sub County to determine the effect of integration of *rhizobium* inoculation (R) and phosphorus (P) on yields and net economic returns in soybean cultivation. The experiment was laid out in a randomized complete block design in a split-split plot arrangement with each treatment replicated three times. The experiment which was conducted between 2018 and 2019 was repeated once and the treatments included; three P rates (0, 20 and 30 kg/ha), three *rhizobium* rates (0, 100 and 200 g/ha) and two soybean genotypes (SB19 and SB24). Triple superphosphate (0:46:0) was used as the source of the phosphorus. The soybean genotypes, *rhizobium* and phosphorus rates were assigned to the main plot, sub-plot and the sub-sub plots respectively. Data collected included soybean yields (kg/ha) and economic analysis was calculated. The data collected was subjected to analysis of variance using Statistical Analysis System® 9.4 and significantly different means separated using Tukeys test at ($p \le 0.05$). The results showed statistically significant difference in soybean yields and net economic benefit within SB19 and SB24 genotypes in both trials at ($p \le 0.05$). Integration of R and P at the rate of 200 g and 30 kg/ha increased soybean yield by 101% and 98%, and 158% and 138% for SB19 and SB24 in trial I and II respectively. 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 I and II, respectively. Both genotypes performed well in yield and net economic benefit and application of R and P at the rate of 200 g/ha and 30 kg/ha promoted yield and net economic benefit of soybean.

Keywords: Soybean production, Yield gaps, Fertilizer application, Rhizobia inoculant

1. INTRODUCTION

Soybean is valued for fixing of atmospheric nitrogen into the soil and their role as a rotation crop with cereals and vegetable crops [1, 2]. It complements staple low-protein cereals as a source of protein and minerals [3], serve as feed and supplement the farmers' incomes [4] and its integration in the predominantly cereal-based farming systems in sub-Saharan Africa offers a pathway for sustainable intensification [5]. *Rhizobium* inoculation with the right strain can promote soybean yield through improved nodulation and nitrogen utilization. Increased soybean production can contribute to food security and income generation to the smallholder farmers. However, globally an average yield of 2.5 tons per ha and in Africa 1.3 tons per ha of soybean is documented [6]. Therefore, soybean yields on smallholder farms in most parts of Africa are far below the potential yield resulting to a huge yield gap. Farmers in most parts of Kenya use unsustainable production practices like limited inputs and production practices. Soybean yields in Kenya have remained under 2.0 tons per ha which is below 3.0 tons per ha realized in other countries [7] and in research stations [8]. In eastern region of Kenya, soybean yield ranges between 0.54 – 1.1 tons per ha although there is potential of producing 3.0 – 3.6 tons per ha [9].

Rhizobia inoculation increase yield of legumes such as soybean, however its performance is influenced by among others; soybean genotype, rhizobia (R) strains, fertilizers and environment [10]. It has been documented that the soybean-*Bradyrhizobium* symbiosis can fix up to between 44-300 kg nitrogen (N) per ha under favourable conditions [11, 12]. In legumes, N is more useful because it is the main component of amino acid as well as protein [13]. The use of R as a source of N is the most profitable way to increase soybean production due to its low cost [14]. Shahid *et al*. [15] reported that seed production in soybean can increase by 70-75% when the proper bacterial strains is used to inoculate soybean seeds. Singh *et al*. [16] reported that higher nodulation due to inoculation led to higher N fixation by R and eventually the number of pods per plant which resulted to higher grain yields as a whole.

Phosphorus is the second most vital plant nutrient apart from N, as it plays an important role in root proliferation [17]. Phosphorus deficiencies in the soil restrict root and nodule development which are key in nitrogen fixation. Further, phosphorus is key in the production of protein, phospholipids and phytin in legume grains [18]. Ndakidemi *et al*.[19], Singh *et al*. [20], and Adeyeye *et al.* [21] reported that combination of beneficial soil bacteria and phosphorus in legume plants significantly increased the marginal rate of return and the grain yield compared with the single use of phosphorus or rhizobia. This was due to the fact that seed inoculation with proper *rhizobium* strain and phosphorus at early growth stage stimulated the root nodulation [22, 23, 24]. Therefore, integration of R and P can be an effective way of enhancing the nodulation attributes; available soil N, P, and subsequently, yields of soybean [25]. Korir *et al*. [26] reported that R and P have a pronounced effect on common bean grain yield, whether applied alone or in integration. In another trial observations depicted that integration of native inoculant and P resulted in higher soybean yields compared to un-inoculated [14].

Because of the increasing price of commercial fertilizers, it is obvious that the cost of nutrients will be increasing in most cropping systems. Evidently, legumes will remain the backbone of farming system of the resource poor farmers due to their capacity to fix nitrogen. There is no single organic or inorganic source that can meet the needs for all plant nutrients, hence integrated use of all nutrient sources namely, organic (e.g., compost, crop residues, and manures), inorganic chemical fertilizers, and biofertilizer needs careful attention and consideration [27]. The use of the high-yielding genotypes, in addition to adoption of appropriate *rhizobium* inoculant application with N and P, has been reported to potentially improve soil fertility and soybean yield [28]. Therefore, research efforts should be directed in assessing the optimum combinations between different soil management practices that will offer a higher economic returns to the resource poor farmers. Despite the roles of soybean in; improving soil fertility, food security and income, little effort has been done to ascertain the response of soybean yield and net economic benefit to integration of rhizobia and phosphorus application in Chuka Sub County and this formed the basis of this study.

2. MATERIAL AND METHODS

2.1 Study Site

The experiment was conducted at Chuka University Research farm, Chuka Sub-County, Tharaka Nithi County, Kenya in two cultivations (Trial I and II) between 2018 and 2019. Chuka University lies at an altitude of approximately. 1399 m above sea leve and at a latitude of 0˚20'0"S and longititude of 37˚39'0"E (Figure 1). Has temperature range of 20.97 ^{o}C to 27.25 ^{o}C, average rainfall of 1178 mm with nitisol type of soils [29]. 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* [30].

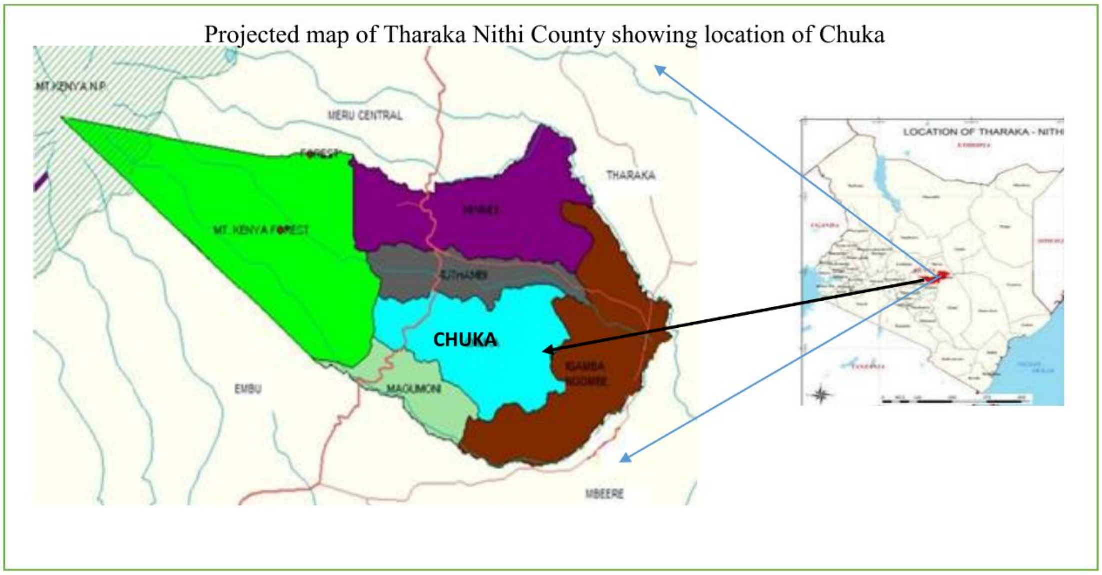

Figure 1: Location of Chuka University in Chuka Sub County in Kenya
Source [31]

2.2 Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) in a split-split plot arrangement with each treatment replicated thrice. Treatments included; combined application of three rates of phosphorus and three rates of rhizobia resulting to 9 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;] 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. 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**.**

2.3 Planting Materials, Establishment and Crop Management

Certified soybean seed was obtained from KALRO-Kakamega, while inoculant (*Bradyrhizobium japonicum*) from MEA Limited-Nakuru. The seed inoculation was done in Plant Science Laboratory of Chuka University. 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 according to Lamptey *et al.* [32]. To ensure the collect viable microbial counts (CFU mL^{-1}) was attained, **t**he mixture was stirred uniformly until even seed coating was attained. The seeds were then spread on flat plywood under a shade and allowed to air dry for 30 minutes. 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 to avoid cross contamination.

A basal application of triple superphosphate 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. Weeding was done manually using a hoe and spraying against pests and diseases were done to all the plots.

2.4 Data collection

The data on seed grain yield was taken from plants in the two middle rows of each plot. The first and last rows including the first and last plants per row formed the guard rows. The net economic benefit was determined using the grain yield output price against the cost of production.

2.4.1 Determination of grain yield

The soybean yield was determined at full maturity where ten plants were randomly selected from the middle rows in each plot in trial I and II. They were harvested, dried, threshed, cleaned and packed separately per plant in labeled paper bags. The threshed grains were used to determine the grain yield per plant, and per hectare. The grain yield for the ten randomly selected experimental plants was later added together and put in a paper bag and weighed with a spring balance in order to get the total grain yield in kg per plot. The grain yield collected was transformed into kilograms by multiplying yield per plant by plant population of 200,000 plants per hectare.

2.4.2 Determination of net economic benefit

Net economic benefit (NEB) of the soybean production was performed after harvest. It was calculated by deducting the gross production cost (variable cost) from gross soybean output (revenue), according to Reckling *et al*. [33] and Berche *et al.* [34]. The gross soybean output was determined by multiplying the yield of harvested soybeans in kg by the prevailing market price per kg at Chuka municipal market. The gross benefit was the gross income derived from sale of the grain. The gross production cost included cost of; phosphorus, rhizobia, soybean 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.

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 minus the gross production costs calculated as shown in Table 1.

2.5 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 [35] and significantly different means were separated using Tukeys test at $p \leq 0.05$.

Table 1: Gross cost of soybean production per hectare

Variables	No. of units	Unit Cost (KSh /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 man-days@ 379.30	18,950
1st Weeding(1 ha x2)	5 Man-days	10 man-days@ 379.30	37,900
Harvesting (1 Ha)	3 Man-days	10 man-days@ 379.30	11,370
Threshing/packaging	5 Man-days	10 man-days@ 379.30	18,950
Inputs			
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. RESULTS AND DISCUSSION

3.1 Effect of Integrated Application of Different Rates of *Rhizobium* and Phosphorus on Soybean Grain Yield

Rhizobia application significantly increased soybean grain yield per plant in both trial I and II. For example, rhizobia application at the rate of 100 g per ha, significantly increased soybean grain yield 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 9.30 g and 7.30 g for SB19 and SB24 soybean genotypes in both trial I and II respectively. Furthermore, application of R at the rate of 200 g per ha, significant increased soybean grain yield per plant from the control treatment (0 g R and 0 kg P per ha) to 8.55 g and 6.55 g, and 10.22 g and 8.25 g for SB19 and SB24 soybean genotypes in both trial I and II respectively. The soybean genotype SB19 had a lower grain yield per plant of 9.34 g, 7.35 g compared to 10.58 g, 8.58 g of SB24 in trial I and II. This showed a mean difference of 1.24 g and 1.23 g for trial I and II respectively (Table 2). This shows, increasing the application of R increases the grain yield per plant in soybean cultivation

Triple superphosphate application significantly increased the soybean grain yield per plant. For example, application of TSP at the rate of 20 kg per ha, significantly increased soybean grain yield 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 soybean genotypes in both trial I and II respectively. Further, application of TSP at the rate of 30 kg per ha, significantly increased the soybean grain yield per plant from the control treatment (0 g R and 0 kg P per ha) to 9.08 g and 7.08, and 9.86 g and 7.86 for SB19 and SB24 soybean genotypes in trial I and II respectively (Table 2). This shows, increasing the application of TSP increases the soybean grain yield per plant in soybean cultivation.

Integration of rhizobia and triple superphosphate application at the rate of 100 g and 30 kg per ha, significantly increased grain yield 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 soybean genotypes in both trial I and II respectively. Furthermore, dual application of R and TSP at the rate of 200 g and 20 kg per ha, significantly increased soybean grain yield per plant from the control treatment (0 g R and 0 kg P per ha) to 10.61 g and 8.61 g, and 11.79 g and 9.72 g for SB19 and SB24 soybean genotypes in trial I and II respectively. Similarly, integration of R and TSP at the rate of 200 g and 30 kg per ha, significantly increased soybean grain yield per plant from the control treatment (0 g R and 0 kg P per ha) to 12.36 g and 10.36 g, and 14.20 g and 12.24 g for SB19 and SB24 soybean genotypes in both trial I and II respectively.

Overall, the mean grain yield was higher in trial I compared to trial II (Table 2). The present study shows that increase in the co-application of R and TSP increases the soybean grain yield per plant in soybean cultivation.

Table 2: Effect of rhizobia and phosphorus application on soybean grain yield (g) per plant

		Trial I	Trial II
Variety	**Treatment**	**Grain yield per plant (g)**	**Grain yield per plant (g)**
SB19	T1	6.14^{f*}	4.13^{e}
	T2	8.49^{de}	6.55^{cd}
	T3	9.08^{d}	7.08^{c}
	T4	7.64^{e}	5.64^{d}
	T5	10.21^{c}	8.21^{b}
	T6	11.01^{b}	9.01^{b}
	T7	8.55^{de}	6.55^{cd}
	T8	10.61^{bc}	8.61^{b}
	T9	12.36^{a}	10.36^{a}
SB24	T1	7.17^{f}	5.13^{e}
	T2	9.28^{de}	7.27^{cd}
	T3	9.86^{d}	7.86^{c}
	T4	9.30^{e}	7.30^{d}
	T5	11.08^{c}	9.15^{b}
	T6	12.29^{b}	10.29^{b}
	T7	10.22^{de}	8.25^{cd}
	T8	11.79^{bc}	9.72^{b}
	T9	14.20^{a}	12.24^{a}
MSD		0.98	0.98
CV(%)		17.4	21.82

*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.

There were significant influence of the integration of R and P in grain yield per ha within genotypes SB19 and SB24 ($p \leq 0.05$) in trials I and II. 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 1128 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, respectively (Table 3). 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 3).

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 3)

Table 3: Effect of rhizobia and phosphorus on grain yield/ha

Variety		**Trial I**	**Trial II**
	Treatment	**Grain yield/ha (kg)**	**Grain yield/ha (kg)**
SB19	T1	1227^{e*}	826^{e}
	T2	1692^{cd}	1312^{cd}
	T3	1816^{c}	1416^{c}
	T4	1529^{d}	1128^{d}
	T5	2042^{b}	1641^{b}
	T6	2201^{b}	1794^{b}
	T7	1709^{cd}	1302^{cd}
	T8	2089^{b}	1722^{b}
	T9	2472^{a}	2138^{a}
SB24	T1	1434^{e}	1026^{e}
	T2	1855^{cd}	1454^{cd}
	T3	1971^{c}	1571^{c}
	T4	1859^{d}	1459^{d}
	T5	2216^{b}	1829^{b}
	T6	2431^{b}	2058^{b}
	T7	2044^{cd}	1650^{cd}
	T8	2324^{b}	1944^{d}
	T9	2840^{a}	2449^{a}
MSD		194.36	199.25
CV (%)		17.19	21.9

*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.

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 3).

In a study to evaluate the on farm response of soybean to rhizobia inoculation and or mineral P fertilizer using no input (control), TSP fertilizer (P), rhizobia inoculant (I) and TSP plus inoculant (P + I) the results showed that the average grain yield of plots that received P or I were higher than control plots [36]. In this study low grain yield was observed 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 [6] 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.* [24] 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. This can be attributed to both genotypes being adapted to the study area. This is contrary to Mudibu *et al.* [37] and van Heerwaarden *et al.* [38] who reported high variations in response of soybean genotypes to application of different rates of R and phosphorus.

Omari *et al.* [39] when studying soybean cultivars, *Bradyrhizobium* strains, and soybean cultivar-*Bradyrhizobium* interaction reported that inoculation significantly increased grain yield by an average of 32% compared with the non-inoculated control. In this study the highest yield increment was observed 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.* [40] 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. Księżak and Bojarszczuk [41] reported that a positive effect of the inoculants and mineral N fertilization was found on the morphological features: pod number, as well as number and weight of seeds. In this study it is possible that the resulting to higher amount of N compounds available in the rhizosphere was absorbed and translocated to the grains, therefore, leading to increase in grain yield. This concurs with Ibrahim *et al.* [42] and Shish *et al.* [25] whose findings reported 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.

3.2 Effect of Integrated Application of Different Rates of *Rhizobium* and Phosphorus on Soybean Net Economic Benefit

The net economic benefit (NEB) of soybean grain enterprise depended on rhizobia, P rates and soybean genotypes which significantly varied among the treatments applied ($p \leq 0.05$). 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 KSh. 70,722.66 and KSh. 11,232.70, and KSh. 109,296.60 and KSh. 41,230 observed with the control treatment (0 g and 0 kg per ha) to KSh. 116,223.30 and KSh. 56,120, and KSh. 168,663.30 and KSh. 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 KSh. 142,796.70 and KSh. 81,763.30, and KSh. 237,563.30 and KSh. 134,080 for SB19 and SB24 genotypes in both trial I and II, respectively (Table 4).

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 KSh. 70,722.66 and KSh. 11,232.70, and KSh. 109,296.60 and KSh. 41,230 observed with the control treatment (0 g and 0 kg per ha) to KSh. 133,030 and KSh. 70,750, and KSh. 156,520 and KSh. 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 KSh. 74,707.34 and KSh. 72,797.30, and KSh. 59,366.70 and KSh. 67,400 for SB19 and SB24 genotypes grain enterprise in trial I and II, respectively (Table 4). Integration of R and P application increased NEB per ha of SB19 and SB24 genotypes grain enterprise in both trial I and II.

Table 4: Effect of rhizobia and phosphorus on net economic benefit

Variety	**Treatment**	**Trial I** Net economic benefit/ha (KSh)	**Trail II** Net economic benefit/ha (KSh)
SB19	T1	70722[e*]	11238[d]
	T2	133030[d]	70750[c]
	T3	145430[cd]	84030[c]
	T4	116223[d]	56120[c]
	T5	184012[bc]	127496[b]
	T6	199663[b]	141630[b]
	T7	142796[bc]	81763[c]
	T8	190830[b]	135430[b]
	T9	239496[a]	192730[a]
SB24	T1	109296[e]	41230[d]
	T2	156520[d]	96330[c]
	T3	168663[cd]	108630[c]
	T4	165730[d]	105730[c]
	T5	210730[bc]	163696[b]
	T6	240963[b]	184930[b]
	T7	237563[bc]	134080[c]
	T8	225780[b]	173630[b]
	T9	297930[a]	239330[a]
MSD		45373	29750
CV (%)		17.2	21.7

Means with the same letter along the column for the same variety are not significantly different at ($p \le 0.05$*) 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 at the rate of 100 g and 20 kg per ha significantly increased NEB per ha from KSh. 70,722.66 and KSh. 11,232.70, and KSh. 109,296.60 and KSh. 41,230 per ha observed with the control treatment (0 g and 0 kg per ha) to KSh. 184,012.60 and KSh. 127496.60, and KSh. 210,730.00 and KSh. 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 KSh. 199,663.30 and KSh. 141,630, and KSh. 240,963.30 and KSh. 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 KSh. 120,107.34 and KSh. 124,197.30, and KSh. 116,483.40 and KSh. 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 KSh. 239,496 and KSh. 192,730, and KSh. 297,930 and KSh. 239,330 per ha for SB19 and SB24 genotypes in both trial I and II, respectively (Table 4).

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, of R and complementarity by P where each enhanced their use efficiency. It concurs with Ndakidemi *et al*. [19], Singh *et al.* [20], and Adeyeye *et al.* [21] who reported that combination of rhizobia and phosphorus in legume plants significantly increased the marginal rate of return compared with the single use of phosphorus or rhizobia. The findings are in agreement with those Nasir *et al.* [40] who observed that on annual basis, the costs of production were reduced due to enhanced biological nitrogen fixation after use of rhizobia. Similarly, this concurred with Nicolas *et al*. [43] who observed that substitution of expensive artificial N fertilizers by natural N2 fixation resulted in an improved net income per crop season. It concurred with Silva & Uchida [44] whose field trials showed that N captured by crops due to the use of rhizobia inoculant cost extremely lower compared to use of artificial N fertilizer.

The use of 200 g of R per ha was equivalent to 3 bags of urea to cover 1 ha which cost KSh. 9,000, which probably, reduced cost of inputs resulting to higher returns on investment. This concurs with Singh *et al.* [45] who observed that crop production using inoculants could be cheaper and more affordable to the poor resource smallholder farmers. Similar report by Adeyeye *et al.* [21] showed that combination of beneficial bacteria and phosphorus in legume plants significantly incremented the grain yield compared with the single use of phosphorus or rhizobia. Overall, this study 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 Chuka sub-County.

4. CONCLUSION

This study depicted that integration of R and P at the rate of 200 g and 30 kg per ha was superior compared to other treatment levels in grain yield and net economic benefit in soybean production. The two genotypes, SB19 and SB24 performed equally well. Farmers could adopt integration of R and P at the rate of 200 g and 30 kg per ha and either of the genotypes for sustainable soybean cultivation. Further research by use of other sources of P such as phosphorus solubilizing bacteria to enhance on yield and hence subsequent net economic returns is recommended.

COMPETING INTERESTS:

Authors have declared that no competing interests exist. the products used for this research are commonly and predominantly use products in our area of research and country. there is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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