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GROWTH AND YIELD PERFORMANCE OF COMMON BEAN (*PHASEOLUS VULGARIS* L.) AS INFLUENCED BY PLANT DENSITY AT NYAGATARE, EAST RWANDA

Musana RF[1]*, Rucamumihigo FX[1], Nirere D[1] and SR Mbaraka[1]

Musana Fabrice

*Corresponding author email: musanafab@yahoo.fr

[1]College of Agriculture, Animal Sciences and Veterinary Medicine, University of Rwanda, P.O Box 210, Musanze, Rwanda

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is one of the most important priority crops grown in Rwanda. It is utilized as a staple food and is consumed as edible seeds and pods for provision of proteins. Best agronomic practices that would promote its optimum growth and maximum yield should be recommended. Plant density affects productivity of common bean and optimizing it would increase light interception by the crop and minimize competition between plants, resulting into improved crop growth rate and yield. To determine the effect of plant density on common bean growth and yield, four different plant densities: 200,000, 250,000, 300,000, 350,000 plants/ha were investigated in a randomized complete block design, with three replications. Interaction effects between plant density with these parameters: plant height, plant biomass, number of pod per plant, 100grain weight and yield were assessed using analysis of variance (ANOVA). Results indicated that plant height was significantly affected by bean planting density ($P<0.001$), and was significantly higher in 350,000 plants ha^{-1} than for all other plant densities. Bean biomass was significantly affected by plant density ($p=0.007$) and was significantly higher in 250,000 plants ha^{-1}. Bean planting density significantly affected the number of pods plant^{-1}($P<0.001$) and total bean yield ($P<0.001$). The number of pods plant^{-1} was highest at 249.5% using 200,000 plants ha^{-1}while 350,000 plants ha^{-1} density produced the lowest number of pods plant^{-1}. Bean yield was significantly higher in 250,000 plants ha^{-1} and lowest in 350,000 plants ha^{-1}. Hundred (100) grains weight was significantly affected by plant density ($p<0.001$). The highest 100grains weight was found in 200,000 plant ha^{-1} while the lowest was found in 350,000 plants ha^{-1}. These results indicate that 250,000 plants ha^{-1} population favors higher bean growth and grain yield. This study will provide an important basis to establish appropriate planting densities recommended for the bean crop in different agro-ecological zones of Rwanda.

Key words: Common bean, plant density, plant growth, field performance, biomass, yield

INTRODUCTION

Like in many other parts of the world, common bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes in Rwanda. It belongs to family Fabaceae, cultivated in the tropics, sub-tropics and temperate zones. It is popularly edible as dry and green grain beans [1]. It has been estimated that around 29 kg of beans are consumed per person in Rwanda per year[2]. Several phaseolus varieties exhibit diversity in morphological, agronomic characteristics and adaptability [3,4]. The bean crop is grown and widely distributed globally and has become a crop of importance in many parts of Africa[5]. It is desired because it is quick maturing, can be cropped under different cropping and smallholder farmer systems. Common bean improves soil fertility through nitrogen fixation, and it is an alternative source of protein and income for the smallholder farmers [6].

In Rwanda, common bean is among the top priority crops and is grown by 97% of farmers and supply about 65% of the dietary protein requirements to rural and urban populations [7]. It is grown for green leaves, green pods, and immature and/or dry seeds. Common beans are grown in all agro-ecological zones of the Rwanda depending on the varieties. The favorable climatic and soil conditions in Northern and Western parts of the country have led to intensive production of both climbing and bush beans. By contrast, Eastern region is characterized by: lower rainfall, higher temperatures and poor soil. These conditions only favor production of bush beans.

Such poor climatic and soil conditions affect plant population pattern, which in turn affect the growth and yield potential of common beans[8]. Increase in yield can be ensured by maintaining appropriate plant population of different planting patterns. The optimum plant density refers to the minimum density of plants required to obtain maximum yields[9].

Planting pattern influences light interception and utilization of moisture from the soil[10]. Plant density determines distribution, dispersion, quality and quantity of light energy quality among plants, which induces improved plant growth and grain yield[11]. Furthermore, plant density affects early ground cover, competitive ability with weed, canopy development, plant architecture and distribution of pods[12]. However, optimum plant density varies depending on crop species or varietal differences in vigor, height and branching, time of sowing, and the nature of the season[13].

Recent research has shown that low and high plant densities interfere with the performance of many crops such as: rice[14], soybean[15] and maize [16]. In several types of bean, high plant density in bean has been associated with pest outbreaks, diseases and shedding of leaves. Under high plant densities, majority of bean plants become too thin, less vigorous and increase in height resulting in lodging due to high competition between plants[17,18]. Low light intensity during high plant population causes less radiation interception, which consequently results in reduced photosynthetic efficiency and reduced number and quality of bean pods[19]. Varietal characteristics of different common beans such as growth habit, days to maturity, seed color, seed size, and weight, and agro-ecological adaptation tend to influence plant density patterns [20].

Generally, information on plant population and yield performance relationship is still limited and majority of farmers in Rwanda still cultivate bean under traditional planting methods, yet there is limited information on appropriate planting methods to be adopted by these bean farmers.

In this study, we evaluated different patterns of plant densities on growth and yield of bush beans. The analysis of variance (ANOVA) was used to analyze the plant height, number of pods and biomass for exploring their differences in regards to bean plant growth and yield.

MATERIALS AND METHODS

Study Area

The study was conducted in Nyagatare district at the University of Rwanda farm in Eastern province of Rwanda. Nyagatare is located in the North-east of Rwanda and shares a border with Uganda to the north and Tanzania to the east. The area lies in the low-lying eastern savannah agro-ecological zone at an average altitude of 1,400 m above sea level. It lies at latitude 1°22' 51.6" South of the Equator and longitude 30° 17' 07" East. The annual rainfall ranges from 800-1000mm per annum. The mean annual temperature ranges from 25.3-27˚C and soils are mainly humic ferrasols and vertisols in higher and in low land areas, respectively and the soil pH is about 6.3.

Experimental Design

Seeds of common bean variety, RWR 1668 were obtained from Rwanda Agricultural Board (RAB). Farmers commonly grow the RWR 1668 in Eastern province of Rwanda. Sowing was undertaken at the beginning of the rainy season when there was enough rainfall to bring the first 30cm depth of the soil to field capacity, through visual inspection of the wetting front in soil pits located at the experimental site. The plots were prepared to fine tilth using hand hoes and a rake, a day before planting; field trials were laid out in a randomized complete block design (RCBD) with three replications. Each block had 4 treatments and the whole design had 12 plots. These treatments were: 200,000; 250,000; 300000; 350,000 plants/ha, respectively. These are commonly used plant densities in the study area. Planting furrows were opened using hoes and diammonium phosphate (DAP) (18%N, 46%P_2O_5) banded evenly into the planting furrows at 100kg ha-1. Beans were thinned to one plant per hill at two weeks after emergence (WAE). The bean crop was side dressed at 4 WAE using urea nitrogen fertilizer (46% N) at 50kg ha-^{1}. The bean crop was weeded at 3 and 6 WAE in both seasons.

Data Collection

Data collection on all treatments involved taking plant samples randomly from each plot after which their heights were measured at the physiological maturity stage as described by Masa *et al.* [20]. Ten plants were randomly selected from each plot and height measurements from the ground level to the tip of the plants taken using a ruler. Plant biomass of bean plants was determined by random sampling of 5 plants per plot at four weeks after emergence (WAE). The samples were oven dried (220/275 scientific oven) at 85 ºC for 48 hours, weighed and then recorded. Number of pods per plant was determined at physiological maturity stage as the total number of pods obtained from randomly selected 5 plants of net plot area. Hundred seed weight was determined by taking weight of 100 randomly sampled seeds from the total harvest from each net plot area. The percent moisture content of seeds was determined using a moisture meter (agraTronix, Streetboro, Ohio) and 100 seed weight and bean seed yield adjusted to 11% moisture content before statistical analysis.

Statistical Data Analysis

All measured parameters were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the GenStat version 15, as interpretations were made following the procedure previously described by Gomez and Gomez [21]. Whenever the effects of the factors were found to be significant, the means were compared using the least significant differences (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Plant height

The statistical analysis of variance demonstrated that the main effect of plant density on pant height for all the different densities were significant ($p<0.01$). Bean plant height increased with increase in plant density. At plant density of 350, 000 plants ha^{-1}; bean plants were significantly taller ($p<0.01$) at 21.6 cm compared to plant heights in other plant densities: 300,000 plantsha^{-1} (17.6 cm), 250,000 plants ha^{-1} (13.5 cm) and 200,000 plants ha^{-1}(11.1 cm) (Table 1). Increase in plant height, development of weaker steams and lodging, as a result of increased plant population have been reported in maize[16], soybean [22], faba bean [23]and green bean [24]. In green beans, Tuarira *et al.* [24] reported bean plant heights of 61.4 cm under plant density of 320,000 plantsha^{-1}and 52.55 cm under plant density of 125,000 plantsha^{-1}. The increase in plant height has been associated with intraspecific plant competition for light, water and soil nutrients [17, 25]. Spacing affects plant height in bush bean cultivation. It was previously reported that as row spacing increased, plant height decreased. Previous studies on effect of spacing in soybean indicated that under a narrow spacing of 30 cm row width, soybean plants grew fairly tall while under a wider spacing of 70 cm row width, short soybean plants were observed [22]. This is also attributed to increased light, air, and space demand for low spaced plant population which results to reduced competition among plants [22].

Plant Biomass

Plant density significantly affected bean biomass at 4WAE ($P=0.007$). Bean biomass was significantly higher in 200,000 plants ha^{-1} (18.89 g) and 250,000 plants ha^{-1} (19.86 g) than in 300,000 plants ha^{-1}(13.74 g) and 350,000 plants ha^{-1}(11.86 g) 4WAE. However, there was no significant difference between plant densities: 200,000 plants ha^{-1} and 250,000 plants ha^{-1} (Figure 1). Previous studies have also shown increased biomass under low plant density as compared to high plant density [17]. Under low plant density plants maximize resources such as light due to reduced competition and hence produce greater bean plant biomass as previously observed in faba and white beans [26, 27]. In maize

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also, different plant densities generally influenced maize plant growth and yield components. The variation in plant biomass across different plant densities might be a result of a number of factors and plant processes such as light interception, plant metabolism and allocation efficiency of photosynthetic products from leaves to other parts of the bean plant.

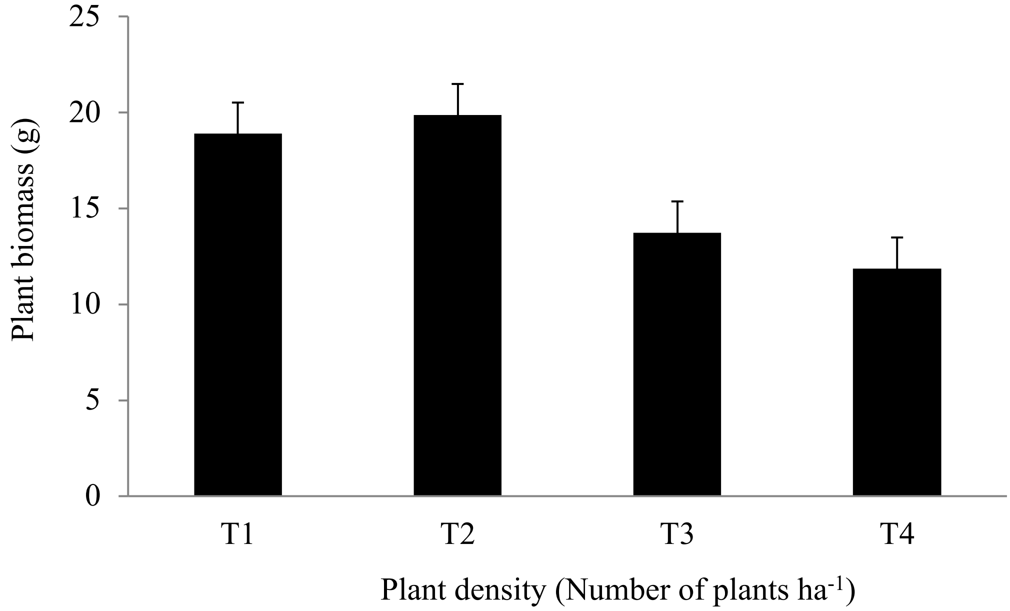

Figure 1: **Effect of plant density on plant biomass. Treatments; T1, T2, T3 and T4 represent plant densities; 200,000, 250,000, 300,000 and 350, 000 plants ha^{-1}, respectively. Plant biomass was recorded at four weeks after emergence (4WAE) and five replications were used for every treatment**

Yield components

The number of pods per plant is one of the major yield components that determine productive potential of common bean and it changes in response to plant density[28]. In the results, the number of pods per plant was significantly ($P<0.001$) influenced by plant density (Table 2). The results indicated that the lowest plant density: 200,000 plants ha^{-1} produced the highest number (11.43) of pods plant^{-1}. The number of pods per plant decreased with increase in plant density. The plant densities; 250,000, 300, 000 and 350,000 plants ha^{-1} produced; 8.83, 5.63 and 3.27 pods per plant, respectively (Table 2). Increased number of pods under low plant densities could be attributed to greater light capture coupled with less interplant competition, and this allows efficient utilization and partitioning of photosynthates into seed production [18,25]. Besides, the increase in number of pods as a result of improved light interception, the number of pods could also increase due to improved nutrient availability, which stimulated the plants to produce more pods as compared to the control [29]. Such phenomenon is in agreement with Donald [30] who indicated that as the number of plants per unit area increased, competition for plant resources also increased. Similar findings in which plant density negatively affected the number of pods per plant and crop productivity have been reported in other legume crops such as in soybean [31,32], peanut [33] and peas [34].

Hundred seed weight usually reveals the level of seed development, which eventually reflects on the final yield of a crop. The results showed that plant density significantly (P<0.001) influenced 100-grains weight. Hundred seed weight was highest (51.67g) when the plant density was kept at 200,000 plants ha^{-1}whereas it was lowest for the 350,000 plants ha^{-1}. However, the 100-grain weight obtained from plant densities: 200,000 and 250,000 plants ha^{-1} was statistically similar (Table 2). In line with our results, Al-Rifaee *et al*. [17] found that lower plant populations produced seeds with heavier 100-grain weight seeds. Less competition between plants under lower populations might increase the available assimilates per pod and result in increased seed weights. Low plant populations offer sufficient resource availability and ensure maximum conversion of these resources into assimilates which are stored in seeds resulting into increased seed weight. The increasing trend in 100-seed weight under low plant density was also reported in soybean and maize by Rahman and Hossain [15] and Farnia and Mansouri [35], respectively. The seed weight is largely affected by varietal heritability characteristics and is, therefore, sometimes not affected by the agronomic practices adopted in a specific geographical [36].

Yield

Bean yield was significantly (P<0.001) affected by plant density. The results indicated that using 250,000 plants ha^{-1} produced the highest seed yield at 2,317 kg ha^{-1}. The lowest bean yield 492 kg ha^{-1}was recorded from using 350,000 plants ha^{-1} (Table 2). Decreased yield due to increased plant density has been reported in several other crops such as faba beans [18] and soybean [37]. Similarly, in tomatoes, the lowest plant density, 25, 974 plantsha^{-1} was found to improve fruit set, fruit number, fruit weight and fruit yield of tomato fruit while use of 35, 714 plants per hectare resulted into tall plants with poor fruit set and low tomato yield [38].

The yield per plant and yield components such as number of pods per plant, number of seeds per plant, hundred seed weight were found to decrease under high plant populations and increase under low plant densities [39].Grain yield is affected by plant growing conditions and different plant populations create different conditions, which influence growth and development patterns of the plant [40].

CONCLUSION

Low yield of beans in Rwanda is attributed to many factors which include poor quality seed, poor agronomic practices such as inadequate plant density, soil infertility, water stress, weed infestation, pest and diseases. Increase in the yield of common bean can be achieved by using appropriate plant density. In this regard, a field experiment was conducted at University of Rwanda, Nyagatare campus, Eastern province of Rwanda to assess the effect of plant density on growth and yield performance of common beans *(Phaseolus* vulgaris L.). Evaluated parameters were: plant height, plant biomass, number of pods per plant, 100-grain weight and yield. Results indicated that using higher plant density of 350,000plants/ha resulted in development of weak and tall plants, which were with 21.6 cm in height. Low plant densities; 200,000 plants/ha and 250,000 plants/ha produced shorter plants of 11.1 cm and 13.5 cm, respectively (Table 1) and the difference in height was attributed to differences in competition for resources. Plant biomass was found to be significantly affected by plant density at 4WAE. Bean biomass was significantly higher when beans were grown under low plant densities than when plants were grown under higher plant populations. The lowest plant population applied 200,000 plants ha^{-1}produced 18.89 g of plant biomass and the highest 350,000 plants ha^{-1}resulted into 11.86 g of plant biomass (Figure 1).

Plant density had great influence on growth and yield components of common bean. For yield components, the number of pods /plants decreased with increase in plant density. When the variety RWR 1668 was subjected to different plant densities; 250,000, 300, 000 and 350,000 plants ha^{-1}, it produced 8.83, 563 and 3.27 pods per plant, respectively. Plant density greatly ($P<0.001$) influenced 100-grains weight. Hundred seed weight was highest (51.67g) when the plant density was kept at 200,000 plants ha^{-1}whereas it was lowest for the 350,000 plants ha^{-1} (Table 2), and decrease in 100-grain weight under high plant density was as a result of poor transfer of photosynthetic materials to the grain.

The grain yield was significantly increased when beans were grown at about 200,000 to 250000 plants/ha (spacing, 50.0 cm x 8.0 cm). Therefore, we can conclude that the application of 200,000 to 250,000 plants per hectare may be recommended for attaining good plant growth and for improving the plant biomass, number of pods per plant, hundred grain weight and bean seed yield of RWR 1668 under field conditions in the East lowlands agro-ecological zone of Rwanda.

Poor agronomic practices such as inappropriate plant density might contribute to low yields of common bean in Rwanda despite efforts in use of improved seed varieties, soil fertility improvement and pest and disease control.

Future research on common bean should be established to assess the interaction of different planting densities on various common bean genotypes, planting dates and seasons under varying agro-ecologies of Rwanda. These studies can produce a combination of factors that can produce better plant growth and maximum yield of common bean in Rwanda.

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Table 1: Effect of plant density on plant height of common bean

Treatment	Plant density (No. Of plants ha^{-1})	Plant height (cm)
T1	200,000	11.08d
T2	250,000	13.47c
T3	300,000	17.60b
T4	350,000	21.55a
	P value	<0.001
	±S.e.d	0.22

Mean ± standard deviation is shown. Values sharing the same letters differ non-significantly (*P*> 0.05).

Table 2: Effect of plant density on yield components in common bean

Treatment	Plant density (Number of plants ha^{-1})	Number of pods plant^{-1}	100 grains weight (g)	Bean yield (kg ha^{-1})
T1	200,000	11.43a	51.67a	1108c
T2	250,000	8.83b	48.20a	2317a
T3	300,000	5.63c	30.67b	1575b
T4	350,000	3.27d	25.83b	492d
	P value	<0.001	<0.001	<0.001
	±S.e.d	0.826	0.999	98.2

Mean ± standard deviation is shown. Values sharing the same letters differ non-significantly (*P*> 0.05)

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