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Responses of biofortified common bean varieties to di-ammonium phosphate fertilizer under climate variability conditions in South-Kivu, DR Congo

Nachigera Gustave MUSHAGALUSA*[1], Arsène KASHEMWA[2], Christelle Bonane SINZA[1], Laurent Chimanuka BIGIRIMWAMI[1], katcho kARUME[1] and Antoine Kanyenga LUBOBO[3]

[1]Faculty of Agriculture and Environmental Sciences, Université Evangélique en Afrique (UEA/Bukavu), The Democratic Republic of Congo.
[2]IITA-Youth Agripreneurs, The Democratic Republic of Congo.
[3]CIAT-HarvesPlus. The Democratic Republic of Congo

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Two trials with the combined effects of seeding density and application of DAP fertilizer on the yield of four biofortified bean varieties were carried out in Kashusha on the experimental site of the Université Evangélique en Afrique during the 2013-2014 agricultural long rains season (September-January) and short rains season (March-May). The overall objective was to investigate the response of biofortified common bean and its response to seeding density, mineral fertilizer application, and good agricultural practices. Four bean varieties were used (RWK-10, HM 21-7, CODMLB001 and RWR2245) and the experimental design was split-split plot whose main plot was occupied by varieties and sub-plots had DAP fertilizer crossed with two seeding spacing. Two seeding densities were considered, 250,000 plants ha^{-1} and 500,000 plants ha^{-1} respectively corresponding to the spacing between plants 40 cm x 20 cm (commonly used) and 20 cm x 20 cm. The plot was divided into 3 blocks (or repetitions), distant of 2 m and each comprising two sub-blocks separated by 1 m. A sub-block was treated with fertilizer (DAP) and the other was kept as control. The yield of bean seeds has varied from one season to another independently of varieties, which had no effect. It was better in long rains season (1725 kg ha^{-1}) than in short rains season (1087.4 kg ha^{-1}). The effect of fertilizer was also dependent on the season, no effect was observed in short rains season, with huge poorly distributed rains. However, in long rains season, the application of DAP has produced a high number of pods per plant and large grains leading to a higher yield of 1368.6 kg ha^{-1} when the fertilizer was applied compared to control which produced only 806.1 kg ha^{-1}. During the same season, doubling the density, a yield of 1842.9 kg ha^{-1} was obtained compared to the density of 250,000 plants ha^{-1} that produced 1607.1 kg ha^{-1}. The agronomic efficiency of fertilizer was low, ranging from 1.53 for the CODMLB001 variety to 5.64 for HM21-7 variety. Multi-local trials, in contrasting environments are needed to better understand the influence of the season on the bean behaviour in dissemination in South Kivu. It is also interesting to test other seeding densities, fertilizer types and doses for adequate recommendation of fertilization of this crop in Kabare territory. Due to low soil pH, it should be important for example to apply lime before applying the fertilizer.

Key words: Bean, seedling density, Di-ammonium phosphate (DAP), variety, yield

INTRODUCTION

Given their high protein content in the dry seed and their symbiotic fixation of atmospheric nitrogen capacity, food legumes are an essential component of cropping systems in the tropics. Unfortunately, these plants are often characterized by low and unstable yields, particularly because of their sensitivity to diseases, pests and low fertility of tropical soils on which they are grown in most of the cases (Baudouin, 2001). Bean, main legume encountered in the Great Lakes Region, is a plant requiring a minimum of nitrogen and optimum phosphorus for both good symbiotic atmospheric nitrogen fixation and to provide a good yield. In South-Kivu, bean is often sown at 40 cm x 20 cm spacings, or 12 plants per m^2, while densities of 15-40 plants per m^2 are possible for bush beans (Carburet and Hekimian, 2009). The low density used in South-Kivu is particularly due to soil poverty in nitrogen and phosphorus that limits the development of the plant.

For over five years, the CIAT HarvestPlus project disseminates bio fortified bean varieties with iron and zinc. The project recommends to seed-multipliers the use of 40 x 20 cm spacing and the yields range from 500 to 800 kg/ha depending on the cropping seasons without fertilizer. Carburet and Hekimian (2009) evoke yields of 1000-3000 kg/ha for growing beans in the US and Europe in intensive cropping system when fertilizers, pests control and improved varieties are used.

In traditional systems where crop association remains the rule, planting densities are relatively low. When the bean is sown with maize, it is commonly practiced at densities of 57,142 to 95,238 plants ha^{-1} against 25,000 – 40,000 ha^{-1} for maize plants (Niringiye et al*.,* 2005). Several authors have found that, in many crops, significant increases in yields are obtained by increasing seeding densities (De Bon et al., 1990; Pasquet and Baudoin, 1997; Nyabyenda, 2005), provided of course that soil fertility allows meeting the nutrient demand of plants. A study by Taffouo et al. (2008), in Cameroon, shows that seeding densities significantly affect stem collar diameter, number of leaves, leaf surface and dry matter produced in different varieties of cowpea.

Niringiye et al. (2005), on their part, have shown that increasing densities of planting climbing beans does not affect, in most varieties, the number of pods per plant, but it reduces the average weight of grains and the total quantities of grains produced per plant.

In Africa, low seeding densities are often justified by the low soil fertility, the non-use of fertilizers and the use of low-yield varieties. This poor soil fertility limits the availability of agricultural resources and led to low agricultural productivity (McCan, 2005). In this region, farmlands are lost due to their poor management, causing average annual losses of topsoil in N, P and K, respectively 22, 2.5 and 15 kg ha^{-1} (Steiner, 1996).

Thus, for better management of land resources, it is imperative to measure the initial soil fertility for its ability to provide essential nutrients for crops development (Bado et al., 2003). Mineral fertilizers play in this respect, an important role in restoring soil fertility strategy.

This study consists at identifying the combined effects of seeding density and application of DAP on 4 biofortified bean varieties performance in Kashusha during two contrasting cultural seasons.

The main research question being whether it would be possible to increase biofortified bean yields by applying DAP fertilizers and doubling the seeding density. The second question is to test whether the effects of DAP and seed density would change from one variety to another and depending on the growing season. The main purpose of this study was to evaluate the interaction between fertilizers, plants densities and varieties in order to improve biofortified common bean yield in a contrasting climate environment. It is hypothesized that increasing seeding density with DAP application will significantly increase biofortified bean yields.

METHODOLOGY

Study area

A first experiment was conducted in Kashusha on the site of the Université Evangélique en Afrique (UEA) in the short rains season (SRS), from March to May 2013. The second experiment was conducted in the long rains season (LRS), from September 12, 2013 to January 3, 2014. Kashusha is located in Kabare territory, 28 km from Bukavu city. The experimental plot was installed at an altitude of 1712 m, 028˚47'72" latitude East and 02˚190 '05" longitude South. Climate data during the trial period are those of the INERA-MULUNGU meteorological station, the closest station to the site. During the LRS, 163.1 mm was recorded in September for 14 days; 136.5 mm in October for 13 days, 148.6 mm for 15 days in November and finally huge amounts of rainfall were recorded in December with 214.1mm in 20 days (Table 1). The optimum rainfall of bean crop varies between 300 and 600 mm of rain for a suitable production (De Bon et al*.,* 1990). In addition to a good amount of rain, bean crop requires a good distribution of the latter. For optimal development, beans require 80-120 mm monthly precipitation from sowing to maturation (Baudouin, 2001). Thus, referring to the optimum rainfall for bean cultivation, the amount of rainfall recorded during the LRS (662.3 mm) are favourable for good bean productivity, while those recorded during the SRS shifted from the optimum (827.5 mm).

The soil of the experimental site is ferrallitique type, clay and humus on basaltic rocks. It had a pH of 4.4, a carbon percentage of 1.76%, a nitrogen content of 0.26%, a C/N ratio of 11 and a cation

*Corresponding author. E-mail: nachigra@yahoo.fr or nachigera@uea.ac.cd.

Table 1. Mulungu climate data, 2013 and 2014.

Month	Rainfall (mm)	Number of rain days	Observation
SRS 2013			
Feb	173.1	02	Rainy
March	362.6	18	Rainier
April	227.4	15	Very rainy
May	63.5	08	Rainy
Total	**827.5**	**44**	
LRS 2014			
September	163.1	14	Rainy
October	136.5	13	Rainy
November	148.6	15	Rainy
December	214.1	20	Very rainy
January 2014	220.8	20	Very rainy
Total	**662.3**	**62**	

exchange capacity of 24.31 cmol/kg. Soil pH was too acidic, away from bean requirements, which normally prefers a pH ranging from 6.0 to 7.5 with critical thresholds of 5.0 to 8.1; then, it probably would have been necessary to make a liming (Baudouin, 2001). The carbon content is acceptable; being above the recommended threshold of 0.8 by Baudouin (2001) while the amount of phosphorus is less than the optimum, estimated at 15 ppm (Godderis, 1995). This low proportion of phosphorus can inhibit root development, flower induction and pods development.

The nitrogen content (0.26%) is below the 0.3% threshold recommended in bean cultivation, though bean cultivation is not too demanding in nitrogen because of its ability to fix atmospheric nitrogen (Baudoin et al*.,* 2001) a minimum of nitrogen is required in the soil for proper development of the plant. The Kashusha soil has good organic carbon content, which is 11, the acceptable optimum being between 9.0 and 12.0 (Godderis. 1995). The C/N ratio is good; it indicates the level of mineralization of organic matter but also the accumulation of ammonium ion. The cation exchange capacity (24.31 cmol/kg) is between the recommended limits, between 10 and 25.

Materials

In this study, four biofortified common bean varieties were used namely: CODMLB-001, HM21-7, RWR2245 and RWK-10) provided by CIAT-HarvestPlus. The four varieties used have equivalent yield potential ranging from 800 - 1500 kg per hectare when suitable environmental conditions are met. Multiplication tests made previously by CIAT/ HarvestPlus and the Université Evangélique en Afrique on the same site gave yields between 500 and 800 kg/ha without fertilizer application. As fertilizers, DAP (Di Ammonium Phosphate) was used dosing 18% nitrogen, 46% P_2O_5 (18-46-0). A dose of 100 kg/ha was applied.

Experiment running

A device in "split-split-plot" has been used with the main plot being the variety (4 different varieties) and sub-plots had DAP fertilizer crossed with two spacing, 40 x 20 cm (commonly used) and 20 cm x 20 cm, giving densities of 250,000 plants ha^{-1} and 500,000 ha^{-1} plants respectively. The spacing of 40 cm x 20 cm is considered as reference and in application in the rural environment.

The plot was divided into 3 blocks (or repetitions), distant from each other of 2 m, each including two sub-blocks distant of 1 m each other; a sub-block has been treated by fertilizer (DAP) and the other was kept as a control to fertilizer response. Each block contained 16 plots (treatments) with 8 plots per sub-block; the plot area was 17.5 m^2, a length of 5 m and a width of 3.5 m. The number of rows per plot planted with spacing of 40 cm x 20 cm was 12 and that planted with spacing of 20 cm x 20 cm was 24. The trial covered a total area of 47 m x 28 m or 1316 m^2.

The DAP was applied to half of the experimental plot as dressing manure at a dose of 0.2 kg per plot corresponding to 100 kg of DAP per hectare or 0.036 kg of nitrogen and 0.092 kg of P_2O_5 per plot, 20.6 kg of nitrogen and 52.6 kg of P_2O_5 per hectare.

The maintenance consisted of two manual weeding for each trial. The first weeding occurred 26 days after planting when the crop was at the stage of pre-flowering and the second took place 57 days after sowing at the stage of pods development. During weeding, we determined the time taken to weed each plot according to the seeding density.

During the experimental period, the parameters related to vegetative development and production were measured. For vegetative parameters we estimated the germination rate (in percentage), which was obtained by a ratio of the number of germinated plants in each plot and the number of seeds sown. The emergence rate was evaluated on Tuesday, October 8, 2013; 13 days after sowing when over 50% of seeds had already sprouted.

The chlorophyll content was measured using a Konica Minolta chlorophylometer, SPAD 502, when the bean was at the pre-flowering stage. The measurements were taken from 10 plants of two diagonals of each plot. On each plant, we performed measurements on 3 different leaves per plant and the average was determined.

At the final harvest, which occurred 100 days after sowing, respectively, we determined the number of pods per plant, number of grains per pod and the weight of 100 grains. The number of pods per plant was estimated on ten plants taken at random per plot to determine the mean of each treatment. The number of grains per pod was obtained by counting the grains in each of 10 pods randomly taken from the lot of pods harvested from each plot.

To determine the weight of grains, 100 grains were taken randomly from the harvest on each plot, they were then weighed with a precision scale, Scout Pro 2000 g. Finally, the harvest obtained in each useful plot of 17.5 m² was extrapolated to the hectare.

The harvest index was calculated in % for each treatment by

Table 2. Analysis of the combined variance of the yield components of four bean varieties subjected to two seeding densities and DAP fertilization during two growing seasons.

Source of variation	df	Chlorophyll		Pods		Grains/pod		W100G		Yield	
		CM	**Prob**	CM	**Prob**	CM	**Prob**	CM	**Prob**	CM	**Prob**
Season (S)	1	155.2	0.077	222.7	**0.001**	11.5	**0.027**	12.76	0.542	9.75	**0.025**
Varieties (V)	3	88.22	**< 0.001**	14.41	**0.032**	1.3	0.057	39.52	0.29	0.52	0.605
Sx V	3	23.77	**0.01**	12.94	**0.043**	2.52	**0.008**	70.34	0.11	0.7	0.491
Fertilizer Dose (D)	1	58.68	**0.02**	36.5	**< 0.001**	0.89	**0.033**	131.7	**< 0.001**	2.14	**< 0.001**
S x D	1	19.31	0.162	3.68	0.036	0.41	0.133	32.14	**0.001**	1.66	**0.001**
V x D	3	4.72	0.671	2.44	**0.041**	0.06	0.756	4.69	0.118	0.07	0.595
S x V x D	3	7.61	0.489	1.34	0.17	0.21	0.316	20.95	**< 0.001**	0.08	0.54
Spacing ('E)	1	4.56	0.318	5.51	0.098	0.01	0.798	8.74	0.278	1.35	**0.02**
S x E	1	4.79	0.307	6.51	0.073	0	0.844	11.32	0.218	0.002	0.985
V x E	3	1.75	0.757	0.85	0.72	0.12	0.342	6.15	0.473	0.03	0.938
D x E	1	0.27	0.805	2.53	0.257	0.48	**0.046**	2.31	0.574	0.002	0.975
S x V x E	3	8.13	0.161	1.75	0.442	0.09	0.501	18.97	0.066	0.067	0.828
S x D x E	1	0	0.998	3.22	0.202	0	0.954	0.49	0.794	0.052	0.633
V x D x E	3	0.78	0.911	0.01	0.999	0.12	0.342	1.07	0.929	0.009	0.989
S x V x D x E	3	9.59	0.112	0.38	0.894	0.33	**0.046**	1.2	0.917	0.023	0.956
Residuals	32	4.44	-	1.9	-	0.11	-	7.18	-	0.22	-
CV (%)		5.9		24.3		8		7		33.9	

df: degree of freedom; CM : Mean Square; Proba: Probability of significance; NGP: Number of pods per plant; NGG: Number of seeds per pod; W100G: Weight of 100 seeds. Bold probabilities are significant.

Table 3. Effect of season on yield parameters.

Season	Chlorophyll content (mg/g)	Pods	Grains/pods	W100 (g)	Yield (kg/ha)
LRS	36.9^a	7.2^a	4.5^a	37.8^a	1725.0^a
SRS	34.4^a	4.1^b	3.8^b	38.5^a	1087.4^b
LSD	3.21	0.42	0.49	4.31	440
CV	5.9	24.3	8	7	33.9

LRS: Long rains Season, SRS: Short Rains Season; W100: Weight of hundred seeds.

dividing the plot grain yield by the total biomass (Donald, 1962). The agronomic efficiency (AE) was calculated using the following equation: AE = (Y1-Y2) / f. Y1, being the yield obtained by applying fertilizer; Y2, yield obtained without fertilizer and f the amount of fertilizer applied per hectare.

Statistix 8.0., Excel and Genstat softwares were used to analyze data. The analysis of variance was used to reveal differences between treatments and interactions, while the LSD test was used for comparison of mean pairwise at 5% significance level.

RESULTS

Effect of season on yield parameters

The analysis of variation, showed a significant effect of the season ($p = 0.025$) on the observed parameters (Table 2). The yield varied significantly from one season to another, the best production was obtained in LRS compared to the SRS (Table 3).

In LRS the number of pods per plant and number of grains per pod was high compared to the SRS, which has seen uneven rainfall, which were abundant compared to the needs of the crop. The effects of fertilizer dose varied very significantly from one season to another ($p \leq 0.001$) as shown in Figure 1.

With or without fertilizer application, the yield was high in LRS compared to SRS (Table 3). Under the control plots, LRS the yield was 1707.2 kg/ha against 806.1 kg/ha in SRS. With the application of fertilizer, the yield in LRS was 1742.9 6 kg/ha against 1368.6 kg/ha in SRS (Table 4).

The spacing, in the other hand, has had a significant effect on yield ($p \leq 0.02$) regardless of season because no interaction is observed for both seasons ($p \leq 0.985$). The spacing of 20x20 cm gave the best yield. Contrary to our initial hypothesis, fertilizer did not interact (Annex 1, $p \leq 0.975$) with bean seeding density, 100 kg dose of DAP. Ha^{-1} is probably not at optimum when applying a 20x20cm planting density.

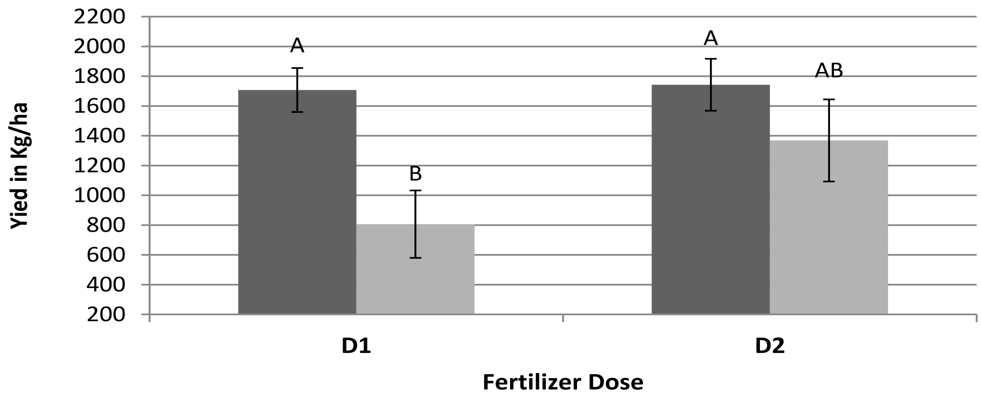

Figure 1. Effect of fertilizer dose interaction with the cropping season on bean yield (LSD = 440), error bars represent standard deviations of the mean. D1=0 kg.ha^{-1} while D2 =100 kg.h^{-1} of DAP fertilizer For each dose, left chat represents Long Rains Season (LRS) and right chat is Short Rains Season (SRS).

Table 4. Average effect of the studied factors (fertilizers. seeding density and varieties) on bean yield parameters in two different growing seasons.

Principal factors		Chlorophyll content (mg/g)	Pods	Grains pods^{-1}	W100G (g)	Yield (kg/ha)	Biomass (kg)	IR (%)
		Long rains season (LRS)						
	D1	36.6^{a}	6.8^{b}	4.5^{a}	37.2^{b}	1707.2^{a}	6.2^{a}	50.1^{a}
Fertilizer dose	D2	37.3^{a}	7.6^{a}	4.6^{a}	38.4^{a}	1742.9^{a}	6.4^{a}	49.3^{a}
	LSD	1.83	0.57	0.26	0.74	80	0.66	4.52
	E1	37.4^{a}	7.7^{a}	4.5^{a}	38.5^{a}	1607.1^{b}	5.8^{b}	50.6^{a}
Spacing	E2	36.5^{a}	6.7^{b}	4.5^{a}	37.2^{b}	1842.9^{a}	6.9^{a}	48.9^{a}
	LSD	*1.45*	*0.98*	*0.24*	*1.16*	*220*	*0.63*	*3.84*
	CODMLB	36.5^{b}	5.8c	4.3^{b}	38.8^{a}	1319.2^{b}	5.0^{b}	46.4^{b}
	HM21	39.5^{a}	7.3^{b}	4.2^{b}	38.7^{ab}	1952.4^{a}	6.1^{b}	57.0^{a}
Varieties	RWK10	33.1c	8.6^{a}	5.3^{a}	36.0^{b}	1733.3^{ab}	8.5^{a}	36.3^{b}
	RWR2245	38.6^{a}	7.2^{b}	4.3^{b}	37.7^{ab}	1895.2^{a}	5.6^{b}	59.1^{a}
	LSD	1.72	1.19	0.45	2.71	470	1.84	10.26
		Short rains season (SRS)						
	D1	33.2^{b}	3.3^{b}	3.7^{b}	36.8^{b}	806.1^{b}		
	D2	35.6^{a}	5.0^{a}	4.0^{a}	40.3^{a}	1368.6^{a}		
Fertilizer dose	*LSD*	2.14	0.54	0.27	1.12	290		
	E1	34.4^{a}	4.1^{a}	3.8^{a}	38.5^{a}	967.7^{a}		
	E2	34.4^{a}	4.2^{a}	3.8^{a}	38.6^{a}	1207.0^{a}		
Spacing	*LSD*	1.09	0.67	0.15	2.00	340		
	CODMLB	33.3^{a}	3.4^{a}	3.8^{a}	36.3^{a}	1134.7^{a}		
	HM21	35.5^{a}	5.5^{a}	4.0^{a}	41.0^{a}	1223.3^{a}		
	RWK10	33.5^{a}	3.4^{a}	3.7^{a}	40.8^{a}	1103.5^{a}		
	RWR2245	35.2^{a}	4.3^{a}	3.8^{a}	36.0^{a}	888.0^{a}		
Varieties	*LSD*	2.31	2.36	0.76	6.99	1180		

NGG = Number of seeds per pod; NGP: Number of pods per plant; W100G: Weight of 100 grains; IR: harvest index; D1: Without fertilizers; D2: 100 KG Contribution of DAP per hectare; CV: Coefficient of variation; a. b. c: The average of the same column and the same factor followed by the same letters are not statistically different at a probability level of 5% according to LSD test (Least Significant Difference).

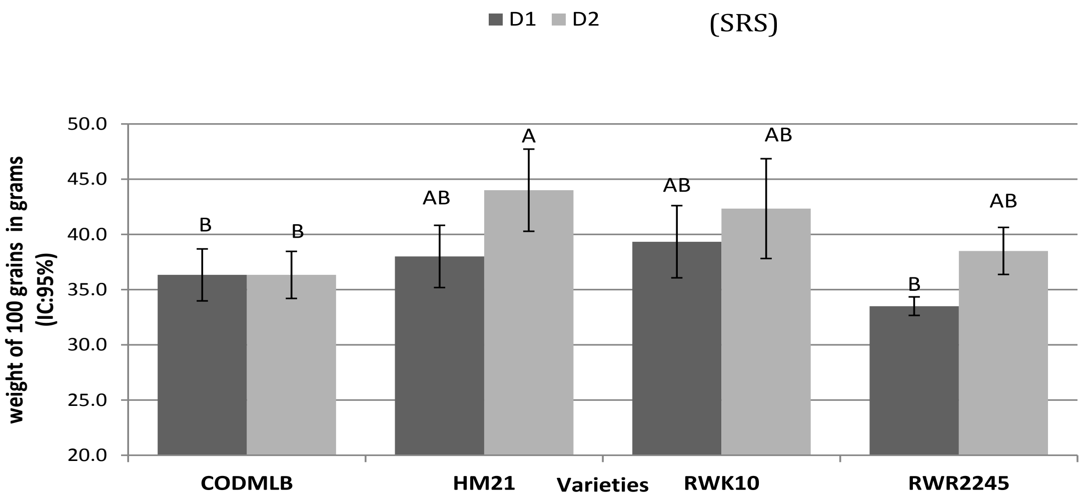

Figure 2. Effect of fertilizer dose on the weight of 100 grains of four bean varieties (SRS; Short Rains Season, LSD = 7.01). The error bars represent the standard deviations on the mean. D1=0 $kg.ha^{-1}$ while D2 =100 $kg.h^{-1}$ of DAP fertilizer.

Effect of variety

In LRS, the HM21-7, RWR2245 varieties gave the best chlorophyll rate (39.5 and 38.6 mg/kg) and higher yields that were respectively 1952.4 and 1895.2 kg/ha. Both varieties also had higher harvest indices 57 and 59% respectively for HM21-7 and RWR2245. The variety CODMLB001 produced the lowest yield (1319.2 kg/ha), which was statistically comparable to the variety RWK10 (1733.3 kg/ha). Both varieties also had the weakest harvest index (HI) but comparable. They were respectively 36.3% for RWK10 and 46.4% for CODMLB001. The low HI for RWK10 is explained by a greater production of foliage biomass than the other three varieties. This variety also gave a lot of grains per pod but low weight.

In SRS, however, no varietal effects were observed; all four varieties have produced comparable grain yields varying from 888 kg/ha for RWR2245 to 1223.3 kg/ha for HM21-7. These yields were statistically low compared to those obtained in LRS, because of the abundant rainfall observed in SRS during the vegetative growth phase. This is a consequence of climate disruption, because in the Kashusha conditions, usually the rainiest season is the SRS.

Effect of seeding density

As indicated in Table 4, in LRS, sowing density influenced the number of pods per plant, grain weight, total biomass and definitely grain yield. The spacing of 20 x 20 cm was better compared to 40 x 20 cm. Its yield was 1842.9 kg/ha while the 40 x 20 cm spacing gave 1607.1 kg/ha. The spacing of 20 x 20 cm produced a reduced number of pods per plant as well as low weight of grains. The observed difference from yield point of view is primarily attributed to the number of harvested plants per unit area varying from the simple (12 plants/m^2) to twice (24 plants/m^2) as a function of the spacing.

In SRS, once more, the study factor, here the seeding density, has not affected all yield parameters.

Effect of DAP application

In LRS, though DAP application has slightly influenced the number of pods per plant and grain weight, in final, grain yield has not changed. It looks like that it was more dependent on the number of grains by pods. An interaction between factors under observation might also explain the results.

In SRS however, the application of 100 kg DAP fertilizer allowed a seed yield (1368.6 kg/ha) which was higher than the control (806.1 kg/ha). The fertilizer has positively influenced all yield parameters including grain weight (Figure 2) and the number of pods per plant (Figure 3).

Figure 2 shows that with the addition of 100 kg of DAP fertilizer, the HM21-7 and RWR2245 varieties gave the best grain weight in SRS. Figure 3 shows that with the addition of 100 kg of the DAP fertilizer, HM21-7 varieties, RWK10 and RWR2245 gave a high number of pods per plant in SRS. To get an idea on the ability of the different varieties to capitalize applied fertilizer to different densities, we computed the agronomic effectiveness of the fertilizer. The results are shown in Table 5.

At 40 cm x 20 cm spacing, HM21-7 variety produces 4 kg of grains for each application of 1 kg of DAP per hectare, and at the spacing of 20 cm x 20 cm each kg of DAP provides 5 kg of dry bean grains. The performance of the HM21-7 variety is seasonal; it is low and even

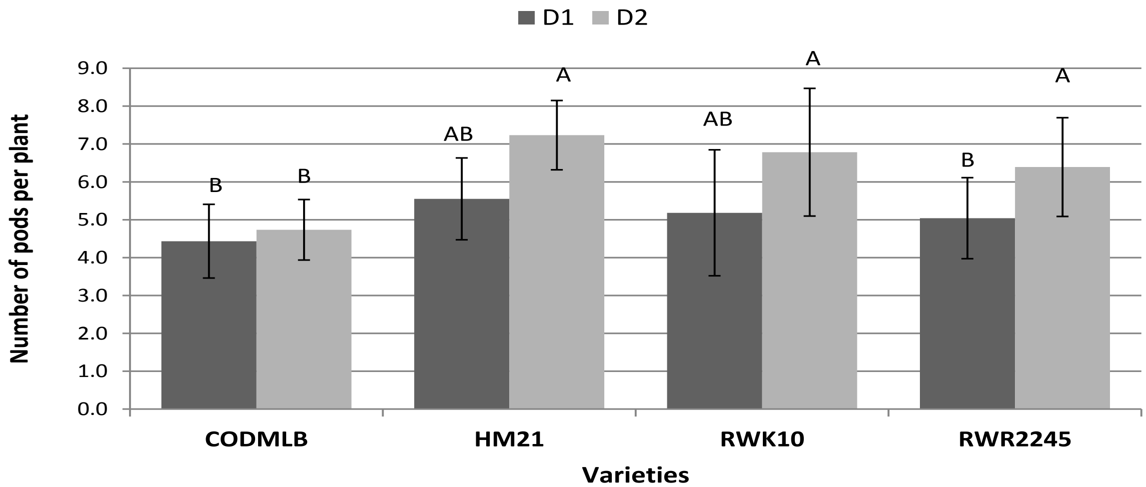

Figure 3. Effect of fertilizer dose on the number of pods per plant for four bean varieties (LSD = 1.25). D1=0 $kg.ha^{-1}$ while D2 =100 $kg.h^{-1}$ of DAP fertilizer. The error bars represent the standard deviations of the mean.

Table 5. Agronomic effectiveness of fertilizer.

Sowing density	Varieties	Seasons		Average
		LRS	SRS	
12 plants/m^2	HM21-7	-0.95	9.00	4.02
	RWK10	1.52	4.65	3.09
	RWR2245	-1.52	6.27	2.37
	CODMLB001	0.38	4.34	2.36
24 plants/m^2	HM21-7	3.05	8.23	5.64
	RWK10	0.38	5.25	2.81
	RWR2245	0.76	4.78	2.77
	CODMLB001	0.57	2.49	1.53

LRS: Long rains Season, SRS: Short Rains Season.

negative in LRS for the density of 12 plants/m^2. It seems that when rainfall is at optimum and well distributed during the crop cycle, then it is not necessary to apply a dose of 100 kg of DAP. The low agronomic efficiency of fertilizer is observed for the CODMLB001 variety for which 1 kg of DAP applied gave on average 1.53 kg of dry grains for the density of 24 plants/m^2. Nevertheless, although the density of 24 plant/m^2 gave good results, it increases the necessary time spent on weeding. Indeed, on average 1 h 13 min were needed to weed a plot of 17.5 m^2 sown at the spacing of 20 x 20 cm against 40 min when the spacing was 40 x 20 cm. The high density not only induces an additional cost in terms of seed and planting work but it also increases the weeding time.

DISCUSSION

Season has influenced all bean yield parameters

Regardless of the varieties, the yield of bean grains varied from one season to another. It was high in the LRS in which rainfall was well distributed and was close to the optimum required for beans cultivation. In fact, the optimum rainfall on bean crop varies between 300 and 600 mm of rain for a good production (De Bon et al., 1990).

In addition to a good amount of rain, bean requires a good distribution of the latter. For optimal development, beans require 80-120 mm monthly precipitation from sowing to maturation (Baudouin, 2001). Thus, the amount of rainfall recorded during the growing LRS (662.3 mm) supported the good bean productivity; while those recorded during the SRS were shifted from the optimum (827.5 mm) and were poorly distributed. Leading to a fall of flowers and a seedling rot in some varieties like CODMLB001 in which the agronomic efficiency of fertilizer was low. These results are in agreement with Bildirici and Yilmaz (2005), who showed that the yield in bean grains varies depending on seasons and the average of all climatic factors such as temperature as well as rainfall amount and distribution.

All the four varieties were affected in the same way by heavy rainfall in SRS, yields were low and comparable, ranging from 888 kg/ha for RWR2245 to 1223.3 kg/ha for HM21-7. However, in LRS, HM21-7 and RWR2245 varieties gave the best yields, respectively 1952.4 and 1895.2 kg/ha. CODMLB001 and RWK10 varieties produced the lowest yields (1319.2 and 1733.3 kg/ha). Indeed, next to nitrogen and phosphorus deficiency, soil moisture is considered to be the main factor that affects growth, nitrogen fixation and yield in most grain legumes (Graham et al., 2003). Bean is considered to be a plant that does not tolerate high humidity of soil but also water stress, and whose performance can vary greatly from one season to another (Khan et al., 2007). Our results show that, under the conditions of seasonal climate disruption, it would be interesting to have on one side, the varieties that tolerate water excess and the other side, varieties resistant to waterlogging.

Effects of fertilizer varied from season to season

The effect of fertilizer varied from one season to another, no effects were observed in SRS with large poorly distributed rains. However, in LRS, the application of DAP has produced a high number of pods per plant and large grains. This is consistent with Wery et al. (1988) and Streeter (1981), who found that; nitrogen intake has a positive effect on legume growth by increasing their ability to fix atmospheric nitrogen and thus contributing to high grains production. A strip application of 200 to 400 kg of nitrogen per hectare in some soils in Latin America showed a positive response (Schwartz et al*.,* 1978). In acid and volcanic ash soils in Colombia, a negative response occurred from a strip application over 80 kg of nitrogen per hectare during the drought; in the same soil, the application of 320 to 640 kg of nitrogen per ha gave negative results due to low pH and subsequent induction of the manganese toxicity. Further, in soils where phosphorus is the limiting factor, bean does not respond to the nitrogen until the amount of phosphorus to be applied is sufficient (Howard and Schaniel*,* 1980; Lunze et al*.,* 2002), thus, the usefulness of having brought the DAP to overcome both the lack of nitrogen as well as phosphorus. Indeed, Wortmann et al. (1998) found nitrogen and phosphorus deficiency in 93 out of 95 soils from East Africa. We should have probably also provided potassium to improve root development. In Burundi, the application of NPK at a rate of 18-46-30 kg/ha gave an average yield increase of 97% compared to the average yield without NPK fertilizer; estimated at 642 kg/ha (Godderis, 1995), the yield increases were variable depending on soil conditions, changes in rainfall and parasitism from one season to another and differences among farmers regarding the application of adequate cultivation techniques (Godderis, 1995).

Agronomic efficiency of DAP has varied from season to season and depending on the common bean variety

The agronomic efficiency of fertilizer was low, ranging from 1.53 for the CODMLB001 variety to 5.64 for HM21-7 variety. According to Dos Santos and Fageria (2007) a bean variety is considered to have responded positively to fertilizer when its agronomic efficiency (AE) is greater than 12. High AE values therefore mean a good response to the supply of fertilizer but should also be calculated. The use efficiency of the fertilizer by the plant, meaning the capacity of the variety to transfer nutrient from soil to grains (Dorvincil et al*.,* 2007). In this work, we did not measure the amount of nitrogen or phosphorus extracted from the ground by the plant; therefore, it is impossible to calculate the efficiency of utilization of nitrogen and phosphorus by the plant. The low agronomic efficiency of fertilizer could be partly explained by the high soil acidity (pH = 4) observed on our test site, which would have reduced the ability of the plant to symbiotically fix nitrogen and to collect soil nutrients (Hungria and Vargas 2000). It could also be related to the intrinsic values of the varieties used. Nodulation for example, is drastically reduced at pH=4.5 (Hungria and Vargas 2000; Streeter, 1981) and the availability of certain nutrients is reduced (Tessier, 2002). A study by Fageria et al (1989) shows that the maximum development of the bean is obtained at pH=5, leaf and root growth was positively correlated with pH and soil exchangeable aluminium. In this study and in the conditions of too acidic soil, it would be interesting to apply liming, for example, to improve soil pH before applying DAP. In acidic and in most tropical soils, only 20 to 30% of brought phosphorus is used by the plant, the rest is often attached or precipitated as non-usable form by the plant (Hissinger, 2001; Vance et al*.,* 2003).

Increasing the seeding density improved the yield of dry grain of beans

Several authors have found in many crops that significant increases in yields are obtained by increasing seeding densities (De Bon et al*.,* 1990; Pasquet and Baudoin, 1997; Nyabyenda, 2005) provided of course that the fertility of the soil makes it possible to meet the nutrient demand of plants. Niringiye et al. (2005) showed that increasing densities of climbing beans does not in most varieties affect the number of pods per plant, but it reduces the average grain weight and the amount of total grains produced per plant. In this work, increasing seeding density from 12 to 24 plants/m^2, has led to increased yields from 1287 to 1525 kg/ha, regardless of the cropping season. In contrast, Hug and Winterthur (2011) working on sunflower crop found no effect of seeding density on yield, probably because of low soil fertility. When increasing plant density and the level of fertilizers in the soil does not cover the nutritional needs of the crop there is a risk of observing a decrease in yield. Contrary to our initial hypothesis, no interaction was obtained between the increase in density and application of fertilizer, except for the number of grains per pod (P = 0.046), but unfortunately not significantly affected grain yield (P = 0.975). It is possible that in this study the dose of DAP; 100 kg/ha does not fully cover the needs of beans with increasing plant density.

Conclusion

The effect of fertilizer on common bean grain yield varied from season to season independently to variety, showing that the chemical fertilizer depends on soil water. In long rains season, the application of DAP has produced a high number of pods per plant and large grains leading to a higher yield of 1368.6 kg ha^{-1} when the fertilizer was applied compared to control which produced only 806.1 kg ha^{-1}. During the same season, doubling the density, a yield of 1842.9 kg ha^{-1} was obtained compared to the density of 250,000 plants ha^{-1} that produced 1607.1 kg ha^{-1}. The agronomic efficiency of fertilizer was low, ranging from 1.53 for the CODMLB001 variety to 5.64 for HM21-7 variety. Therefore, in the context of climate change it's very difficult to have an accurate dose of chemical fertilizer, which will lead to optimum yield without taking into account unpredictable rainfall or weather disturbance. Applying 100 $kg.ha^{-1}$ of DAP seems to not be efficient when rainfall is not sufficient or when its distribution among cultural cycle is not conform to bean's water demand. It would be interesting to test several seeding densities and different doses of DAP fertilizer in order to determine the density and the dose that achieve an economic yield in dry grains of beans. As said earlier, it would be also interesting not only to raise the pH level with a liming before applying the DAP but in addition to compare the effect of DAP and NPK in different contrasting environmental conditions. Finally, an attention should be given to soil water management when dealing with chemical fertilizer in a context of climate change.

Conflict of Interests

The author has not declared any conflict of interest.

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