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Determining Optimal Dose of Chemical Fertilizer on Biofortified Bean in Sud-Kivu Highlands

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Abstract

Rational application of chemical fertilizer increases crop yield of biofortified bean. This study aimed at determining the optimal dose of chemical fertilizer to apply on two biofortified bean varieties used in the community in order to maximize their yield. Following a split-plot design, a field experiment was carried out on CODMLB001 and HM21-7 varieties, in Kashusha (Kabare territory) in Sud-Kivu Highlands, after a strategic application of increasing doses of chemical fertilizer NPK 17-17-17 (D_0: Control; D_1: 50 kg·ha^{-1}; D_2: 75 kg·ha^{-1}; D_3: 100 kg·ha^{-1}; D_4: 125 kg·ha^{-1} and D_5: 150 kg·ha^{-1}). The said doses were applied on the sowing day in a parallel gutter at 5cm from the sowing line. The germination rate, the number of days at both the flowering stage and the stage of physiological maturity, as well as the number of harvested crops and beans per plant, number of beans per pod, weight per 1000 grains and yield were observed. Positive and negative interaction between different increasing doses of chemical fertilizers regarding the two varieties were observed. This strategic application allows increased performance according to considered varieties and doses. For instance, the HM21-7 variety gave the best performance with the D_5 dose, while the CODMLB001 variety did better under D_2.

Keywords: biofortified bean, Sud-Kivu highlands, increasing doses, chemical fertilizers, yield

1. Introduction

Africa has a complexity of climate conditions and a range of soils (Goudie, 1996; Griffiths, 2005; ODINAFRICA, 2007; UNEP, 2008; Casinga et al., 2015b, 2016). However, the latter have generally low fertility because of their ageing due to the lack of volcanic substrata for the establishment of new structures and their rejuvenation (Bationo et al., 2006). Nearly 16% of Africa's soils are of the best quality, 13% are of average quality, 16% of the least quality and 55% of poor quality although supporting a diversity of crops (Eswaran et al., 1996). On the one hand, approximately 900 million hectares of soils of high and average quality bear 400 million of persons or 45% of the African population. On the other hand, nearly 30% of the population (about 250 millions) live or depend on soils with low production potentiality and so leads to a situation of food insecurity (Eswaran et al., 1996; Bationo et al., 2006, 2008).

Most of sub-Saharan Africa's soils as well as those of the Democratic Republic of Congo, and particularly those of Sud-Kivu highlands are less fertile and productive because of increased degradation due to overexploitation (Casinga et al., 2015c). Besides, inadequate conservation and improvement agricultural practices affecting soil fertility correlate there and lead to low yield of crops, including bean (Blondel, 1971; Westelaar & Ganry, 1982; Ganry et al., 1990; McCan, 2005; Casinga et al., 2015b). Furthermore, an exponential increase in population exerting pressure on this resource contributes to it (FAO, 2005, 2010; Casinga et al., 2015a, 2015c). In the southern countries, the annual mean loss of the arable top soils in macronutrients, including Nitrogen, Phosphorus and Potassium are respectively about 22 kg·ha^{-1}, 2.5 kg·ha^{-1} and 15 kg·ha^{-1} (Steiner 1996). These bad farming practices have led some writers to characterize the agriculture of these countries as "mining agriculture" (Stoorvogel & Smaling, 1990) since outputs exceed inputs in these exploitation systems (Van Keulen & Breman, 1990; Van Reuler & Prins, 1993; Van Reuler, 1996). Due to rapid demographic explosion and dietary needs that follow, agricultural production must increase significantly in order to feed the population and eradicate malnutrition (Useni et al., 2012; Casinga et al., 2015a, 2015b, 2015c, 2016). Recourse to chemical fertilizers proves a key factor in the modernization of agriculture in developing countries due to the existence of a positive correlation between yield and the amount of chemical fertilizers used properly (Useni et al., 2012). The other advantage of fertilizers is that they not only improve efficiency but also crop residues serve as organic fertilizer from the previous crop (Batiano et al., 2006; Casinga et al., 2015b). In Sud-Kivu, the yields of the bean crop are low and do not exceed 500 kg·ha^{-1} in farming without fertilization (Casinga et al., 2015b). In large farms, with the use of improved varieties and the use of mineral fertilizers, yields varying from 800 to 1200 kg are achieved, HarvestPlus (2013). The present study aims to determine the optimal dose of chemical fertilizers NPK 17-17-17 able of inducing and enhancing increase in the yield of biofortified beans and the identification of the variety that best responds to mineral fertilization.

2. Method

2.1 Location

The experiment was carried out during the growing season 2011A-2012A, in the experimental site of the "Université Evangélique en Afrique (UEA)" at Kashusha, Kabare territory, Sud-Kivu in the Democratic Republic of Congo. The geographical coordinates of the station are 028°47′ East longitude and 02°19′ South latitude while the altitude is 1712 m. Kashusha has an AW_3 climate type, according to Köppen's classification. The average annual rainfall reaches 1450 mm while the average annual temperature is 19.5 °C. The soil of the experimental site belongs to the class of Ferralsols, according to FAO-UNESCO classification (Baert, 1995; Beernaert, 1999; Baert et al., 2012; Botula et al., 2012; Casinga et al., 2015b); whereas its texture silty-clay (Casinga et al., 2015a).

2.2 Materials

2.2.1 Biological Material

Two biofortified beans varieties were used as biological material: the CODMLB001 and the HM21-7 varieties.

2.2.2 Mineral Fertilizers

The ternary chemical NPK 17-17-17 was used as fertilizer.

2.3 Method

The experiment was conducted on a split-plot design. Varieties of biofortified beans randomized and sown in line in the subplots at the depth of 4 cm with two seeds per hole, with a distance of 0.40 × 0.20 m were the main factor, while six doses of chemical fertilizer (D_0: Control; D_1: 50 kg·ha^{-1}; D_2: 75 kg·ha^{-1}; D_3: 100 kg·ha^{-1}; D_4: 125 kg·ha^{-1} and D_5: 150 kg·ha^{-1}) represented the secondary factor. Fertilizers were spread at sowing and applied in a gutter parallel to the sowing line, at a distance of more or less 0.5 cm, and a depth of more or less 5 cm. The latter were immediately covered with a little soil after application. At the beginning of vegetation germination rate was determined with the ratio of number of plants raised per the number of grains sown multiplied by one hundred. During vegetation, the numbers of days to flowering were determined by the difference in number of days between the date of the appearance of inflorescences (at least 50% on a plot) and sowing date. The yield components (number of pods, number of grains per pod and weight of 1000 grains) and the yield obtained by the formula were determined.

$$\text{Yield}\,(\text{kg·ha}^{-1}) = \frac{\text{Poids des Graines SU} \times 10000}{\text{Surface Utile (SU)}} \tag{1}$$

The experimental results were assessed by the Analysis of Variance, correlation and multiple regression while the averages were separated by the test LSDα = 0.05. Excel 2013 software, R 3.3.0 and Assistat 9.5.1 were used as calculation tool.

3. Results

Statistical analysis revealed significant differences in the parameters of the number of days at the flowering stage, the number of harvested plants and yield for the different increasing doses of mineral fertilizers. However, they revealed the lack of significant differences in the parameters of the germination rate, the number of days at the stage of physiological maturity, number of pods per plant, number of grains per pod and weight of 1000 grains, depending on the different increasing doses of mineral fertilizers.

Table 1. Effect of increasing doses of chemical fertilizers on the growth of bean

	Treatment	Rate of Germination (%)	Days to the flowering stage (n°)	Days to physiological maturity stage (n°)
CODMLB001	D_0	83 ± 6,5	36	78
	D_1	75 ± 11,9	36	78
	D_2	78 ± 4,1	36	78
	D_3	82 ± 8,6	36	82,7 ± 6,5
	D_4	78 ± 5,7	36	78
	D_5	80 ± 13,4 *	36 ***	78
HM21-7	D_0	59 ± 8,5 *	38 ± 1,4 **	80
	D_1	53 ± 10,8 **	39 ***	80
	D_2	57 ± 4,7 **	39 ***	80
	D_3	59 ± 0,8 *	39 ***	80
	D_4	47 ± 3,2 *	39 ***	80
	D_5	59 ± 8,4 *	39 ***	80

Note. D_0: Control, D_1: 50 kg·ha^{-1}, D_2: 75 kg·ha^{-1}, D_3: 100 kg·ha^{-1}, D_4: 125 kg·ha^{-1}, D_5: 150 kg·ha^{-1}.

Table 2. Effect of doses of increasing chemical fertilizers on the yield and its components

	Treatment	Number of plants harvested (n°)	Number of pods per plant (n°)	Number of grains per pod (n°)	Weight of 1000 grains (gram)	Yield kg·ha^{-1}
CODMLB001	D_0	45 ± 3,3	5 ± 1	4 ± 1	396 ± 75,8 *	584 ± 104,3
	D_1	41 ± 2,2	6	4 ± 1	420 ± 24,5	814 ± 127,9
	D_2	46 ± 3,6	5 ± 1	4 ± 1	420 ± 78,7 *	1196 ± 222,7
	D_3	46 ± 3,6	6 ± 2	4	403 ± 52,5	1052 ± 401,6
	D_4	39 ± 4,5	5 ± 2	4 ± 1	366 ± 26,5	725 ± 142,9
	D_5	44 ± 6,5	6 ± 2	4 ± 1	427 ± 105,8	883 ± 203,4
HM21-7	D_0	27 ± 9,5 *	5 ± 1	3 *	436 ± 68,5	687 ± 146,8 *
	D_1	34 ± 11,6	6 ± 2	4 ± 1	413 ± 65,9	1018 ± 226,2
	D_2	26 ± 7,3 **	7 ± 1	4 ± 1	537 ± 83,4	1016 ± 277,3 *
	D_3	21 ± 9,6 **	7 ± 1	4	423 ± 79,3	837 ± 470,4
	D_4	27 ± 1,2 *	6 ± 2	4 ± 1	460 ± 29,4	991 ± 68,4
	D_5	36 ± 4,4 *	7 ± 2	4 ± 1	477 ± 61,8	1250 ± 277,1 *

Note. D_0: Control, D_1: 50 kg·ha^{-1}, D_2: 75 kg·ha^{-1}, D_3: 100 kg·ha^{-1}, D_4: 125 kg·ha^{-1}, D_5: 150 kg·ha^{-1}.

The CODMLB001 variety presented a better rate of germination in comparison to the HM21-7 variety. Furthermore, it happened earlier than the latter since it reached flowering and physiological maturity earlier. At the harvest, the number of harvested plants for the CODMLB001 variety was greater than that of the HM21-7 variety. The number of pods per plant and the number of seeds per pod were similar for the two varieties, the increasing doses of chemical fertilizers and their interactions. The weight of 1000 seeds was positively correlated with the increasing doses of chemical fertilizers for the two varieties. The HM21-7 variety had the better yield in comparison to the CODMLB001 variety.

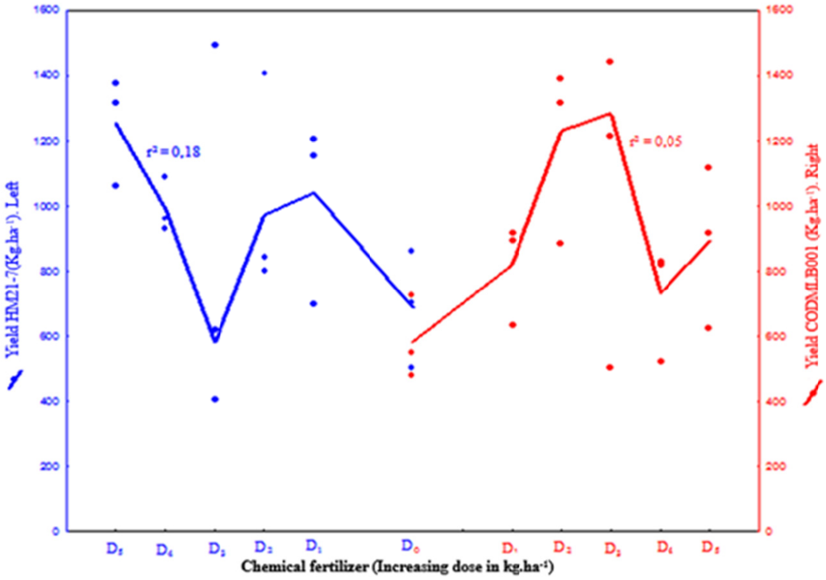

Figure 1. Correlation between HM21-7 and CODMLB001 yields varieties and their treatment

This figure highlights the interaction between the varieties and certain increasing doses of chemical fertilizers, where the HM21-7 variety got the better yield under D_5 treatment while for the CODMLB001 variety it was under D_2 treatment.

4. Discussion

According to FAO (2003) land degradation remains a major global concern because of its adverse impacts on agricultural production, food security and the environment. Responses to these mineral fertilization varieties depended on the dose applied and so confirmed de Nascente et al. (2015)'s results stigmatizing that the application the increasing doses of chemical fertilizer at sowing greatly increases the performance of beans. Indeed, the strategic application of increasing doses of chemical fertilizer induced an increase in the number of pods per plant for the different varieties in different treatments, thus confirming the results of Abdel-Mawgoud et al. (2005) and Mahmoud et al. (2010) who found similar results. Moreover, the number of seeds per pod did not vary according to treatment in both genotypes contradicting the work of Kamanu et al. (2012) who found that increasing fertilizer application results in an increase in the number of seeds per pod in some varieties. This is accounted for by the fact that it is a highly stable genetic characteristic of these genotypes not to react to this environmental component (Beebe et al., 2000). This increasing application of doses of chemical fertilizers induced an increase in yield, respectively 204.7% for CODMLB001 variety because of the dose D_2, comparatively to D_0 and 211% for the variety HM21-7 due to D_5 dose compared to D_0, confirming the work of Abdel-Mawgoud et al. (2005) and Tantawy et al. (2009) as well as Zucareli et al. (2011) and Kamanu et al. (2012) who found similar results compared to the control. Declining results observed for doses ranging from D_2 to D_5 in the CODMLB001 variety confirm Mitscherlich (1909)'s law of less proportional surpluses highlighting that increasing quantities of fertilizers, crop surpluses obtained are lower and lower, producing a depressing, let alone toxic effect.

5. Conclusion

The application of increasing doses of chemical fertilizer induced significant interactions on crop varieties under study. The variety HM21-7 gave the better performance under treatment D_5 while for CODMLB001 variety was under treatment D_2. We recommend that the Sud-Kivu population adopt these doses depending on the varietal preference. Extensive studies of these doses based on physiological critical stages must be considered in determining the value end cost.

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