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Effect of Plant Density, Phosphorus and Rhizobium Inoculant on Growth and Yield of KAT B1 and GLP 585 Beans in Medium Potential Agro Ecological Zones of Imenti South, Kenya

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***Abstract*: Common bean (Phaseolus vulgaris (L) is adapted to different agro ecological zones. Its genetic makeup and agronomic practices affects their growth and production. Some farmers have grown bean varieties not bred for certain localities with minimal or no understanding of their agronomic practices. Bean variety KAT B1 bred for lower agro ecological zones perform well in medium agro ecological zones despite its agronomic practices being less understood by farmers. Therefore, this study sort to determine the effect of plant densities, phosphorus and rhizobium inoculum on growth of KAT B1 and Red Haricot beans in medium agro ecological zones. Field experiments were conducted for two seasons i.e., October - December 2021 and March – May 2022 at Kaguru Agricultural Training Centre, Imenti South, Kenya. A 3 x 2 x 2 x 2 factorial experiment was laid out in a randomized complete block design with three replications. There were four factors; plant densities (111,111, 166,666 and 222,222 plants/ha), two common bean varieties (KAT B1 and Red Haricot GLP 585), rhizobium inoculum (0g and 100g/ha) and rock phosphate fertilizer (0 kgP/ha and 60 kgP/ha). Data collected on chlorophyll content, number of leaves and branches were subjected to analysis of variance using SAS version 9.4 and significant means separated using LSD at α= 0.05. Treatment R0V1D1P0 and R0V2D2P0 recorded the least chlorophyll content and number of leaves across the growth stages in both seasons. Similarly, treatment R1V1D3P1 and R1V2D2P1 recorded the highest chlorophyll content and number of leaves across the growth stages in both seasons at 7, 14, 21, 28 and 35 days after sowing (DAS). Treatment R0V1D1P0 recorded the least number of branches (0.50 and 0.79; 2.16 and 2.70) while treatment R0V2D2P0 also recorded the least number of branches (0.54 and 1.04; 2.12 and 2.82l) in season 1 and 2 respectively. Treatment R1V1D3P1 recorded the highest number of branches (2.34 and 3.58; 3.12 and 4.04) while treatment R1V2D2P1 also recorded the highest number of branches (2.58 and 4.91; 3.29 and 4.12) produced across the growth stages at 28 and 35 DAS in season 1 and 2, respectively. GLP 585 gave the highest yield 3.037 tonnes/ha in treatment R1V2D2P1 compared to KAT B1 yield of 2.670 tonnes/ha in treatment R1V1D3P1. Therefore, incorporation of rhizobium inoculant and rock phosphate fertilizer is recommended in common beans to increase yield and enhance food security.**

***Keywords*: Beans, Growth, Phosphorus, Plant density, Rhizobium inoculant.**

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important legume crop that is mainly produced for human consumption. However, its average production generally remains low, due to infertile soils, inadequate soil moisture, insect pests and diseases [1]. These conditions have continued to worsen with an increase in the rate of bean production but with little additional inputs like fertilizer, quality seeds and poor agronomic practices that lead to low yield [2]. The common bean has a wider ecological adaptation and wide range of yield maturity phases depending on the genetic basis of the variety [3]. Each ecological zone has its own recommended agronomic practices with respect to plant density and fertiliser application.

Growing of a particular bean cultivar in a certain agro ecological zone require appropriate adjustment of the recommended agronomic practices [4]. Use of suboptimal agronomic practices result to frequent low bean yields [5]. Agronomic practices such as planting density, fertiliser application and rhizobium inoculation need to be reviewed and re-optimized frequently, as these practices change with climatic conditions, farming practices and farmer's preferences consequently affect plant growth [6]. Plant density has been shown to affect growth of various crops, which in turn influences yield. As plant density increases, it affects the structure of the plant as well as its developmental patterns [7]. Planting density modifies the photosynthetic rate and photosynthetic carbon assimilation capacity of different parts of leaves. This is because planting density influences the nutritional status and light distribution characteristics of plants. Studies by [8] reported that stem thickness of common bean increased as plant population decreased since there was low intra - specific competition, while thin stems were observed as the density of bean population increased due to increase in competition reducing yield. [9] showed that close spacing of haricot bean led to reduced number of branches compared to wider spacing hence reduced crop yield.

Phosphorus is a very important nutrient for crop growth and yield. Its application increase in leaf area which in turn

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increases the surface area for photosynthesis that improves growth. Studies by [10] reported that application of phosphorus to common beans resulted in significant increase in leaf area which in turn increased yield as a result of efficient utilization of nutrients applied. Biological nitrogen fixation forms an alternative to synthetic fertilizers and promote growth and yield in crops. A study by [11] has shown that the increase in number of leaves was attributed to the symbiotic relationship of rhizobium bacteria with the roots of leguminous crops, which helped to fix atmospheric nitrogen into the roots of legumes. Biological inoculation was attributed to the maximum number of leaves that were produced because of inoculation, which promoted photosynthesis hence encouraging the plants to produce more shoots and in turn increased yield [12].

The availability of growth promoting resources in the soil determines plant density [13]. Whenever plant resources are limited, competition for nutrients, light and soil moisture limits productivity of individual plants [14]. Adequate spacing between plants is necessary to increase growth [15]. Medium agro ecological zones require close spacing of crops due to availability of growth resources compared to lower agro ecological zones [16]. Close spacing leads to an increase in plant density hence a possibility of increasing yield if grown under proper management practices. Plant density of KAT B1 that is recommended in lower agro ecological zones is 111,111 plants/ha, while that for other bean varieties grown in medium agro ecological zones, for example, Red Haricot (GLP 585), is 222,222 plants/ha. Farmers in Medium agro ecological zones have adopted the plant density that is recommended for KAT B1 in other regions [17]. This may lead to suboptimal plant populations and thus reduced potential yields. Hence, there is need for studies on optimizing KAT B1 plant density in the medium ecological zones in order to enhance yield.

A major challenge affecting bean production in medium agro ecological zones is soil infertility [18]. Moreover, some edaphic factors that constrain bean production include nitrogen and phosphorus deficiency. The recommended application rate of phosphorus is 60 Kg/ha. However, the high cost of inorganic fertilizers may have resulted to application of suboptimal fertilizer levels by the farmers. Although the bean plant has a capacity for biological nitrogen fixation (BNF), biologically fixed nitrogen can be enhanced through different methods, like inoculation with proven rhizobium strains [19]. Biological nitrogen fixation through rhizobium inoculation offers an environmentally friendly alternative to use of chemical fertilizers by resource poor farmers [20]. Rhizobium inoculation increases common bean growth and yield [21].

Since phosphorus (P) is an important plant macronutrient and its deficiency causes significant yield reduction in leguminous crops [22], there is need to enhance P usage through application of adequate amount for better legume productivity and soil sustainability. This is because inadequate P availability restricts root growth, the process of photosynthesis, translocation of sugars and other processes that directly influence nitrogen fixation by legume plants [23]. Although beans fix nitrogen in the soil, they require high input of P for their optimal growth, energy transformation and boosting nodulation, because BNF requires high adenosine triphosphate (ATP) energy [24]. Therefore, there is need for studies to optimize the agronomic practices, such as fertilizer requirements, inoculation and plant densities on growth of common bean under its current growing environmental conditions for sustainable yield production.

2. Materials and Methods

A. *Study Site*

The study was conducted at Kaguru Agricultural Training Centre (ATC) in Meru County, Kenya during the two growing seasons; October - December 2021 short rains and March - May 2022 long rains. The site is in South Imenti whose GPS coordinates lies at latitude: -0.04747º longitudes: 37.65351º. The altitude of the area is approximately 1200 m above local sea level. It has an annual mean minimum and maximum temperature of 17ºC and 21°C, respectively, and annual rainfall varies from 1200 to 1600 mm. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October through December. The soils are Humic Nitisols [25] which are deep, well weathered with moderate to high inherent fertility. The main crops grown include coffee, maize, beans, tea, bananas and vegetables. Livestock reared include cattle, goats, sheep and poultry.

B. *Experimental Design*

The experiment was a 3 x 2 x 2 x 2 factorial laid out in a Randomized Complete Block Design (RCBD) and replicated three times. There were four factors at various levels, which included plant densities (111,111, 222,222, 166,667 plants/ha), two common bean varieties (KAT B1 and Red Haricot (GLP 585), rhizobium inoculum (0 g and 100 g/ha) and rock phosphate fertilizer (0 kgP/ha and 60 kgP/ha). Each experimental plot measured 1.6 m x 1.6 m in size and the distance between the blocks was 1 m, while the distance between experimental plots was 0.5 m.

C. *Data Collection*

In determining the growth and yield of bean plants, measurements were taken on eight randomly selected data plants in each plot on the two centre rows. Chlorophyll content was measured at 7, 14, 21 28 and up to 35 days after sowing (DAS) as described by [26]. A chlorophyll meter SPAD 502 Plus (Spectrum Technologies) with Data Loggers and RS-232 was used. A leaf on the second branch from the bottom was selected, put in the leaf chamber of a chlorophyll meter and readings recorded in ug/l. The number of leaves per plant were counted at intervals of 7, 14, 21 and 28 DAS per experimental unit. Number of branches were physically counted from the selected plants and recorded at intervals of 28 and 35 DAS. Grain yield was determined by weighing the seeds using a weighing balance then converted to tonnes/ha.

D. *Data Analysis*

Field data on chlorophyll content, number of leaves, no of branches and grain yield was subjected to analysis of variance (ANOVA) using the statistical analysis software (SAS, version 9.4). The significant means were then separated using least significance difference (LSD) at 5 % probability level.

3. Results and Discussion

A. Effect of Plant Density, Phosphorus and Rhizobium Inoculant on Chlorophyll Content

Analysis of variance showed that there was significant ($p < 0.05$) effect of plant densities on chlorophyll content in both seasons (Table 1 and 2). Chlorophyll content was significantly high at plant density 222,222 plants/ha while the least chlorophyll content was observed when common beans were grown under plant density 111,111 plants/ha in both seasons. Generally, chlorophyll content decreased during the last days to flowering period.

Table 1
Mean of chlorophyll content at different plant densities in season 1 at Imenti south

Plant Density	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS
D1	28.532c*	33.963c	26.893c	14.559c	7.265b
D2	36.146a	41.131a	30.926a	16.974a	8.958a
D3	34.289b	39.779b	29.101b	15.800b	8.690b
Mean	33.0951	38.3908	29.0296	15.7446	8.28471
CV	2.01290	2.01290	2.01290	2.01290	2.01290
LSD	0.9568	0.5427	0.44	0.4174	0.325
R-square	0.99705	0.99468	0.99366	0.99298	0.97256

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha). CV is the coefficient of variation and LSD is least significant difference.

Table 2
Mean of chlorophyll content at different plant densities in season 2 at Imenti south

Plant Density	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS
D1	16.671c*	25.438c	18.642b	18.340c	9.187c
D2	20.902a	31.328a	20.694a	27.139a	12.828a
D3	20.464b	30.634b	20.433a	21.232b	10.39b
Mean	19.3523	29.1116	19.9235	22.1518	10.7573
CV	2.01669	2.01808	2.01290	2.0166	2.0166
LSD	0.2386	0.3035	0.3495	0.43	0.2991
R-square	0.9961	0.9974	0.9943	0.9933	0.9842

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha). CV is the coefficient of variation and LSD is least significant difference.

Analysis of variance indicated that there was significant ($p < 0.05$) treatment effect on chlorophyll content in both seasons (Table 3 and 4). The results of this study showed that there was a significant effect of plant density, rock phosphate and rhizobium inoculant application on the chlorophyll content of common beans at different growth stages. The chlorophyll content significantly increased with an increase in plant density. This was in agreement with [27] who showed that there was an increased chlorophyll levels at high plant density and decreased quantities of chlorophyll at low plant densities.

Generally, treatment R0V1D1P0 and R0V2D2P0 recorded the least chlorophyll content across the growth stages in both seasons. Similarly, treatment R1V1D3P1 and R1V2D2P1 recorded the highest chlorophyll content across the growth stages in both seasons. Chlorophyll concentration was found to be increased with growth of common bean up to 14 DAS. Thereafter there was decrease in chlorophyll concentration till 35 DAS in both seasons. This could be because the chlorophyll concentration of the leaves influences the leaf biochemical properties and biochemical interactions because of molecular composition of the leaf. In turn, these properties could be responsible for colour changes as a result of differences in pigment concentration. This study is in agreement with the observation of [28].

Table 3
Means for chlorophyll content at different treatments and growth stages of KAT B1 and GLP 585 common bean varieties in season 1 at Imenti south

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS
R0V1D0	23.24k	26.24i	21.36k	10.80k	6.32e
R0V1D11	40.82c	48.26bk	36.54cl	12.26j	7.78d
R0V1D20	39.06dm	28.84h	23.44j	13.49i	6.42e
R0V1D30	25.30j	39.12e	36.20c	15.85g	7.30h
R0V1D31	34.79e	40.48m	31.16f	16.36fl	7.65dh
R1V1D1P0	33.03fn	41.39dm	21.36k	16.87f	9.79b
R1V1D11	40.60c	47.39ck	25.81i	14.80h	8.80cg
R1V1D2P0	39.06dm	48.01b	36.53bc	13.49i	7.41dh
R1V1D2P1	32.31gn	46.40cl	31.09f	18.57d	7.40dh
R1V1D3P0	30.75h	33.97g	21.76k	15.67n	8.46g
R1V1D3P1	43.90b	49.01b	37.53b	20.55b	9.94b
R0V1D2P1	39.40d	42.16d	28.18gl	10.88k	7.63dh
R0V2D1P0	18.16l	20.90j	21.68k	10.82k	6.80e
R0V2D1P1	31.91g	34.27g	32.14e	17.53e	9.87b
R0V2D2P0	25.32j	29.56h	27.11h	15.73gm	5.92f
R0V2D2P1	29.42io	36.68f	37.34bl	16.03gln	9.04c
R0V2D3P0	35.16e	47.46ck	25.97i	16.20gn	9.83b
R0V2D3P1	35.16e	45.98l	27.25h	18.51d	9.96b
R1V2D1P0	29.86i	34.21g	35.04d	15.73gn	9.22c
R1V2D1P1	38.67dm	42.12d	35.04d	13.25im	9.22c
R1V2D2P0	31.53g	31.15g	27.65hl	15.69n	7.46dh
R1V2D2P1	47.60a	52.34a	40.06a	22.20a	11.36a
R1V2D3P0	23.18k	27.15i	25.82i	16.20gl	7.75dh
RIV2D3P1	28.65o	36.60f	23.15j	16.31l	8.94c
CV	1.43821	1.921857	1.881784	1.974679	3.429465
LSD	0.9568	0.5427	0.44	0.4174	0.325
Mean	33.09516	38.39086	29.02965	15.74468	8.284714
R-square	0.997058	0.994688	0.993660	0.992986	0.972564

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without phosphorus application and P1 is rock phosphate fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

In the whole chain, nitrogen played a very important role hence the use of rhizobium inoculant in the present study significantly increased common bean growth by enhancing nutrients availability to supplement tissue development like chlorophyll integrity. [29] reported that increase in plant growth following rhizobium bacteria treatment can be as a result of production of phytohormones and the enhancement of nutrient availability hence increasing chlorophyll content. The decrease in chlorophyll concentration after 14 DAS can be related with nutrient allocation since mature plants often redirect nutrients from the leaves to other parts of the plant such as seeds, fruits, or roots. This reallocation can result in a decrease in chlorophyll production as the plant prioritizes reproduction or storage over maintaining high levels of chlorophyll in older leaves hence increasing yield.

Table 4
Means for chlorophyll content at different treatments and growth stages of KAT B1 and GLP 585 common bean varieties in season 2 at Imenti south

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS
R0V1D1P0	9.90n	18.02m	19.46m	18.97l	9.03jk
R0V1D1P1	18.04i	27.92g	26.97c	26.22d	13.07e
R0V1D2P0	13.60lm	29.50f	28.29k	14.12c	9.21ijk
R0V1D3P0	19.00gh	26.36h	23.99k	13.57fg	11.70fg
R0V1D3P1	20.74f	28.75m	23.14fg	22.57fg	11.03gh
R1V1D1P0	21.07f	28.19g	26.90i	18.03d	9.15ljk
R1V1D1P1	25.35c	35.03c	22.90l	13.87gh	11.06e
R1V1D2P0	18.11i	26.81h	22.20m	12.22hi	10.34ef
R1V1D2P1	18.33hi	26.85h	20.35h	20.20jk	9.75ijk
R1V1D3P0	20.66f	26.61h	24.93d	24.60ef	9.16ijk
R1V1D3P1	28.24b	35.38c	35.09b	31.52b	15.12bc
R0V1D2P1	16.87j	30.75de	22.80ef	21.18ij	10.30hi
R0V2D1P0	10.38n	18.63m	10.34m	10.24p	5.04l
R0V2D1P1	23.80d	29.40f	25.72d	24.69de	8.50j
R0V2D2P0	17.86i	29.17f	26.60c	15.60n	5.56l
R0V2D2P1	14.60kl	23.90i	17.77j	10.47p	5.65l
R0V2D3P0	16.38j	22.86ij	18.76ij	16.97m	15.94b
R0V2D3P1	21.09f	33.21d	28.19gh	21.32c	14.35cd
R1V2D1P0	20.74f	38.74b	22.38ef	17.40m	9.95ij
R1V2D1P1	19.25g	33.22d	16.67l	12.97m	8.36j
R1V2D2P0	15.35jk	21.91k	18.78i	12.95o	8.38j
R1V2D2P1	33.86a	53.84a	42.37a	33.85a	16.98a
R1V2D3P0	22.45e	37.99b	34.23e	23.53b	13.95
RIV2D3P1	18.26i	21.38kl	21.35g	19.29ij	9.48ijk
CV	2.0720	1.73892	3.01881	3.26211	4.67245
LSD	0.6806	0.8682	0.9885	1.2265	0.8531
Mean	19.35238	29.1116	19.92355	22.1518	10.7573
R-square	0.996115	0.99746	0.99433	0.99330	0.98427

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without phosphorus application and P1 is rock phosphate fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

The decrease in chlorophyll content was also shown with the difference in time that both common beans took to mature as the variety that showed earlier senescence is the one that matured faster due to earlier nutrient reallocation. Similarly, there could be a transfer of nutrients from the senescent leaf to other parts of the plant that lead to leaf death, hence a decrease in chlorophyll concentration. This is in agreement with [30] who showed that during senescence, the leaf yellows as chlorophyll degrades and photosynthesis is reduced.

The treatments with application of rock phosphate fertilizer resulted in plants that are more vigorous with more intense green colour indicating higher chlorophyll content and greater photosynthetic ability. This study is in agreement with the results of [31]. The observed improvement could be due to functional importance of phosphorus in legume growth such as sugar and starch utilization, cell division and organization, photosynthesis use efficiency and formation of green pigment in plant, which finally improved plant growth and chlorophyll synthesis. [32] have also reported such significant result in legumes.

The treatments that incorporated rhizobium inoculant and rock phosphate fertilizer showed more dark green leaves, which were found to be rich in chlorophyll content as compared with un-inoculated treatments. [26] and [33] reported that P and N deficiency decreases chlorophyll content. This is seen in treatments without rhizobium inoculant and rock phosphate fertilizer. [34] observed that the leaf chlorophyll content increased significantly with rhizobial inoculation and phosphorus application in common bean. These improvements in integrated treatments could be accredited to improved biological nitrogen fixation by rhizobial inoculants and phosphorus supply, which increased nitrogen supply to the plants and subsequently increased total leaf chlophyll contents of the legumes. The promising results attained from this study conclude that application of rhizobium inoculant and rock phosphate fertilizer may substitute the expensive inorganic N fertilizers in improving plant growth and chlorophyll synthesis leading to an increase in yield.

B. *Effect of Plant Density, Phosphorus and Rhizobium Inoculant on the Number of Leaves*

Analysis of variance showed that there was significant ($p < 0.05$) effect of plant densities on the number of leaves in both seasons (Table 5 and 6). It was observed that the number of leaves produced was significantly high at plant density 222,222 plants/ha while the least number of leaves were produced when common beans were grown under plant density 111,111 plants/ha in both seasons.

Table 5
Mean of the number of leaves at different plant densities in season 1 at Imenti south

Plant Density	7 DAS	14 DAS	21 DAS	28 DAS
D1	2.297c*	5.304b	8.880a	11.258c
D2	2.492a	5.559a	8.994a	12.494a
D3	2.382b	5.311b	8.969a	12.123a
Mean	2.38927	5.39181	8.94766	11.9642
CV	2.01290	2.01290	2.01290	2.01290
LSD	0.0416	0.0767	0.2455	0.6128
R-square	0.98169	0.97967	0.98153	0.98811

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha). CV is the coefficient of variation and LSD is least significant difference.

Table 6
Mean of the number of leaves at different plant densities in season 2 at Imenti south

Plant Density	7 DAS	14 DAS	21 DAS	28 DAS
D1	2.460a*	6.269c	15.052c	29.754c
D2	2.506a	8.465a	17.802a	32.729a
D3	2.479a	7.322b	16.083b	30.578b
Mean	2.48226	6.35280	15.31275	30.3542
CV	2.01290	2.01290	2.01290	2.01290
LSD	0.063	0.1025	0.161	0.2152
R-square	0.910271	0.965868	0.987058	0.995037

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha). CV is the coefficient of variation and LSD is least significant difference.

Analysis of variance indicated that there was significant ($p < 0.05$) treatment effect of plant density, rock phosphate and rhizobium inoculant application on the number of leaves per plant at different growth stages (Table 7 and 8). Increase in plant density significantly increased the number of leaves probably due to adequate growth resources. This in turn increased the leaf area per plant, consequently increasing the crop photosynthesis hence increased plant vigour and yield. Treatment R0V1D1P0 and R0V2D2P0 recorded the least number of leaves across the growth stages in both seasons. Similarly, treatment R1V1D3P1 and R1V2D2P1 recorded the highest number of leaves produced across the growth stages in both seasons. These results indicated a general trend increase in number of leaves in response to application of rhizobium inoculant and rock phosphate fertilizer in both seasons. Application of rhizobium inoculant to common bean enhanced the availability of nitrogen which affect the photosynthetic rate per unit leaf area hence increases the leaf area per plant, consequently increasing the crop photosynthesis. This finding is in agreement with [35], who showed that application of rhizobium inoculants significantly improved the growth of mung bean leaves and the photosynthetic rate.

Table 7
Means for number of leaves at different treatments and growth stages of KAT B1 and GLP 585 common bean varieties in season 1 at Imenti south

Treatment	7 DAS	14 DAS	21 DAS	28 DAS
R0V1D1P0	2.00k	4.66g	8.12ijk	9.54j
R0V1D1P1	2.58d	5.58d	10.33bc	12.66de
R0V1D2P0	2.16f	5.16fi	8.58hi	11.45ef
R0V1D3P0	2.08gh	5.08ft	8.95g	11.54ef
R0V1D3P1	2.61cd	5.50dh	9.37ef	11.33ef
R1V1D1P0	2.20ef	5.45dh	8.08jk	10.83gh
R1V1D1P1	2.20ef	5.04fj	8.00klm	10.41hi
R1V1D2P0	2.13fg	5.25ei	8.16kl	11.25efg
R1V1D2P1	2.33de	5.37eh	8.62gh	10.54h
R1V1D3P0	2.50cd	5.58d	8.95gh	12.37de
R1V1D3P1	2.72c	5.95b	10.40b	13.79cd
R0V1D2P1	2.33de	5.04fj	8.25ijk	11.41ef
R0V2D1P0	2.00gh	4.50g	7.75m	10.08hi
R0V2D1P1	2.40e	5.37ef	8.04klm	11.37ef
R0V2D2P0	2.16f	5.16fi	9.12fg	10.00h
R0V2D2P1	2.08gh	5.35ef	9.95c	17.2bc
R0V2D3P0	2.54cd	6.04b	7.79lm	13.77c
R0V2D3P1	2.83b	5.12fi	8.33ij	11.33ef
R1V2D1P0	2.81bc	6.08b	9.79cd	12.27de
R1V2D1P1	2.75bcd	5.95b	9.50ef	11.00g
R1V2D2P0	2.53de	5.72c	9.54de	12.37d
R1V2D2P1	2.91a	6.33a	10.54a	18.00a
R1V2D3P0	2.08gh	4.79g	8.12jk	11.41ef
RIV2D3P1	2.39e	4.95j	10.28bc	11.04fg
CV	2.0470	1.4628	1.7322	2.2920
LSD	0.0416	0.0767	0.2455	0.6128
Mean	2.3892	5.3918	8.9476	11.9642
R-square	0.9816	0.9796	0.9815	0.9881

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without rock phosphate fertilizer application and P1 is rock phosphate fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

The increase in number of leaves because of inoculation could also be attributed to the supply of nitrogen that was made into available form of N nutrients, hence increased plant vigour. This resulted in more number of leaves per plant that was recorded towards the end of the growing season. This study is in agreement with the findings of [36] who showed that the number of leaves per plant were significantly higher in egusi melon as a result of nitrogen application. The results of this study agree with the findings of [37] who reported a great improvement in the number of leaves with application of rhizobium inoculant. In addition to that, [38] in his study indicated that there was maximum number of leaves per bean plant due to higher nitrogen fixation during inoculation. The study also agrees with the results of [39] who reported that inoculation with effective rhizobium brought a significant effect on the number of leaves in legumes.

Table 8
Means for number of leaves at different treatments and growth stages of KAT B1 and GLP 585 common bean varieties in season 2 at Imenti south

Treatment	7 DAS	14 DAS	21 DAS	28 DAS
R0V1D1P0	2.12jk *	6.06ijk	12.45k	22.79no
R0V1D1P1	2.33ghi	5.91jkl	15.25f	30.79hi
R0V1D2P0	2.45fgh	6.33ghi	16.16de	29.62kl
R0V1D3P0	2.37fgh	6.08ijk	15.25f	30.04jk
R0V1D3P1	2.37fgh	6.16hij	13.87ij	26.07n
R1V1D1P0	2.39fgh	6.08ijk	15.83e	27.60m
R1V1D1P1	2.29ijk	5.87kl	13.66j	29.20l
R1V1D2P0	2.50fgh	7.00cd	16.29d	30.45fg
R1V1D2P1	2.50fgh	6.41fg	14.29hi	26.75n
R1V1D3P0	2.54def	6.45fg	14.66gh	27.54m
R1V1D3P1	2.66cde	6.29ghi	14.58gh	31.58f
R0V1D2P1	2.37fgh	5.25o	12.87k	29.06jk
R0V2D1P0	2.04k	5.29o	11.58l	26.20mn
R0V2D1P1	2.37fgh	5.33no	14.75g	30.31ijk
R0V2D2P0	2.63de	7.08cd	16.95c	33.70de
R0V2D2P1	2.70bcd	7.25bc	13.70j	26.70m
R0V2D3P0	2.12j	5.83klm	14.79g	30.41hij
R0V2D3P1	2.83bc	7.25bc	17.29c	36.66bc
R1V2D1P0	2.54fgh	6.66ef	16.33d	32.41cd
R1V2D1P1	2.29ijk	5.58mn	14.25hi	30.20ijl
R1V2D2P0	2.63de	6.80ef	18.21b	36.33c
R1V2D2P1	3.33a	8.38a	20.37a	39.70a
R1V2D3P0	2.87b	7.37b	16.25de	30.95gh
RIV2D3P1	2.20ijk	5.66lm	17.79b	37.00b
CV	4.3672	2.7765	1.8095	1.2202
LSD	0.1782	0.2899	0.4554	0.6087
Mean	2.4822	6.3528	15.3127	30.354
R-square	0.9102	0.9658	0.98705	0.9950

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without rock phosphate fertilizer application and P1 is rock phosphate fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

Application of rock phosphate fertilizer to common beans led to an increase in the number of leaves in the current study. This is probably because phosphorus is an essential component of nucleic acids, phospholipids, and energy-rich phosphate compounds, thus, plays a crucial role in root growth hence enhance nutrient uptake that is translocated to the leaves leading to an increase in the number of leaves hence increasing yield. This was consistent with [40] who reported that phosphorus application induced an increase in the number of leaves per plant. This study is also in agreement with the findings of [35]. Similarly, the finding of this study is in agreement with that of

[41], who reported an increase in the number of leaves with application of phosphorus in soybean plants. [32] also reported an increase in the number of leaves in response to the application of phosphorus fertilizer in cowpea. The incorporation of rhizobium inoculant and rock phosphate fertilizer resulted in better photosynthesis and accumulation of photosynthates leading to an increase in plant vigour and more leaves due to the presence of nutrients, plant growth promoters and increased activities of microbes, which improved plant growth significantly hence increased the number of leaves and yield.

C. Effect of Plant Density, Phosphorus and Rhizobium Inoculant on the Number of Branches

Analysis of variance showed that there was significant ($p < 0.05$) effect of plant densities on the number of branches in both seasons (Table 9). It was observed that the least number of branches were produced when common beans were grown under plant density 111,111 plants/ha in both seasons.

Table 9
Mean of the number of branches at different plant densities in the two seasons at Imenti south

Plant Density	**Season 1**		**Season 2**	
	28 DAS	35 DAS	28 DAS	35 DAS
D1	1.258c	1.778b	2.713a	3.401c
D2	1.629a	2.158a	2.750a	3.554a
D3	1.421b	2.158a	2.725a	3.462b
Mean	1.441949	2.036888	2.729663	3.472743
CV	7.463457	7.752728	3.812497	2.812006
LSD	0.0959	0.164	0.0605	0.0567
R-square	0.983878	0.982520	0.953973	0.971021

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha). CV is the coefficient of variation and LSD is least significant difference.

A significant ($p<0.05$) effect of plant density, rock phosphate and rhizobium inoculant application on the number of branches at different growth stages was exhibited in this study (Table 10). Plant density significantly influenced the number of branches produced. This probably might be due to less competition for light, space and nutrients among the plants due to use of appropriate planting population which increased vegetative growth especially those having more primary branches. The result agreed with the finding of [42] who reported that the number of primary branches was highly significant among Desi and Kabuli type Natoli and Acos Dobie of the chickpea varieties, respectively. These results are also in conformity with the findings of [43]. This enhanced vegetative development resulted to subsequent increase in the number of branches which in turn probably provided more space for higher pod attachment and development hence increasing yield.

Treatment R0V1D1P0 and R0V2D2P0 recorded the least number of branches across the growth stages in both seasons. Similarly, treatment R1V1D3P1 and R1V2D2P1 recorded the highest number of branches produced across the growth stages in both seasons. Application of rhizobium inoculant on common beans in the current study increased the number of branches in both seasons. This probably is because nitrogen is an important nutrient for plants since it is a component of chlorophyll and a building block for amino acids and protein. This finding concur with that of [44] who reported that adding nitrogen increased the number of branches significantly because nitrogen stimulates vegetative growth.

Table 10
Means for number of branches at different treatments and growth stages of KAT B1 and GLP 585 common bean varieties in season 1 and 2 at Imenti south

	Season 1		**Season 2**	
Treatment	**28 DAS**	**35 DAS**	**28 DAS**	**35 DAS**
R0V1D1P0	0.50m	0.79n	2.16ij	2.70m
R0V1D1P1	1.79def	2.25ef	2.25j	3.66fg
R0V1D2P0	0.91ij	1.25lm	2.95cde	3.75def
R0V1D3P0	1.87de	1.66hi	2.83def	3.70ef
R0V1D3P1	0.83jk	1.25lm	2.79efgh	3.54gh
R1V1D1P0	0.75kl	1.12lm	2.64hi	3.68efg
R1V1D1P1	1.70ef	2.41e	3.04bc	3.83cde
R1V1D2P0	1.50g	1.58jk	2.79efgh	3.45hi
R1V1D2P1	2.33c	3.12c	3.00bcd	3.25jk
R1V1D3P0	1.68f	2.04fg	2.62hi	3.91bc
R1V1D3P1	2.34bc	3.58b	3.12bc	4.04b
R0V1D2P1	2.41bc	2.75	2.81efg	3.87bc
R0V2D1P0	1.00ij	1.25lm	2.70gh	3.37ij
R0V2D1P1	1.79ef	1.87ghi	2.45i	3.64hi
R0V2D2P0	0.54m	1.04mn	2.12ij	2.82lm
R0V2D2P1	2.37bc	2.75d	3.04bc	2.91l
R0V2D3P0	1.91d	3.16c	2.25j	2.85l
R0V2D3P1	0.91jk	2.04fg	2.95cde	2.95l
R1V2D1P0	0.58lm	1.18lm	2.62hi	3.95bc
R1V2D1P1	1.17hi	1.75hij	3.12bc	3.33ij
R1V2D2P0	1.20g	1.95gh	3.05bc	3.62fg
R1V2D2P1	2.58a	4.91a	3.29a	4.12a
R1V2D3P0	0.75kl	1.33kl	2.45i	3.16k
RIV2D3P1	0.91jk	1.91ghi	3.16b	3.33ij
CV	7.4634	7.7527	3.8124	2.8120
LSD	0.0959	0.164	0.171	0.1605
Mean	1.4419	2.0368	3.4727	1.4227
R-Square	0.9838	0.9825	0.9710	0.9680

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without rock phosphate application and P1 is phosphorus fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

The significant increase in branches as a result of rhizobium inoculation was probably due to increased photosynthetic activity as a result of optimal availability of plant nutrients. Subsequently, rhizobium inoculant increased the availability of photosynthates for branch expansion and consequently greater branch numbers. The increase in number of branches in this research was probably associated with adequate availability of nitrogen as a result of rhizobium inoculation, which consequently enhanced pronounced vegetative growth and development. This is in conformity with [45] who reported that incorporation of rhizobia inoculant enhanced vegetative development, subsequently, resulting to more number of branches. [46] also showed that higher number of branches are attributed to high mineral content from inputs which stimulate rapid leaf production and play an essential role in branching.

The positive effect of rock phosphate fertilizer application on the number of branches per plant could be due to the significant role of the element on cell division and elongation which resulted in the production of more lateral buds that developed into branches with more space for higher pod attachment and development increasing yield. [47], reported that phosphorus fertilizer application to cowpea varieties had a positive effect on number of branches per plant. [48] also reported that the total number of branches per plant increased with phosphorus application. [49], was of the same opinion that an increment in number of branches with phosphorus application in cell division led to an increase in number of branches. Similarly, [50] agreed with this research that the higher number of branches in plots with phosphorus fertilizer can be attributed to the high mineral content in phosphorus that is expected to stimulate rapid leaf production and play an essential role in branching. The results also agreed with the findings of [51] who showed that there was a significant effect of phosphorus application on the number of branches produced by chickpea plant. [52] also observed an increase in the number of branches in spider plant that had received phosphorus fertilizer supplementation.

D. Bean Grain Yield

Analysis of variance showed that there was significant ($p < 0.05$) effect of plant densities on grain yield. In season 1, the average grain yield produced by common beans ranged from 1117.48 tonnes/ha to 1861.11 tonnes/ha and from 1305.55 tonnes/ha to 2050.23 tonnes/ha in season 2 (Table 11). Above ground biomass ranged from 1796.29 tonnes/ha to 2865.46 tonnes/ha in season 1, and from 2059.60 tonnes/ha to 3216.43 tonnes/ha in season 2. In both seasons plant density 222,222 plants/ha gave the highest grain yield while the least was obtained when common bean was grown under plant density 111,111 plants/ha.

Table 11
Mean of bean grain yield at different plant densities in the two seasons at Imenti south

Plant Density	Season 1	Season 2
	Grain Yield (t/ha)	Grain Yield (t/ha)
D1	1117.48c*	1305.55c
D2	1861.11a	2050.23a
D3	1774.31b	2027.78b
Mean	1584.298	1794.522
CV	2.6625	2.0257
LSD	24.511	21.123
R-square	0.9956	0.9977

*Means followed by the same letter are not significantly different from each other at 5 % level of significance. Where D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), CV is the coefficient of variation and LSD is least significant difference.

Analysis of variance indicated that there was significant ($p < 0.05$) treatment effect on grain yield. In season 1, grain yield ranged from 0.500 tonnes/ha in treatment R0V1D1P0 to 2.66 tonnes/ha in treatment R1V2D2P1. In season 2, grain yield ranged from 0.671 tonnes/ha in treatment R0V1D1P0 to 3.037 tonnes/ha in treatment R1V2D2P1 (Table 12). Treatment R1V2D2P1 significantly gave the highest grain yield (2.66 and 3.037 tonnes/ha) while treatment R0V1D1P0 gave the least grain yield (0.500 and 0.671 tonnes/ha) in season 1 and 2 respectively (Table 12).

Table 12
Means for grain yield at different treatments of KAT B1 and GLP 585 common bean varieties in season 1 and 2 (in tonnes/ha) at Imenti south

	Season 1	**Season 2**
Treatment	**Grain Yield (t/ha)**	**Grain Yield (t/ha)**
R0V1D1P0	0.500op*	0.671op
R1V1D3P1	2.520b	2.670b
R1V1D1P1	1.981cd	2.076gh
R0V1D1P1	1.078mn	1.217m
R0V1D2P0	1.175k	1.592j
R1V1D1P0	1.481i	1.615j
R0V1D3P1	1.805e	1.430lm
R1V1D2P1	1.944cd	2.347cd
R0V1D2P1	1.111kl	0.916o
R1V1D3P0	1.465h	1.416lm
R1V1D2P0	1.685f	1.944h
R0V1D3P0	1.159k	1.229m
R0V2D2P1	1.351ij	1.518jk
R1V2D3P1	2.231bc	2.694b
R1V2D1P0	1.462i	1.587ij
R0V2D1P0	0.935n	0.981no
R1V2D2P0	1.694f	2.118g
R1V2D1P1	1.916cd	2.604d
R1V2D3P0	1.833e	1.754i
R0V2D3P1	1.812e	2.208ef
R1V2D2P1	2.666a	3.037a
R0V2D2P0	0.805op	1.185m
R0V2D3P0	1.902de	2.027bc
R0V2D1P1	1.500gh	2.222de
CV	2.662	2.025
LSD	69.329	59.745
Mean	1584.29	1794.52
R-Square	0.9956	0.9971

*Means followed by the same letter along the column in both bean varieties are not significantly different from each other at 5% level of significance. Where R0 is beans without inoculant, R1 is inoculated beans, V1 is KAT B1 (variety 1), V2 is Red Haricot (GLP 585, variety 2), D1 is plant density 1 (111,111 plants/ha), D2 is plant density 2 (222,222 plants/ha), D3 is plant density 3 (166,666 plants/ha), P0 is the control without phosphorus application and P1 is rock phosphate fertilizer at 30 kg/ha. The treatment was made up of a combination of the above factors, CV is the coefficient of variation and LSD is least significant difference.

The results of this study showed that there was a significant effect of plant density, rock phosphate and rhizobium inoculant application on grain yield in both seasons. Increase in plant density significantly increase grain yield. This probably is due to availability of growth resources with optimum plant density. This finding is similar with the results of [53] who reported that there was highest fruit yield when tomatoes were grown at the highest planting density than when grown under the lowest planting density. Generally, treatment R0V1D1P0 and R0V2D2P0 recorded the least grain yield between the two common bean varieties in both seasons. Similarly, treatment R1V1D3P1 and R1V2D2P1 recorded the highest grain yield in both seasons. This suggest incorporation of rhizobium inoculant and rock phosphate in a treatment may offer optimum plant nutrition.

The increase in grain yield is attributed to the effect of nitrogen as a result of rhizobium inoculant application, whereas the control produced the lowest grain yield. This means that rhizobia inoculant application can alleviate the soil fertility problem, which is a direct cause of poor production in the study area. In other words, enhanced grain production with rhizobium inoculation could be attributed to increased availability of nutrients like phosphorus. Higher availability of these nutrients is important for growth, development, and assimilates production [54], which leads to increased grain production via photo-assimilates being re-translocated from the vegetative to the yield components. The results of this study are supported by the findings of different authors [55]. [56] also found that inoculating common bean had a substantial impact on grain yield.

Inoculation with rhizobium inoculant probably played the role of increasing the number of leaves in this study translating into higher photosynthetic capacity, which increases the source strength. The increased source strength enhances retention of many flowers hence increases the number of grains and eventually the grain yield. The findings of this study are in agreement with those of [57] who reported that rhizobium inoculant contained essential nutrient elements that favour high photosynthetic activities to promote plant roots and vegetative growth. [58] confirms with this reported that rhizobium inoculant contains readily available nitrogen that lead to improved vegetative growth of plants which result in more storage and subsequent utilization of carbohydrates hence improved grain yield.

Rock phosphate application on common beans increased grain yield since the crop was able to adapt to the environment or translocate and use the absorbed phosphorus for grain formation. GLP 585 significantly produced higher grain yield compared to KAT B1 variety. The difference in seed yield among the common bean cultivars might be related to the genotypic variations for P use efficiency [59], which may arise from variation in P acquisition and translocation and use of absorbed P for seed formation [60]. Hence, the cultivars which gave higher seed yield might have either better ability to absorb the applied P from the soil solution or translocation and use the absorbed P into plant biomass and seed yield, which is related to reduce P requirement in plant tissues than the low yielding cultivar [61].

Similarly, increase in seed yield might be attributed to overall improvement in growth attributes such as number of leaves and number of primary branches thereby increasing yield attributing traits such as number of pods per plant and number of seed per pod upon partitioning, which also showed an increasing trend as a result of P application. Finding of this study is in agreement with [62] Gobeze and Legese, (2015) who observed significant variations in seed yield for different crops including common bean in response to P application under field and greenhouse conditions.

4. Conclusion

Incorporation of rhizobium inoculant with rock phosphate fertilizer in common beans significantly influenced the chlorophyll content, number of leaves, number of branches and bean grain yield in medium potential agro ecological zones. Plant density 222,222 plants/ha significantly produced the highest chlorophyll content, number of leaves, number of branches and grain yield. KAT B1 being a drought tolerant bean variety that was bred for low agro ecological zones, performs well in medium agro ecological zones. Therefore, integration of rhizobium inoculant and phosphorus under plant density 166,666 plants/ha and 222,222 plants/ha in KAT B1 and GLP 585 common bean varieties respectively, is an important strategy to increase common bean production in medium potential agro ecological zone of Imenti South.

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