Original Research Article

Development and Seed Production Of Black-Bean With Molybdenum Foliar Application

ABSTRACT

The objective of the work was to evaluate the development and yield of beans with foliar application of Molybdenum. The experiment was conducted in randomized blocks in a 2 x 4 x 3 factorial scheme (sowing season x doses x application time), with treatments consisting of two sowing season: autumn/winter (sowing in February - dry season) and spring/summer (sowing in October - rainy season), four Mo doses (0, 50, 150 and 300 ml ha^{-1} of commercial Mo based product) and three application times, starting the count after 50% plant emergence (10 days after emergence - DAE, 20 DAE and 30 DAE). The experiment was performed at the Experimental Farm of the Grand Dourados Federal University, at the municipality of Dourados, MS, Brazil. The Mo source was a commercial product with a concentration of 216 g L^{-1} Mo. Black beans were sown using a conventional procedure, with soil preparation by subsoiling, harrowing and leveling. A pneumatic seeder was used with a spacing of 0.45 m, 12 seeds per meter of furrow, in plots of 5 x 5 m, totaling 10 plants per meter, a population of 222,222 plants ha^{-1} and depth of 0.02 m. For the agronomic evaluations, five plants per plot were collected at the end, when the crop reached physiological maturity, in the central line, for the following determinations: number of pods per plant; number of seeds per plant; number of seeds per pod; mass of a thousand seeds and yield. Positive Results in yield components and effective yield of black-beans were found when 50 mL ha^{-1} of molybdenum was applied via foliar application. Although it was not one of the objectives of the study, it was concluded that the amount of rainfall in the crop cycle affects the action of molybdenum on bean plants.

Keywords: Sowing season, bean yield, foliar fertilizer

1. INTRODUCTION

Global agricultural production has been growing exponentially and this is due to research that guarantees greater yield in less time as well as the emergence of new technologies.

Brazil occupies a prominent place in global agricultural production as its unique soil and climate characteristics guarantee year-round production of various plant species.

Among them, beans, a species belonging to the Fabaceae family, stand out due to their great importance for Brazilian agriculture, as the relevance for population eating habits and for being one of the countries that produces and consumes more.

Despite this, bean production has not varied much over time and remains stagnant, as shown by data published by the Brazilian Supply Company (CONAB), in which the average production in season 2011/2012 harvest was 890 kg ha^{-1} and in 2023/2024 harvest it was 1,141 kg ha^{-1}, an increment of just 211 kg in twelve years [1].

Low crop yield occurs, among other factors, due to inadequate mineral nutrition based on chemical fertilization, commonly by nitrogen, phosphorus and potassium.

This type of fertilization is advantageous by rapid availability of nutrients for plants, since they are soluble sources. However, this high solubility may bring disadvantages, as its application must be done annually, and therefore, what is not assimilated by the crops may be lost through leaching and may contaminate surface and groundwater.

Therefore, it is necessary that different management methods be tested in order to guarantee maximum efficiency and absorption of these nutrients by plants, such as the use of molybdenum (Mo) application via foliar.

The importance of Mo for the biological nitrogen fixation (BNF) process was first described by Bortels [2], who demonstrated that *Azotobacter vinelandii*, when inoculated in a culture medium without N, required Mo to grow, a fact that did not occur if the source of N in the culture medium was ammonium, that is, in a medium where N was present, the bacteria did not need Mo to synthesize assimilates.

In soil, in general, the amount of Mo is in the range of 0.5 to 5.0 mg kg^{-1}, occurring in soluble form at soil solution, adsorbed in colloidal fraction, retained in the crystalline network of primary minerals and chelated to organic matter [3].

The Mo participates in two factors of nitrogen metabolism that are of utmost importance for plants of the Fabaceae family: it participates in nitrate reductase (NO^{-3}), in which this element is reduced to nitrite (NO^{-2}), as well as nitrogenase, a process in which nitrogen-fixing bacteria convert dinitrogen gas (N_2) into ammonia (NH_3) [4], Mo synthesizes enzymes for the fixation of atmospheric nitrogen.

As with other nutrients, soil pH may also influence the availability of Mo for plants, being low at acidic pH (5.0 to 5.5) and high at pH levels greater than 7.0 [5].

Taking into account the importance of Mo in BNF and all the possibilities of this micronutrient not being available to plants, it may be seen that at at region where the experiment was conducted, the Red Latosol presents in majority of agricultural areas is rich in iron and/or aluminum oxides with low pH (4.0 to 5.5) witch means ideal conditions for unavailability of Mo, thus being necessary to add at system by seed treatment and/or via foliar application.

Thus, the objective of the work was to evaluate the development and yield of beans with foliar application of Molybdenum.

2. MATERIAL AND METHODS

The experiment was performed at the Experimental Farm of the Grand Dourados Federal University, at the municipality of Dourados, MS, Brazil. The experimental location is located at latitude 22º14’08” S, longitude 54º59’13” W and altitude of 434 m. The climate, according to the Koppen classification, is Cwa and the soil is a Dystroferric Red Latosol [6]. Average temperature and precipitation data during the experiment period are described in Figure 1.

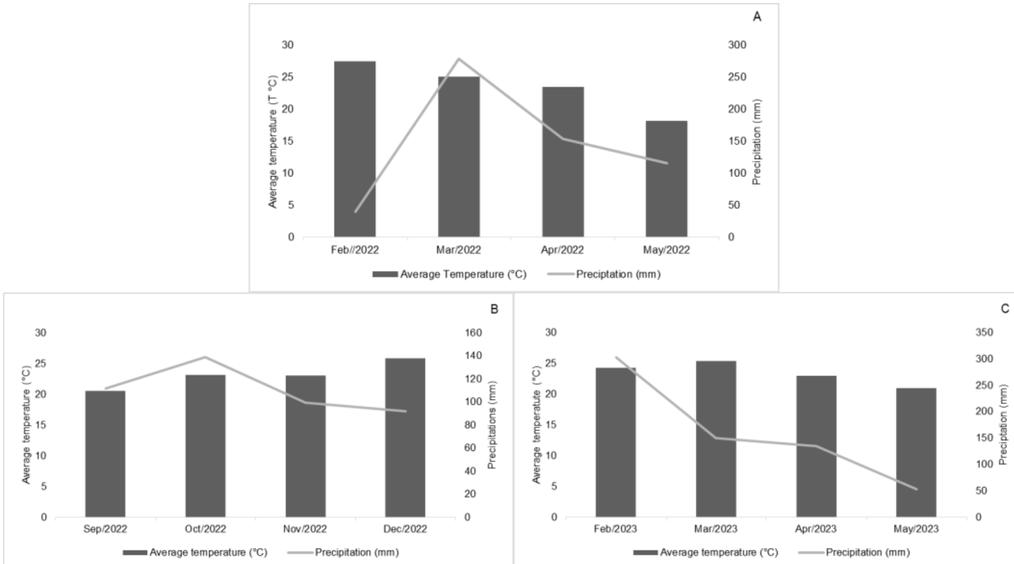


Fig. 1. Monthly average temperature and precipitation accumulation during the growing seasons; A: 2022 dry season; B: 2022 rainy season; C: 2023 dry season.

The experiment was conducted in randomized blocks in a 2 x 4 x 3 factorial scheme (sowing season x doses x application time), with treatments consisting of two sowing times: autumn/winter (sowing in February - dry season) and spring/summer (sowing in October - rainy season), four Mo doses (0, 50, 150 and 300 ml ha^{-1} of commercial Mo based product) and three application times, starting the count after 50% plant emergence (10 days after emergence - DAE, 20 DAE and 30 DAE).

The Mo source was a commercial product with a concentration of 216 g L^{-1} Mo. Black beans were sown using a conventional procedure, with soil preparation by subsoiling, harrowing and leveling. A pneumatic seeder was used with a spacing of 0.45 m, 12 seeds per meter of furrow, in plots of 5 x 5 m, totaling 10 plants per meter, a population of 222,222 plants ha^{-1} and depth of 0.02 m.

Fertilization was performed in the seeding furrow in all plots, regardless of treatment with 250 kg ha^{-1} of 08-28-16 formulation. For topdressing, 60 kg of N ha^{-1} was applied (urea will be used as N source). Molybdenum was applied using a CO_2 backpack sprayer with a "fan" spray tip, applying a spray volume equivalent to 200 L ha^{-1}. Molybdenum application times were repeated each season for comparison.

During the crop cycle, phytotechnical practices were carried out according to necessity, such as: control of weeds, diseases and insect pests. For this, specific products were used for each case, aiming to obtain the best crop development.

For the agronomic evaluations, five plants per plot were collected at the end, when the crop reached physiological maturity, in the central line, for the following determinations: number of pods per plant: all pods with seeds were selected and divided by the number of plants evaluated; number of seeds per plant: the pods obtained in the previous evaluation were manually threshed and counted. The value obtained was divided by the number of plants evaluated to obtain the number of seeds per plant; number of seeds per pod: was calculated by dividing the number of seeds per plant by the number of pods per plant; mass of a thousand seeds: 8 samples of 100 seeds per plot were selected and weighed on a precision scale (0.01 g) and yield (kg ha^{-1}): two central lines of 1 m in length were harvested, from which the pods were removed, threshed, and these grains were weighed, extrapolating in kilograms per hectare. Both the mass of a thousand seeds and yield had their moisture corrected to 13%.

The results were subjected to analysis of variance using the F test ($P<0.05$) and the means were compared using the Tukey test, at 5% probability. The molybdenum doses and application times were analyzed using polynomial regression.

3. RESULTS AND DISCUSSION

The statistical analysis showed significant effects for evaluated characteristics, both for Molybdenum doses, application times and seasons.

Regarding the number of seeds per pod (Figure 2), it was observed that there was a significant difference, only for 2022 dry season, for Mo application times, with a quadratic trend for regression analysis in which at 10 days after emergence (DAE) an average of 4.7 seeds per pod was observed; there was a reduction at 20 DAE and a subsequent increase at 30 DAE.

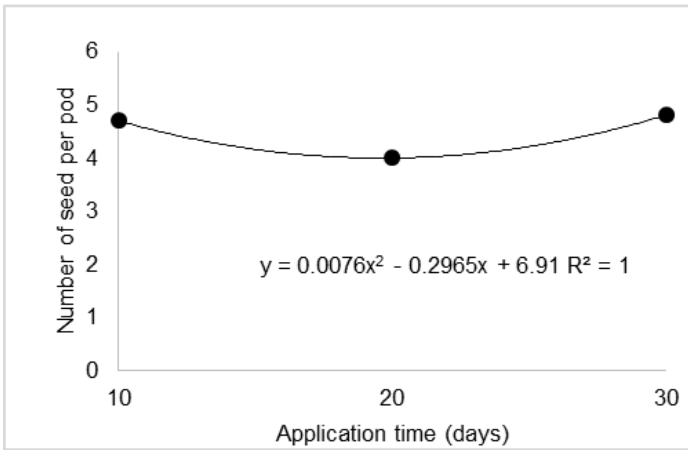


Fig. 2. Average number of seeds per black-bean pod with foliar application of Molybdenum at different application times at 2022 dry season.

Oliveira et al. [7], when working with beans, obtained a greater number of pods and consequently greater yield with the application of molybdenum. According to Kubota et al. [8], the effect generated by Mo doses is due to the fact that this element is a constituent of the nitrogenase enzymes, responsible for the conversion of atmospheric nitrogen into ammonia, and nitrate reductase, which acts in the assimilation of N, essentially in the reduction of nitrate to nitrite.

The justification for the increase in N accumulation in the aerial part may be justified by the increase in the efficiency of biological nitrogen fixation (BNF) due to the application of Mo. Epstein and Bloom [4] mention that N is the nutrient that is directly related to the increase in plant biomass production, as observed by Souza et al. [9], for soybean and Xavier et al. [10] for cowpea.

Therefore, the accumulation of biomass that generates a greater number of pods is directly related to the greater production of grains per pod, which will result in greater production due to the greater allocation of nitrogen for grain production. As nitrogen is absorbed in greater quantities by bean plants, approximately 50% of the total N absorbed is exported to seeds [11].

The weight of a thousand seeds (WTS) showed significant results with the application of Mo in the three sowing seasons. In the 2022 dry season (A) at a dose of 0 mL ha^{-1} (control), the WTS was 143.43 g and increased to 145.72 g at a dose of 50 mL ha^{-1} and subsequently there was reduction in mass (Figure 3A).

In Figure 3B and 3C, the regression curves showed similarities with an increase in mass gain at a dose of 150 mL ha^{-1} and decline with higher doses, demonstrating that even in different harvests, the application of Mo provides mass accumulation up to a certain applied concentration.

As the rainfall levels and average temperature of each harvest were different (Figure 1), it was possible to observe that in the dry harvest (C) with less precipitation distributed between February to May, the masses were greater compared to the others.

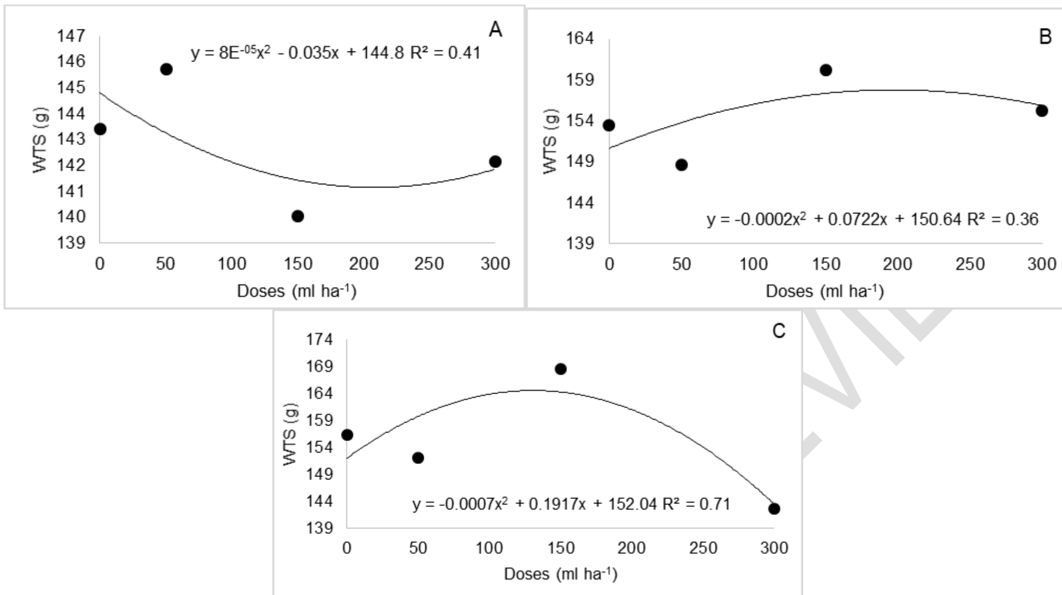


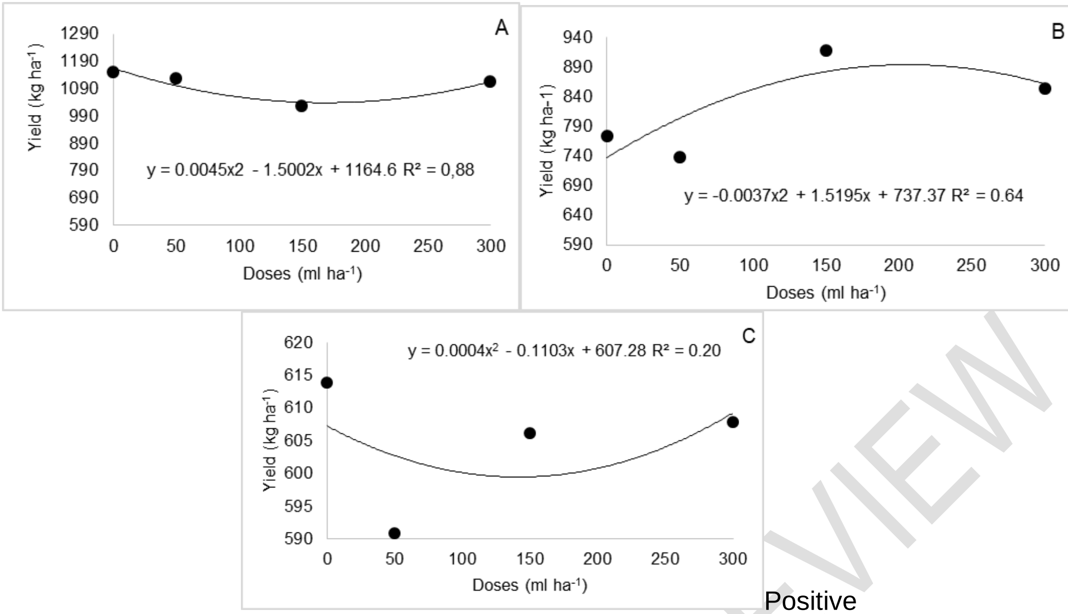
Fig. 3. Weight of a thousand seeds (WTS - g) of black-beans with Molybdenum via foliar application at different application times. A: 2022 dry season; B: 2022 rainy season; C: 2023 dry season.

Some authors state that even in small concentrations, the presence of Mo in this legume promotes better expressivity of agronomic variables [12].

The process of acetylene reduction and N remobilization at the time of grain development occurs due to the participation of Mo, which results in greater mass accumulation in grains [13]. The dose of 150 mL ha^{-1} promoted greater WTS due to NBF in which the plant obtained greater use of atmospheric N.

Therefore, smaller masses was observed in the 2022 dry harvest and even smaller in the 2022 rainy harvest (Figure 3A and 3B) due to the heavy rainfall in the period close to harvest (Figure 1), which is the time of physiological maturation. The excess water in this period may impair the maturation, harvesting and pods drying, significantly affecting the grain yield. According to Conceição et al. [14], excess water in the maturation period may generate intense enzymatic degradation and consequently reduction in grain mass.

Regarding the yield (Figure 4), the molybdenum doses showed significant results in the three sowing seasons, demonstrating that there was nonconformity between harvests due to climatic factors. Therefore, the effects of the doses were also different in the harvests, as in the two dry harvests the highest averages were 1,150.29 kg ha^{-1} (A) and 613.89 kg ha^{-1} (C) at control, however, compared to the rainy harvest (B) they were 918.88 kg ha^{-1} at the dose of 150 mL ha^{-1}, thus, the effects of the doses were greater in crops with better rainfall distribution.



Positive

Fig. 4. Black-bean yield (kg ha^{-1}) at different doses of Molybdenum via foliar application. A: 2022 dry season; B: 2022 rainy season; C: 2023 dry season.

According to the precipitation data (Figure 1), it may be seen that the availability of water during the cycle did affect yield between harvests, but it was also what most influenced the results of the doses (Figure 4), demonstrating that in the harvest that had better rainfall distribution, molybdenum was more active in the plants, generating a difference in grain production.

This may have possibly occurred due to N stress caused by the reduced amount of water in the soil, making it difficult to absorb the nutrient made available in fertilization, and because there is no synchronization between the period of nitrogen depletion in the cotyledons and the beginning of N_2 fixation, as in bean plants this period is around 15 to 20 days after emergence [15].

Due to the delay in N absorption, it can directly affect the flowering and grain filling period, as the demand for this nutrient is very high [16]. According to Rosolem [17], good plant nutrition should be carried out at a time that can increase the number of pods per plant, which would be until the beginning of flowering.

As with the weight of a thousand seeds (Figure 3) and the number of seed per pods (Figure 2), the accumulation of mass is directly related to yield, making plants have greater availability during the reproductive period and grain formation, as 60% of the accumulation of N during the bean cycle is absorbed and metabolized between the flowering and grain filling stages [18].

In relation to the average yield of the Central West region of Brazil, the three harvests were lower, considering that they were cultivated in the dry harvests of 2022 and 2023; and in the rainy harvest of 2022, where the region's productions were 992.00 kg ha^{-1}, 1,239.00 kg ha^{-1}, 2,263.00 kg ha^{-1} respectively [1].

4. CONCLUSION

Positive results in yield components and effective yield of black beans were found when 50 mL ha-1 of molybdenum was applied via foliar application.

Although it was not one of the objectives of the study, it was concluded that the amount of rainfall in the crop cycle affects the action of molybdenum on bean plants.

Disclaimer (Artificial intelligence)
Option 1:
Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.
Option 2:
Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology
Details of the AI usage are given below:
1.
2.
3.

REFERENCES

1. Conab - Companhia Nacional De Abastecimento (2024). V. 6 - SAFRA 2023/24 - N. 12 – Decimo segundo levantamento agosto de 2024. Accessed 20 August 2024. Available: https://www.conab.gov.br/info-agro/safras/graos.
2. Bortels H. Molybdän als Katalysator bei der biologischen Stickstoffbindung. Archives of Microbiology. 1930; 1():333-342. Germany.
3. Marcondes JAP. Nodulação e absorção de nitrogênio pela soja em resposta à aplicação de cobalto e molibdênio. 2001. 47 f. Dissertação (Mestrado em Agronomia) – Universidade Federal do Paraná, Curitiba; 2001. Portuguese.
4. Epstein E, Bloom AJ. Nutrição mineral de plantas. 2nd ed. Londrina: Planta; 2006. Portuguese.
5. Abreu CA, Lopes AS, Santos GCG. Micronutrientes. In: Novais RF, Alvarez VVH, Barros NF, Fontes RLF, Cantarutti RB, Neves JC, editors. Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo; 2007. Portuguese.
6. Embrapa - Empresa Brasileira De Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 3th ed. Brasília: Embrapa; 2013. Portuguese.
7. Oliveira CAB, Pelá GM, Pelá A. Inoculação com Rhizobium tropici e adubação foliar com Molibdênio na cultura do feijão comum. Revista de Agricultura Neotropical. 2017;4(1):43-50. Portuguese.
8. Kubota FY, Andrade Neto AC, Araújo AP, Teixeira MG. Crescimento e acumulação de nitrogênio de plantas de feijoeiro originadas de sementes com alto teor de molibdênio. Revista Brasileira de Ciência do Solo. 2008;32():1635-1641. Portuguese.
9. Souza RA, Hungria M, Franchini JC, Chueire LMO, Barcellos FG, Campo RJ. Conjunto mínimo de parâmetros para avaliação da microbiota do solo e da fixação biológica do nitrogênio pela soja. Pesquisa Agropecuária Brasileira. 2008;43(1):83-91. Portuguese.
10. Xavier TF, Araújo ASF, Santos VB, Campos FL. Influência da inoculação e adubação nitrogenada sobre a nodulação e produtividade de grãos de feijão-caupi. Ciência Rural. 2008;38(7):25-32. Portuguese.
11. Soratto RP, Carvalho MAC, Arf O. Nitrogênio em cobertura no feijoeiro cultivado em plantio direto. Revista Brasileira de Ciência do Solo. 2006;30(2):259-265. Portuguese.

12. Kamicker BJ, Brill WJ. Identification of Bradyrhizobium japonicum nodule isolates from Wisconsin soybean farms. Applied and Environmental Microbiology. 1986;51(3):487-492.
13. Vieira RF, Cardoso EJBN, Vieira C, Cassini STA. Foliar application of molybdenum in common beans. I. Nitrogenase and reductase activities in a soil of high fertility. Journal Plant Nutrition. 1998;21(1):169-180.
14. Conceição CG, Robaina AD, Peiter MX, Parizi AC, Conceição JA, Bruning J. Economically optimal water depth and grain yield of common bean subjected to different irrigation depths. Revista Brasileira de Engenharia Agrícola e Ambiental. 2018;22(7):482-487. Portuguese.
15. Barradas CA, Hungria M. Seleção de estirpes de Rhizobium para o feijoeiro. I. Precocidade para nodulação e fixação de nitrogênio. Turrialba. 1989;39(2):236-242. Portuguese.
16. Portes TA. Ecofisiologia. In: Araújo RS. et al. (Coords.). Cultura do feijoeiro comum no Brasil. Piracicaba: Potafós, 1996. p. 101137. Portuguese.
17. Rosalem CA. Nutrição e adubação do feijoeiro. Piracicaba: 1987.p 93. Portuguese.
18. Hungria M, Neves MCP, Victoria RL. Assimilação do nitrogênio pelo feijoeiro. II. Absorção e translocação do N mineral e do N2 fixado. Revista Brasileira de Ciência do Solo. 1985;9(1):201-209. Portuguese.