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Phosphorus and potassium fertilization increase common bean grain yield in Mozambique

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Key words:

Phaseolus vulgaris
yield components
soil fertility

ABSTRACT

There is little information about common bean fertilization in African Savannas. The objectives of this study were as follows: i) to evaluate the common bean yield potential in the environmental conditions of Lichinga, Niassa, Mozambique, and ii) to determine the common bean response to phosphorus and potassium fertilization applied together in order to verify whether the interpretation of soil analysis for the Brazilian Cerrado could be adopted for Savanna soils in Mozambique. The experimental design was a randomized block design in a 5 x 4 x 2 factorial arrangement. Treatments consisted of a combination of phosphorus doses (0, 35, 70, 140 and 280 kg ha⁻¹ of P₂O₅), potassium doses (0, 50 100 and 200 kg ha⁻¹ of K₂O), and different growing seasons (2012/2013 and 2013/2014). The field rainfed experiments were conducted in Lichinga city, province of Niassa. Common bean crops presented high productivity potential in rainfed systems in the environmental conditions of Lichinga, Niassa, Mozambique, reaching grain yields of up to 3,600 kg ha⁻¹ depending on the rates of fertilization with phosphorus and potassium. Common beans responded to phosphorus and potassium fertilization despite high contents of these nutrients in the soil, according to the interpretation of soil analysis for the Brazilian Cerrado. Maximum grain yield in the average of two growing seasons was estimated to occur for 239 kg ha⁻¹ of P₂O₅ and 141 kg ha⁻¹ of K₂O, indicating that further calibration studies for P and K are required for this specific region of Mozambique.

Palavras-chave:

Phaseolus vulgaris
componentes de produção
fertilidade do solo

Adubação fosfatada e potássica elevam a produtividade de grãos do feijoeiro em Moçambique

RESUMO

Há pouca informação sobre sua fertilização nas Savanas Africanas. Os objetivos deste trabalho foram: i) avaliar o potencial de produtividade de feijão nas condições ambientais de Lichinga, Niassa, Moçambique e ii) determinar as curvas de resposta da cultura à adubação com fósforo e potássio, aplicados juntos, a fim de verificar se a interpretação da análise de solos do Cerrado brasileiro poderia ser adotada para os solos do Cerrado de Moçambique. O delineamento experimental foi em blocos casualizados, em esquema fatorial 5 x 4 x 2. Os tratamentos foram formados pela combinação de doses de fósforo (0, 35, 70, 140 e 280 kg ha⁻¹ de P₂O₅) com doses de potássio (0, 50 100 e 200 kg ha⁻¹ de K₂O) e safras agrícolas (2012/13 e 2013/14). Os experimentos de sequeiro a campo foram realizados na cidade de Lichinga, província de Niassa. A cultura de feijão-comum apresentou alto potencial de produtividade em sistema de sequeiro nas condições ambientais de Lichinga, Niassa, Moçambique, atingindo rendimento de grãos de até 3 600 kg ha⁻¹, dependendo das doses de adubação com fósforo e potássio. O feijão-comum respondeu à fertilização de fósforo e potássio apesar do alto teor desses nutrientes no solo, de acordo com a interpretação da análise do solo para o Cerrado brasileiro. O rendimento máximo de grãos, na média de duas safras, foi estimado em 239 kg ha⁻¹ de P₂O₅ e 141 kg ha⁻¹ de K₂O, indicando que estudos de calibração para P e K são necessários para esta região específica de Moçambique.



INTRODUCTION

Over 200 million people in sub-Saharan Africa depend on the common bean (*Phaseolus vulgaris* L.) as a primary staple (Petry et al., 2015). However, despite the crop's importance, in Africa Savannas, the common bean grain yield achieved by farmers is very low (CGIAR, 2015). During the 2013 growing season in Africa, grain yield was 657 kg ha⁻¹ and only 345 kg ha⁻¹ in Mozambique (FAO, 2015). In Brazil, for example, there are farmers reaching yields of 3,500 kg ha⁻¹ in common beans (Nascente et al., 2012, 2014; CONAB, 2017).

The Triangular Co-operation Programme for Agricultural Development of the Tropical Savannah in Mozambique (Pro SAVANA, 2014) is a large project created to investigate new agricultural development models. The target area was the Nacala corridor, an area of 11 million ha that ranges from the border of Mozambique with Malawi to the port of Nacala on the west coast of the country. This area has the same latitude as the Cerrado Region in Brazil, with similar conditions of climate and soil. The main objective was to bring technologies used in Brazil to be tested in the Nacala corridor (Pro SAVANA, 2014). For example, currently there are no regional calibration studies that can be used to recommend P and K fertilization for crops, such as the common bean, based on soil analysis.

The common bean is a high demand plant for nutrients, and thus low natural soil fertility is one of the major factors that can limit productivity of this crop in tropical regions (Ávila et al., 2012; Fageria & Nascente, 2014; Argaw et al., 2015; Silva et al., 2016). Therefore, to avoid soil impoverishment and reduced productivity over time, it is necessary to replace at minimum the quantity of nutrients exported by the grains. In addition, there has been increasing demand for fertilizer recommendations covering the major foods and cash crops in Mozambique (Geurts & Berg, 1998). The objectives of this study were as follows: i) to evaluate the common bean yield potential in the environmental conditions of Lichinga, Niassa, Mozambique, and ii) to determine the common bean response to phosphorus and potassium fertilization in order to verify whether the interpretation of soil analysis for the Brazilian Cerrado could be adopted for the Savanna soils of Mozambique.

MATERIAL AND METHODS

The study was conducted in the experimental field of the Centro Zonal de Investigação Noroeste (CZINw), of the Instituto de Investigação Agrícola de Moçambique (IIAM), in the district of Lichinga, province of Niassa, located in northern Mozambique, with coordinates of 13° 23' 48" S and 35° 13' 43" E. The altitude of the region varies from 1000 to 1300 m. According to the classification of Köppen-Geiger (1928), the climate of this region is humid temperate (Cwb), with two well-distinguished seasons (temperate and rainy summers and dry cold winters). The region presents average annual rainfall varying between 1000 and 1500 mm, while the average annual temperature is between 20 and 23 °C (Mbanze et al., 2015). The temperature and rainfall data during the trials are shown in Figure 1.

The soil was classified as a clay loam Ferralsols (FAO, 1998). The experiments were repeated in adjacent areas in the same field. Before the trials were set up, in September 2012, soil chemical analyses were performed at a depth of 0-0.20 m to characterize the experimental area (Table 1). The chemical analyses were performed according to the methodology proposed by Donagema et al. (2011).

The experimental design was a randomized block design in a 5 x 4 x 2 factorial arrangement, with four replications. For each growing season, the trial was located in different locations within the same larger area, which was sampled for soil analysis in both growing seasons (Table 1). Treatments were the combination of phosphorus doses (0, 35, 70, 140 and 280 kg ha⁻¹ of P₂O₅), potassium doses (0, 50, 100 and 200 kg ha⁻¹ of K₂O), and growing season (2012/13 and 2013/14). The sources of these nutrients were triple superphosphate and potassium chloride.

The soil was prepared with conventional tillage (one plowing and two disking). The sowing of the rainfed common bean cultivar BRS 'Pontal' was manually completed on December 12th, 2012 and January 15th, 2014, with a row spacing of 0.45 m and a density of 8 seeds m⁻¹. Each plot consisted of five rows six meters long, with a useful area of three central rows, disregarding 1.5 m from the ends of each row. A sowing fertilization was applied with 23 kg ha⁻¹ of N as urea, and a topdressing fertilization at the V₄ vegetative stage of the common bean (three trifoliolate leaves) was applied with 67 kg ha⁻¹ of N as urea. Other cultural practices were performed according to the recommendations for the crop to keep the area free of weeds, diseases and insects. Harvesting occurred on March 21st, 2013 and May 9th, 2014.

The usable area of the plots was harvested by hand, followed by a mechanized thresher. The harvested common bean grains were weighed, and the yield was adjusted to 130 g kg⁻¹ of water content. In addition, the following yield components were assessed: the number of pods per plant, the number of grains per pod (evaluated in 10 plants per plot that were chosen at random), and the 100-grain weight (calculated from eight random samples per plot) corrected to 130 g kg⁻¹ of water content.

Data were subjected to analysis of variance, and means were compared using Tukey's test at p < 0.05. Regression analysis was conducted for quantitative data (P and K rates) if they were found to be significant. SAS statistical software was used for these analyses.

RESULTS AND DISCUSSION

The number of pods per plant, the number of grains per pod and the 100-grain weight are the main components of common bean grain yield (Fageria & Santos, 2008). Analysis of variance revealed no effects of P or K fertilization on the number of grains per pod or on the 100-grain weight (Table 2). The number of grains per pod is a characteristic specific to each cultivar and is genetically determined with little influence from the environment (Pelá et al., 2009). Although strongly genetically controlled, the 100-grain weight is also influenced by environmental conditions, such as soil pH and N, P and

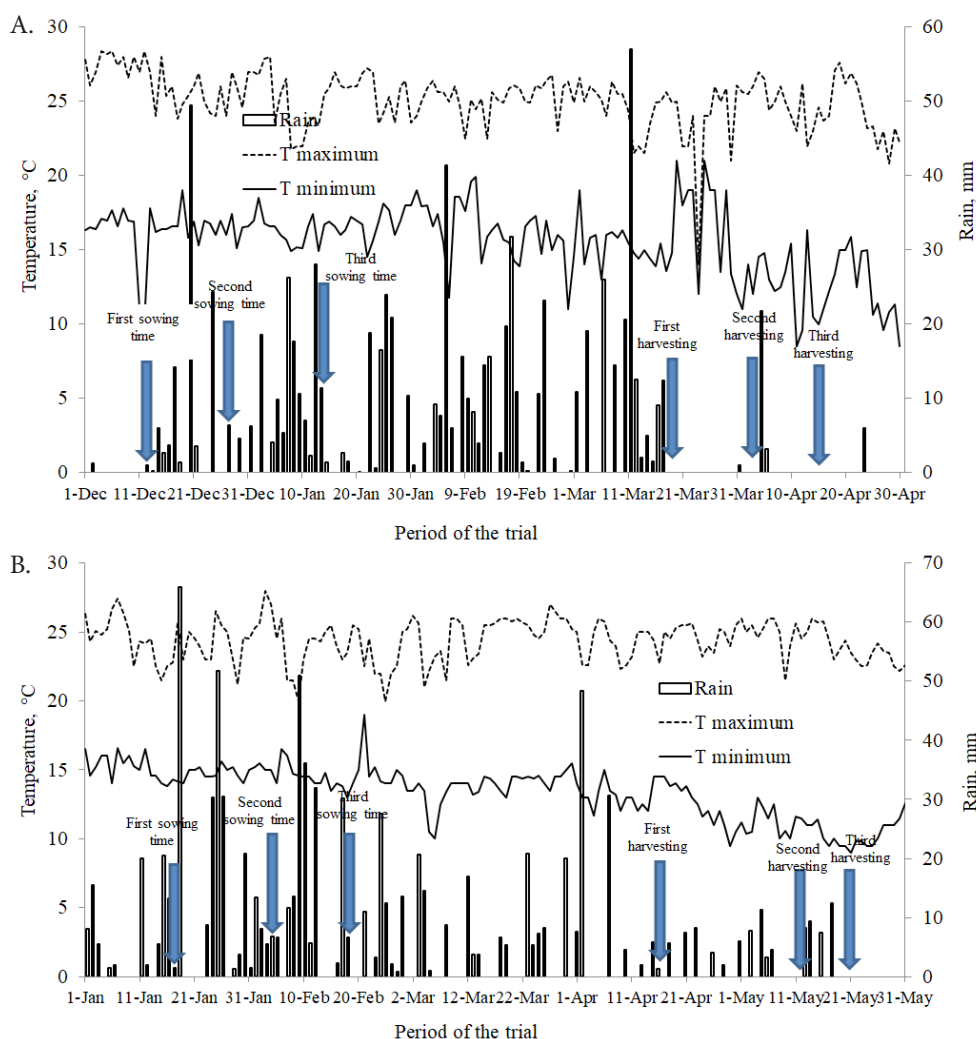


Figure 1. Temperature and rainfall of the experimental area during the trials performed in the growing seasons 2012/13 (A) and 2013/14 (B)

Table 1. Soil property results of the experimental area. Lichinga city, province of Niassa, Mozambique. Growing seasons 2012/13 and 2013/14

Growing season 2012/13								
Layer	¹ P mg kg ⁻¹	¹ K ⁺	Al ³⁺	Ca ⁺²	Mg ⁺²	(Ca+Mg)/K	Ca/K	Mg/K
			mmol _c kg ⁻¹					
0-0.20 m	23	3.0	6.5	11.5	4.5	5.3	3.8	1.5
IBC ²	High	High	High	Low	Low	Low	Low	Low
	pH in water	H + Al	CEC	ECEC	BS	SOM	Clay	
			mmol _c kg ⁻¹			%	g kg ⁻¹	
0-0.20 m	6.1	54.9	73.8	25.5	19.0	24	440	
IBC ²	Good	High	Medium	Low	Low	Medium	Clay	
Growing season 2013/14								
	P mg kg ⁻¹	K ⁺	Al ³⁺	Ca ⁺²	Mg ⁺²	(Ca+Mg)/K	Ca/K	Mg/K
			mmol _c kg ⁻¹					
0-0.20 m	23	3.0	6.7	11.0	4.4	5.1	3.7	1.5
IBC ²	High	High	High	Low	Low	Low	Low	Low
	pH in water	H + Al	CEC	ECEC	BS	SOM	Clay	
			mmol _c kg ⁻¹			%	g kg ⁻¹	
0-0.20 m	6.3	55.1	72.7	23.4	18.0	23	440	
IBC ²	Good	High	Medium	Low	Low	Medium	Clay	

CEC - Cation exchange capacity; ECEC - Effective cation exchange capacity; BS - Base saturation; SOM - Soil organic matter; Al saturation (Al/ECECx100) = 29%; ¹ P and K were extracted by Mehlich-1; ² Interpretation for Brazilian Cerrado soils, Sousa & Lobato (2002)

K fertilization (Fageria et al., 2001; Fageria & Santos, 2008). However, 100-grain weight was not affected by P or K doses in our trial, likely because the content of these nutrients in the soil (Table 1) was not limiting to grain filling. Corroborating these results, Zucareli et al. (2006), Pelá et al. (2009), Zucareli et al.

(2011) and Nascente & Cobucci (2015) found no significant differences in the number of grains per pod or 100-grain weight with increasing levels of P in the soil. Rodrigues et al. (2013) also did not report differences in the number of grains per plant with the increasing K levels. Thus, it can be inferred

Table 2. Number of pods per plant (PODS), number of grains per pod (GRAIN), 100-grain weight (100G) and grain yield (YIELD) of the common bean cultivar 'BRS Pontal' as a function of phosphorus and potassium fertilization and analysis of variance in the growing seasons 2012/2013 and 2013/2014

Factors	PODS	GRAIN	100G	YIELD
Growing season	number	number	g	kg ha ⁻¹
2012/2013	17.9 a*	6.7	27.3	2796 a
2013/2014	16.7 b	6.3	27.2	2499 b
ANOVA F value (F probability)				
Rates of P ₂ O ₅ (P)	< 0.001	0.3514	0.2874	< 0.001
Rates of K ₂ O (K)	< 0.001	0.3001	0.3481	< 0.001
Growing season (GS)	0.0398	0.0716	0.4018	< 0.001
P x K	0.3217	0.3216	0.4179	< 0.001
P x GS	0.4461	0.2418	0.3519	0.0235
K x GS	0.5016	0.4664	0.6915	0.0247
P x K x GS	0.7998	0.6789	0.7731	0.0331
C.V. (%)	21.94	8.25	9.62	15.46

*Means followed by the same letter in columns did not differ by Tukey's test $t_p < 0.05$

that to achieve high grain yield, these nutrients should be in an adequate balance.

There were significant single effects of P and K rates and growing season for the number of pods per plant (Table 2). Increasing P and K levels resulted in an increased number of pods per plant and were fitted to quadratics equations, which resulted in a maximum of 17.49 pods per plant for doses of 295 kg ha⁻¹ of P₂O₅ and 254 kg ha⁻¹ of K₂O (Figure 2). According to Fageria & Santos (2008), among the yield components, the number of pods per plant is the most important factor that determines grain yield of the common bean because of its higher and more consistent correlation with grain yield. The number of pods per plant is genetically controlled and is also strongly influenced by environmental factors and management

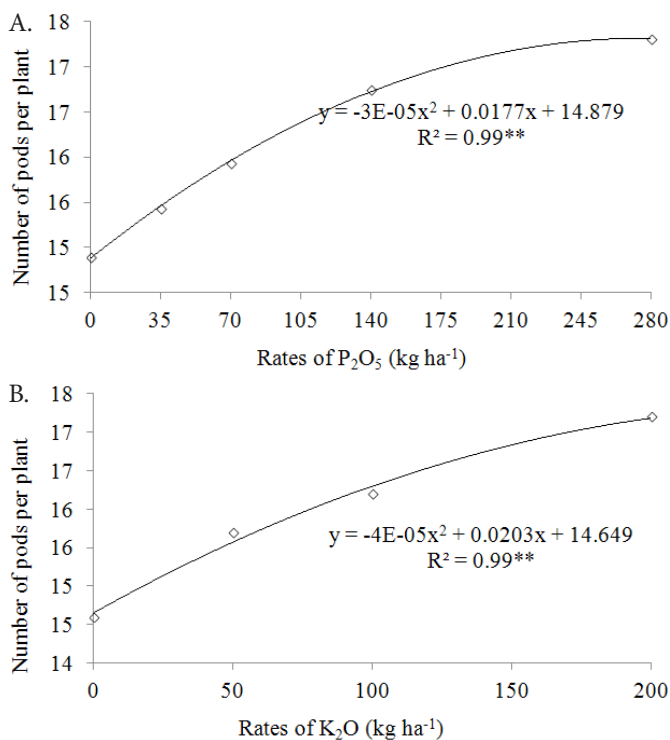
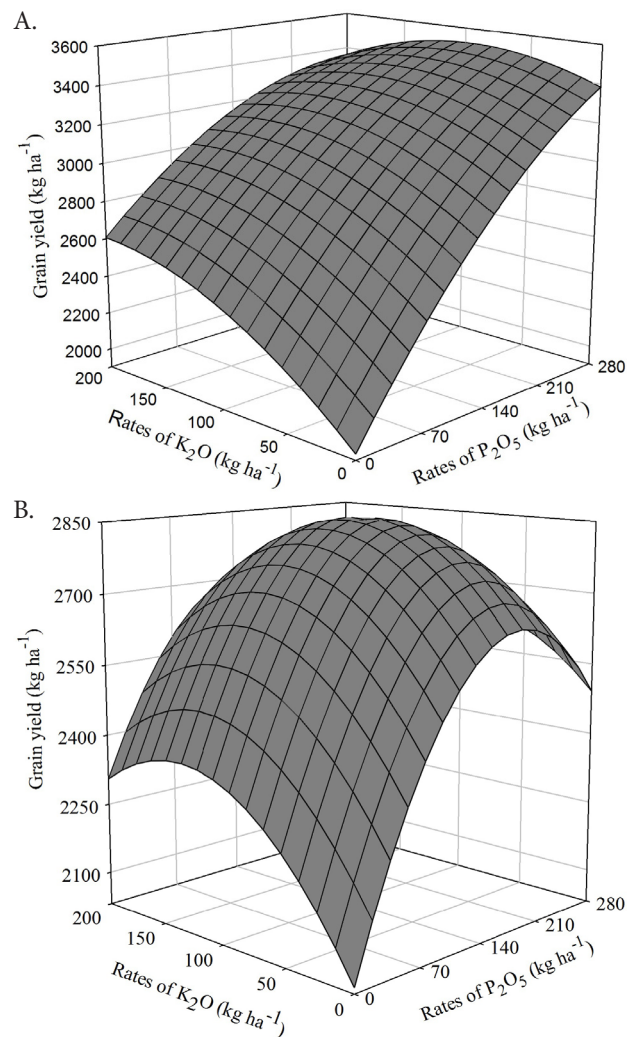


Figure 2. Number of pods per plant as a function of rates of P₂O₅ (A) or K₂O (B). Average of growing seasons 2012/2013 and 2013/2014

practices, such as P and K fertilization, as shown in this study. Phosphorus acts as an energy transfer agent within the plant, playing an essential role in physiological and biochemical processes such as photosynthesis and respiration (Hawkesford et al., 2012). Potassium also has various important physiological functions contributing to plant growth and grain yield, such as photosynthesis, enzyme activity, protein synthesis, cell elongation, translocation and utilization of photosynthates, and osmoregulation (Hawkesford et al., 2012). Thus, any factor impairing P or K uptake by common bean plants can negatively affect plant development, pod filling, and consequently, grain yield. Zucareli et al. (2006, 2011), Pelá et al. (2009), Santos et al. (2011), Silva et al. (2014) and Nascente & Cobucci (2015) also reported increases in the number of pods per plant due to increased levels of P fertilization.

There was a significant triple interaction between P and K fertilization, growing seasons, and grain yield (Table 2). In both growing seasons, the variation of common bean grain yield in response to P and K rates was adjusted by a response surface model, and the inflection point (or maximum point) ranged from one growing season to another (Figure 3). In the growing



Response surface (A): Yield = 1930 + 7.63P + 6.35K - 0.0087P² - 0.0125PK - 0.0148K²
 $R^2 = 0.63$ ($p < 0.01$).

Response surface (B): Yield = 2042 + 6.56P + 4.975K - 0.0177P² - 0.0063PK - 0.0183K²
 $R^2 = 0.63$ ($p < 0.01$).

Figure 3. Grain yield of common bean cultivar BRS Pontal as a function of P and K fertilization in the growing season 2012/13 (A) and 2013/14 (B)

season 2012/13, the maximum grain yield of 3616 kg ha⁻¹ was estimated with the combined rates of 406 kg ha⁻¹ of P₂O₅ and 43 kg ha⁻¹ of K₂O (Figure 3A). In growing season 2013/14, the maximum grain yield of 2616 kg ha⁻¹ was estimated with the combined rates of 166 kg ha⁻¹ of P₂O₅ and 107 kg ha⁻¹ of K₂O (Figure 3B). In the Brazilian Cerrado region, common bean yield is not expected to respond positively to the application of P and K in soils with high content of these nutrients (Table 1). The positive effects in the Nacala corridor region, even at P and K levels considered to be high in soils from the Brazilian Cerrado (Fageria et al., 2001; Sousa & Lobato, 2002), indicate that calibration studies for P and K are required for this specific region of Mozambique. It was observed that Ca and Mg contents in the soil were low and that exchangeable Al was high, resulting in low base saturation in the soil (Table 1). This implies unfavorable conditions for the development of the root system (Silva et al., 2004) and, therefore, lower uptake of nutrients by plants due to the exploitation of the small soil volume. Föhse et al. (1988) demonstrated that the common bean is a low P uptake efficiency species, with both a low root-shoot ratio and a low influx rate. Therefore, the magnitude of the common bean response to P fertilization depends in part on root development, which is influenced by base saturation of the soil (Silva et al., 2004).

The decrease in grain yield after a maximum point in both growing seasons (Figure 3) was likely the result of adverse interactions between excess P and K and other nutrients in the rhizosphere. It is known that excess phosphorus, for example, causes decreases in zinc uptake (Singh et al., 1988; Fageria et al., 2010). An excess of K further decreases the ratios (Ca + Mg)/K, Ca/K and Mg/K, which were already very low (Table 1). In the Brazilian Cerrado, which has similar conditions to those in Mozambique soil, it is assumed that the ratios between these cations are (Ca + Mg)/K = 20 to 30, Ca/K = 15 to 25, and Mg/K = 5 to 15 (Sousa & Lobato, 2002). Therefore, in this study, in addition to the absolute levels of Ca and Mg in the soil being low (Table 1), the ratios of these two nutrients to K are also very low. This likely resulted in the impaired uptake of Ca, and especially of Mg, in the roots as higher doses of potassium were applied to the soil.

Based on the average results of the 2012/2013 and 2013/2014 harvests (Table 2), it can be inferred that the common bean confirmed its high nutritional requirements, especially for phosphorus, by responding to balanced fertilization with increasing grain yield. In the regression analysis of the two growing seasons, grain yield corresponded to P and K rates according to quadratic equations (Grain yield = 2264 + 6.62P - 0.013P², R² = 0.93**); Grain yield = 2460 + 4.60K - 0.016K², R² = 0.63*), and the maximum grain yield was estimated using the rates of 239 kg ha⁻¹ of P₂O₅ and 141 kg ha⁻¹ of K₂O. However, the results of production for only two harvests, without proper monitoring of soil fertility and nutritional status of the crops and without knowledge of market indicators and input prices are insufficient to establish P and K rates for optimum economic yield.

The results indicate that there were differences in the number of pods per plant and in grain yield of the common bean for both growing seasons (Table 2). The number of pods per plant and the grain yield were higher in the 2012/2013

harvest compared to 2013/2014. This is possibly because in 2012/13, there was a rainfall of 322.6 mm during the flowering and grain filling stages, and in the 2013/14 growing season, there was a rainfall of 234 mm during this same period (Figure 1). This lack of rainfall in the second growing season in relation to the first likely affected the number of pods per plant, which was greater in the first growing season. According to Guimarães et al. (2011), during the flowering and grain filling stages, common bean plants require increased amounts of water, and a deficit drastically reduces yield components and grain yield. In addition, Zucareli et al. (2006) reported that the number of pods is the variable that most strongly influences common bean yield. However, it is noteworthy that the grain yields were highly satisfactory, with values higher than the average typical for Mozambique of 345 kg ha⁻¹ (FAO, 2015). The average grain yield of 2796 kg ha⁻¹ in 2012/2013 and 2499 kg ha⁻¹ in 2013/2014 (Table 2) is much higher than the Mozambique average and is also higher than the average productivity of rainfed systems in Brazil, which was 1795 kg ha⁻¹ in the first season and 893 kg ha⁻¹ in second season (CONAB, 2017). Based on these results, it can be inferred that Lichinga has good environmental conditions for common bean development and good management practices, such as adequate fertilization with P and K can effectively increase the grain productivity of common bean crops in Lichinga, Niassa, Mozambique, Africa. These data are very important and indicate further opportunities to expand food production in places that have serious problems of malnutrition and hunger (CGIAR, 2015).

CONCLUSIONS

1. Common bean crops presented high productivity potential in rainfed systems in the environmental conditions of Lichinga, Niassa, Mozambique, reaching grain yields of up to 3600 kg ha⁻¹ depending on the rates of fertilization with phosphorus and potassium.
2. Common bean crops responded to phosphorus and potassium fertilization despite high contents of these nutrients in the soil, according to the interpretation of soil analysis for the Brazilian Cerrado. Maximum grain yield, in the average of two growing seasons, was estimated to occur with 239 kg ha⁻¹ of P₂O₅ and 141 kg ha⁻¹ of K₂O, indicating that further calibration studies of P and K are required for this specific region of Mozambique.

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