Maize crop response to different levels of mineral and organomineral fertilization associated with plant growth promoting bacteria (PGPBs)

Resposta da cultura do milho a diferentes níveis de adubação mineral e organomineral associada à bactérias promotoras do crescimento de plantas (BPCPs)

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Fabrício Resende de Aguiar
PhD student in the Post-Graduation Program in Plant Production
Institution: Universidade Federal dos Vales do Jequitinhonha e Mucuri
Address: Campus JK, MGT 367, Km 583, Nº 5000, Alto da Jacuba, Diamantina - MG,
CEP: 39100-000
E-mail: fabricio.resende@ufvjm.edu.br

André Cabral França
Doctor of Phytotechnology
Institution: Universidade Federal de Viçosa
Address: Campus JK, MGT 367, Km 583, Nº 5000, Alto da Jacuba, Diamantina - MG,
CEP: 39100-000
E-mail: cabralfranca@gmail.edu.br

Miguel Henrique Rosa Franco
Doctor in Agronomy
Institution: Universidade Federal de Uberlândia
Address: Av. João Naves de Ávila, 2121, Santa Mônica, Uberlândia - MG,
CEP: 38408-100
E-mail: miguelmhrf@yahoo.com.br

Júlio Eduardo Santana Maia
Agronomist Engineer
Institution: Universidade Federal de Uberlândia
Address: Av. João Naves de Ávila, 2121, Santa Mônica, Uberlândia - MG,
CEP: 38408-100
E-mail: julioesmaia@hotmail.com

Nathalia Oliveira de Araújo
Agronomy undergraduate student
Institution: Universidade Federal de Uberlândia
Address: Av. João Naves de Ávila, 2121, Santa Mônica, Uberlândia - MG,
CEP: 38408-100
E-mail: natyaraugo2008@hotmail.com
ABSTRACT
Corn has a high nutritional requirement, especially with regard to NPK fertilization. However, the low efficiency of conventional fertilizers combined with the high cost of the input has limited the reach of high yields. The use of fertilizers with increased efficiency seeks to mitigate these limitations, reducing potential losses due to the gradual release of nutrients. The objective of this work was to compare the nutrition, growth and production of maize plants subjected to different doses and special NPK fertilizers fully applied at planting, as well as their residual effect on the soil. A randomized block design was used, in a 3 x 4 factorial scheme, with four replications. The first factor consisted of conventional mineral, polymer coated and organomineral fertilizers inoculated with PGPBs. The second factor was doses of 0, 60, 90 and 120 kg ha⁻¹ of NPK. Vegetative growth, foliar nutrition (N, P and K), yield growth components, productivity, profitability and P and K nutrient content remaining in the soil after cultivation were evaluated. The conventional mineral fertilizer presented higher production of dry biomass of the aerial part and profitability in relation to the special fertilizers. However, the special fertilizers presented better results in the vegetative and productive growth, in general, still showing a potential reduction of the applied doses, without compromising the grain yield, especially in the organomineral fertilization + PGPBs. The same showed greater residual effect of K in the soil, proving to be relevant longterm studies for better elucidation of these effects in the soil and subsequent culture.

Keywords: bacillus, controlled release, slow release, organomineral, polymer, zea mays.

RESUMO
O milho representa um dos cereais de maior importância econômica e social do mundo, e a cultura é altamente responsiva à adubação NPK. Neste âmbito, buscando-se atingir altos índices de colheita, a adubação com fertilizantes de eficiência aumentada tem ganhado campo na pesquisa e no mercado, assim como a utilização de bioinoculantes à base de bactérias solubilizadoras de fosfato/promotoras do crescimento de plantas (BPCPs). Contudo, existem poucos relatos sobre os efeitos destas tecnologias associadas. Dessa forma, objetivou-se com este trabalho avaliar plantas de milho submetidas à adubação com fertilizantes mineral, organomineral e organomineral inoculado com BPCPs (OM+BPCPs), nas doses de 0, 50, 75 e 100% da recomendação de P e K para a cultura. As plantas de milho responderam positivamente ao aumento das doses de P e K, apresentando plantas com maior altura, biomassa fresca e seca da parte aérea, QGF, PMG e produtividade de grãos sob aplicação de 100% da dose recomendada. Não houve diferença estatística entre os tratamentos organomineral e mineral. Contudo, a aplicação do OM+BPCPs acarretou em incrementos significativos.
sobre todas as características vegetativas e produtivas das plantas de milho em comparação ao fertilizante mineral, demonstrando efeito potencializador dos microrganismos sobre a adubação NPK.

**Palavras-chave**: bacillus, liberação controlada, liberação lenta, organomineral, polímero, *zea mays*.

## 1 INTRODUCTION

Corn (*Zea mays* L.) is considered worldwide as a staple crop for human consumption and animal fodder. It is considered a highly responsive plant to fertilization, which often creates an expensive dependence on chemical fertilizers in order to obtain high yields (RANUM; PEÑA-ROSAS; GARCIA-CASAL, 2014).

However, excessive applications of mineral fertilizers associated with their high potential for soil losses can lead to environmental risks such as the eutrophication of soil and surface and groundwater, in addition to the emission of greenhouse gases (DUNGAIT *et al*, 2012; MARKS *et al*, 2013). Furthermore, the partial supply of nutrients required by the plant can compromise development and, consequently, reflect on the yield obtained at the end of the crop cycle (VALDERRAMA; BUZETTI, 2017).

To increase the sustainability of agricultural systems, some farmers, encouraged by researchers, have preferred the use of fertilizers with less environmental impact and greater efficiency in the supply of nutrients, such as organominerals (MOREIRA *et al*, 2017).

Consisting of a mineral matrix coated with biodegradable organic polymer, the organomineral fertilizer has a relatively lower reactive chemical potential than the conventional mineral, gradually releasing nutrients, which reduces potential losses, in addition to supplying the crop throughout its cycle (PROFIRO, 2015).

The addition of bioinoculants containing Plant Growth-Promoting Bacteria (PGPBs) to organomineral fertilizers constitutes a promising strategy to improve the mentioned technology, given the fundamental role of microorganisms in agriculture and the viability of the bioinoculants production process. The introduction of microorganisms in the system provides greater sustainability in the production process and savings in the purchase of fertilizers (AGUIAR *et al*, 2021).

The effects of these bacteria on plants are broad, with the potential to stimulate plant growth, increase plant tolerance to biotic and abiotic stresses, inhibit
phytopathogens and promote the availability of nutrients through biochemical transformations, including phosphate solubilization (MENDONÇA et al., 2020).

Among these, those of the genus *Bacillus* stand out, especially the species *B. subtilis*, whose benefits have been demonstrated in different crops of economic interest such as soybean (CHAGAS JUNIOR et al., 2022; CHAGAS JUNIOR et al., 2021; OLIVEIRA-PAIVA, 2020), beans (ARAUJO et al., 2010) and cotton (DIAZ, 2018). However, there are few studies on the co-inoculation of organomineral fertilizers with a bioinoculant based on *Bacillus subtilis* and *Bacillus licheniformis*.

**2 MATERIALS AND METHODS**

**2.1 PLACE OF CONDUCTION AND DESCRIPTION OF EXPERIMENTAL TREATMENTS**

The experiment was carried out at Escola Agrotécnica Afonso Queiroz, Campus II of the Centro Universitário de Patos de Minas – UNIPAM, city of Patos de Minas – MG, Brazil, under the geographic coordinates 18°34' S and 46°31' W, at altitude average of 815 m, from November 18, 2020 to April 26, 2021. According to the Köppen classification, the region has a high-altitude tropical climate (Cwa), with average annual precipitation around 1400 mm. The data relating to temperature and average precipitation for the location during the experiment's conduction period are shown in figure 1, using the interval averages of the variables for every ten days.
Figure 1. Precipitation (mm) and tenay averages of maximum, minimum and average temperatures (°C), referring to the months from Nov./20 to Apr./21 in Patos de Minas/MG, Brazil.

For soil sampling, the recommendations of the Minas Gerais State Soil Fertility Commission (ALVES et al, 1999) were followed, which was classified as Clay Red Latosol. Table 1 shows the chemical and physical characterization of the medium before the experiment was implemented in the 0-20 cm depth layer.

Table 1. Initial chemical and physical characterization of the soil.

| Chemical characteristics | pH (H$_2$O) | pH (CaCl$_2$) | Ca$^{2+}$ | Mg$^{2+}$ | Al$^{3+}$ |
|--------------------------|------------|--------------|----------|----------|----------|
|                           | 5.95       | 6.23         | 2.52     | 1.15     | 0.04     |
| H+Al                     | 3.46       | 7.29         | 3.83     | 90.25    | 19.37    |
| Cmol dm$^{-3}$           | 3.87       | 3.70         | 2.15     | 0.20     | 11.50    |
| Solo                     | 63.3       | 76.4         | 3.0      | 52.5     | 1.03     |

| Physical characteristics | Sand | Silt | Clay |
|--------------------------|------|------|------|
|                          | 310  | 406  | 284  |

pH em H$_2$O; Ca, Mg, Al, (KCl 1 mol L$^{-1}$); P, K = (HCl 0.05 mol L$^{-1}$ + H$_2$SO$_4$, 0.0125 mol L$^{-1}$) P available (extractor Mehlich-1); S in calcium phosphate 0.01 mol L$^{-1}$; H + Al = (Buffer Solution – SMP a pH 7.5); Cu, Fe, Mn, Zn = (DTPA 0.005 mol L$^{-1}$ + TEA 0.1 mol L$^{-1}$ + CaCl$_2$ 0.01 mol L$^{-1}$ a pH 7.3) cmol dm$^{-3}$ x 10$^{-3}$ / mg dm$^{-3}$ = ppm / dag kg$^{-1}$ = %; CTC a pH 7.0; V = Base saturation; m = aluminum saturation; M.O. = Colorimetric Method; Texture analysis by the pipette method and chemical analyzes based on (RIBEIRO; GUIMARÃES; ALVAREZ, 1999).
2.2 EXPERIMENTAL DESIGN, DESCRIPTION OF TREATMENTS AND EVALUATIONS

The experimental design was in randomized blocks, under a 3 x 4 factorial scheme, with four replications. The first factor corresponds to three fertilizers, being conventional mineral (10-52-00) and (00-00-60), granulated organomineral (05-26-00 and 00-00-32) and granulated organomineral 05-26 -00 and 00-00-32 with addition of plant growth-promoting bacteria (PGPBs). The second factor concerns the doses of 0, 60, 90 and 120 kg.ha⁻¹ of P₂O₅ and K₂O, based on the recommendation for the corn crop [25].

All sources tested used urea, monoammonium phosphate (MAP) and potassium chloride as mineral raw materials. The organomineral fertilizer used had as organic fraction composted residue from the pulp industry. The chemical composition of the fertilizers used is described in Table 2.

Table 2. Identification of treatments and respective chemical analyzes of each fertilizer.

| Treatment                      | N     | P₂O₅ | K₂O | CO₂ | CTC³ |
|-------------------------------|-------|------|-----|-----|------|
| Conventional mineral 10-52-00 | 10.0  | 52.3 | 0.0 | 0.0 | 0.0  |
| Conventional mineral 00-00-60 | 0.0   | 0.0  | 60.2| 0.0 | 0.0  |
| Organomineral 05-26-00        | 4.9   | 26.5 | 0.0 | 12.2| 420.0|
| Organomineral 00-00-32        | 0.0   | 0.0  | 32.1| 13.1| 296.2|
| OM+PGPBs¹ 05-26-00           | 4.9   | 26.5 | 0.0 | 12.2| 420.0|
| OM+PGPBs¹ 00-00-32           | 0.0   | 0.0  | 32.1| 13.1| 296.2|

¹OM + PGPBs: Organomineral fertilizer inoculated with Plant Growth-Promoting Bacteria; ²COT = Total organic carbon; ³CTC = Cation exchange capacity.

The inoculation of the organomineral source was carried out with spraying of bioinoculant based on *Bacillus subtilis* and *Bacillus licheniformis* using the proportion of 700 mL of bioinoculant for each ton of fertilizer per hectare, with a minimum guarantee of 1x10¹¹ colony forming units (CFU).

Fertilizers containing phosphorus (P) and potassium (K) were applied in the planting furrow. Corn cultivation was carried out in a row, with a spacing of 0.5 cm and population density adjusted to approximately 70,000 plants per hectare. The transgenic maize cultivar VIP 3 KWS was used. The experimental units were composed of 30 m² (3 m x 10 m) with a spacing of 1 meter between blocks.

Topdressing fertilization was performed when the corn plants reached the V4 stage, using conventional urea (45% N) to supply nitrogen, in the equal amount of 400 kg ha⁻¹ for all treatments. The application of micronutrients and phytosanitary management were carried out equally throughout the experimental area.
At 54 days after sowing (DAS), analyzes of the vegetative growth of the corn plants were carried out, removing 10 plants per experimental plot to evaluate the average height of plants (cm) using a graduated ruler; SPAD index, using the portable SPAD-502 meter (Minolta Corporation Ltda.), sampling the central part of the newly expanded and physiologically mature leaf, taking care not to reach the midrib; stem diameter, with the aid of a digital caliper; fresh biomass shoot, weighing the stem and leaves with the aid of a scale.

The plant samples were packed in paper bags and sent to the laboratory for determination of the dry biomass of the shoot. At the end of the crop cycle, at the time of senescence, the ears of 54 plants were removed, corresponding to the three central lines of each plot, in 5 meters of length, using a useful area of 7.5 m² per subplot experimental for evaluation of: number of rows of corn per ear (NRE); length of spikes; quantity of grains per row (QGR); thousand grain weight (TGW), determined from eight repeated counts of 100 grains, weighed on a precision scale (0.001g), with subsequent correction to 13% humidity; productivity and sieve retention test (SRT), performed from a sample of 100 grams of grains subjected to distribution over the set of sieves from 18 to 24 mesh, following the criteria established by RAS (BRASIL, 2009), expressed in percentage.

2.3 STATISTICAL ANALYSIS

Analysis of variance was used to interpret the data, using the F test at 5% probability. The significant interaction was broken down, using Tukey's test ($p < 0.05$) for the comparison of means between sources, and regression analysis for fertilizer doses, with model selection based on its significance, in the biological phenomenon and in the coefficient of determination ($R^2$).

Thus, the objective of this work was to evaluate the effect of different doses of mineral and organomineral fertilizer, inoculated and not inoculated with plant growth-promoting bacteria, on the growth and production of corn plants carried out in the field.

3 RESULTS

3.1 VEGETATIVE GROWTH

The plants responded positively to the increase in the P and K doses for all evaluated traits, regardless of the fertilizer used, adjusting to the quadratic polynomial model. There was a significant effect ($p < 0.05$) of the interaction between the factors
(fertilizers x doses) on the vegetative characteristics plant height, fresh biomass and dry biomass of the shoot. The SPAD index was only influenced by the different fertilizer sources. For the other characteristics, no significant statistical difference was observed between the evaluated managements.

3.1.1 Spad index

The SPAD index of corn plants was influenced only by the different fertilizer sources tested (Table 3). The treatment OM + PGPBs presented better results for the variable in question in relation to the conventional mineral fertilizer. However, organomineral fertilizers did not differ statistically from each other. The mineral, organomineral and OM + PGPBs fertilizations reflected an average SPAD index of 50; 53 and 55 units, respectively.

Table 3. SPAD index of corn plants grown in Patos de Minas - MG, in the 2020/21 crop, under application of different fertilizers containing P and K in the planting furrow.

| Fertilizer                      | SPAD   |
|--------------------------------|--------|
| Mineral                        | 49.77 b|
| Organomineral                  | 52.98 ab|
| Organomineral + BGPBs          | 55.04 a|
| CV (%)                         | 10.09  |

* Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% significance.

3.1.2 Plants height

There was an increase in the mean values for the trait as the P and K doses were increased, reaching 2.36; 2.44 and 2.51 m under supply of 120 kg.ha⁻¹ of P and K through mineral fertilizer, organomineral and OM+ PGPBs, respectively (Figure 2). Fertilization resulted in gains of around 6.8; 9.4 and 11.1% in the plots submitted to mineral, organomineral and OM+PGPBs fertilization, in the following order, in relation to zero dose, without fertilization.

Comparing the effect between the different fertilizers, the supply of 120 kg ha⁻¹ of P and K through the organomineral fertilizer inoculated with microorganisms promoted better results for the trait in relation to conventional mineral fertilization. However, there was no significant difference from the non-inoculated treatment for the dose in question.

The results obtained with the application of 90 kg ha⁻¹ of P and K through the organomineral fertilizer, inoculated or not with microorganisms, were superior to those
obtained for the mineral treatment. The nutrient supply reduced to 60 kg ha\(^{-1}\) of P and K did not lead to significant differences for plant height when comparing the different sources.

Figure 2. Height of corn plants grown in Patos de Minas - MG, in the 2020/21 crop, under application of different doses and fertilizers containing P and K in the planting furrow. * Means followed by the same letter for fertilizers within each dose do not differ from each other by the Tukey test at 5%. (cv = 3%).

3.1.3 Fresh shoot biomass

The highest accumulations of fresh shoot biomass were observed in the application of 120 kg ha\(^{-1}\) of P and K for all fertilizers. However, the OM + PGPBs treatment provided higher production of fresh shoot biomass when compared to the mineral treatment for all P and K supply levels studied. The same was observed for the organomineral fertilizer without inoculation, with the exception of the application of 60 kg ha\(^{-1}\) of P and K, in which no significant difference was observed between the inoculated and non-inoculated organomineral treatment.

There was an increase of 13.9 and 18.4% in the production of fresh mass of plants fertilized with organomineral and OM+PGPBs compared to mineral fertilizer, respectively, under the highest level of P and K tested (120 kg ha\(^{-1}\)). The dose reduction to 90 kg ha\(^{-1}\) of P and K resulted in a reduction of 5.2; 6.2 and 8.1% in the production of
green matter under OM+PGPBs, organomineral and mineral fertilization, in the order described. The application of 60 kg ha\(^{-1}\) reflected in decreases in the values of the variable of 13.4; 13.9 and 15.5% for the OM + PGPBs, organomineral and conventional mineral treatments, respectively.

The organomineral fertilizers showed the potential to reduce the P and K dose by up to 17 to 22%, essentially or inoculated with PGPBs, in that order, without compromising the production of fresh biomass of the shoot of the corn plants in relation to conventional mineral fertilization under application at recommended level (Figure 3).

Figure 3. Fresh biomass of the shoot of corn plants cultivated in Patos de Minas - MG, in the 2020/21 crop, under application of different doses and fertilizers containing P and K in the planting furrow. * Means followed by the same letter for fertilizers within each dose do not differ from each other by the Tukey test at 5%. (cv = 7.23%).

3.1.4 Dry shoot biomass

The production of dry biomass from the shoot of the plants did not differ statistically for the different fertilizers tested (Figure 4). However, it is worth noting that, similarly to the previous characteristic, the organomineral treatments showed greater efficiency in supplying the nutrients under study to increase the values of the variable, since even under application of the lowest dose tested (60 kg ha\(^{-1}\) of P

**Observed Values**

- ● Mineral  
  \[ Y = 622.7743 + 1.6217x + 0.0034x^2 \]  
  \[ R^2 = 0.99 \]

- ○ Organomineral  
  \[ Y = 667.0065 + 3.7711x - 0.0080x^2 \]  
  \[ R^2 = 0.97 \]

- ▲ OM + PGPBs  
  \[ Y = 638.9978 + 5.4934x - 0.0175x^2 \]  
  \[ R^2 = 0.97 \]
and K), results were found for the trait similar to those observed in the mineral treatment under fertilization at the recommended level (120 kg ha\(^{-1}\) of P and K).

Regarding the maximum biomass accumulated in the corn plants for each treatment, the organomineral fertilizers reflected in the production of 515 and 545g, when inoculated and not inoculated, respectively, under a supply of 90 kg ha\(^{-1}\) of P and K. The plots fertilized with conventional mineral fertilizer presented about 486g of dry biomass of the aerial part, corresponding to gains of 21.1% in comparison to the respective control treatment.

The application of 60 kg ha\(^{-1}\) resulted in decreases of 4.9; 6.4 and 11.3% under organomineral, OM + PGPBs and conventional mineral fertilization, respectively.

Figure 4. Dry biomass of the shoot of corn plants cultivated in Patos de Minas - MG, in the 2020/21 crop, under application of different doses and fertilizers containing P and K in the planting furrow. * Means followed by the same letter for fertilizers within each dose do not differ from each other by the Tukey test at 5%. (cv = 9.86%).

3.2 PRODUCTION AND PRODUCTIVITY COMPONENTS

Among the variables analyzed, the amount of grain present in the row of the ear, the weight of a thousand grains and the grain yield were influenced by the doses, as well as by the fertilizers under study.
### 3.2.1 Number of grain rows on the ear, ear diameter and cob diameter

The variables in question were not influenced by the P and K doses tested, only by the different fertilizers. Similar to the SPAD index, it was verified that the fertilizer OM + PGPBs reflected in a greater number of rows of grains in the ear, diameter of the ear and cob of the corn plants compared to mineral fertilization, as shown in Table 4. There was also no statistical difference between the organomineral treatments, inoculated and non-inoculated, for these characteristics.

Table 4. Number of grain rows on the ear, ear diameter and cob diameter of corn plants cultivated in Patos de Minas - MG, in the 2020/21 crop, under application of different fertilizers containing P and K in the planting furrow.

| Fertilizer     | Number of rows | Ear diameter (mm) | Cob diameter (mm) |
|----------------|----------------|------------------|------------------|
| Mineral        | 14.32 b        | 49.86 b          | 28.42 b          |
| Organomineral  | 14.81 ab       | 51.01 ab         | 28.73 ab         |
| OM + PGPBs     | 15.09 a        | 51.73 a          | 29.79 a          |
| CV (%)         | 4.01           | 2.98             | 4.49             |

* Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% significance.

### 3.2.2 Amount of grains present in the ear row

The OM + PGPBs treatment showed better results for the characteristics compared to the conventional mineral at the levels 90 and 120 kg ha\(^{-1}\) of P and K (Figure 5). There was no significant difference between the mentioned treatments in response to the application of 60 kg ha\(^{-1}\) of P and K. The organomineral fertilizer presented intermediate and statistically similar results to the other two sources, for all doses tested.

Plants submitted to organomineral fertilization, with or without previous treatment with microorganisms, produced up to 41 grains per row of corn cobs under the highest P and K dose tested (120 kg ha\(^{-1}\)). The supply of nutrients in the mineral form provided, at the mentioned dose, the production of 38 grains per ear row.

The plants responded positively to the supply of P and K for the trait in question, since increments of 4.8 were observed; 10.8 and 11.8% when using conventional mineral source, organomineral and OM + PGPBs, respectively.
3.2.3 Thousand grain weight

The thousand grain weight variable (TGW) presented a behavior similar to the QGR in response to fertilization with P and K, reaching higher values under the supply of 106 and 120 kg ha\(^{-1}\) of nutrients, for mineral and organomineral fertilizers, respectively. Mineral and organomineral fertilization and OM + PGPBs reflected in estimated TGW of 419, 421 and 447 g, respectively. The supply of P and K reduced by 50% resulted in a decrease in the values of the variable estimated at approximately 2.3; 3 and 10.7% in the values of the variable under mineral fertilization, OM + PGPBs and organomineral, in the respective order (Figure 6).
Figure 6. Weight of a thousand grains of corn plants grown in Patos de Minas - MG, in the 2020/21 crop, under application of different doses and fertilizers containing P and K in the planting furrow. * Means followed by the same letter for fertilizers within each dose do not differ from each other by the Tukey test at 5%. (cv = 4.87%).

3.2.4 Yield

With regard to corn grain yield, plants responded positively to fertilization with P and K up to the highest dose tested (120 kg ha\(^{-1}\)), regardless of the source (Figure 7). The maximum estimated productivity was around 185, 206 and 207 bags (60 kg) of grains, corresponding to the mineral, organomineral and OM + PGPBs treatments, in response to the application of the mentioned dose. Still, in relation to the respective treatments without fertilization, there were increments of 8.5; 15.5 and 16.7% for mineral, organomineral and OM+PGPBs fertilization.

Fertilization with 90 kg ha\(^{-1}\) of P and K did not lead to a statistically significant difference due to the different fertilizers tested, in terms of productivity, with estimates around 180, 190 and 207 bags ha\(^{-1}\) under fertilization. mineral, organomineral and OM + PGPBs.

For the dose reduced to 50% of the P and K recommendation for the crop (60 kg ha\(^{-1}\)), the estimated productivity was 170, 176 and 185 bags ha\(^{-1}\). However, there was a significant difference between OM + PGPBs and conventional mineral fertilizers, with
an increase in corn grain productivity estimated at 17% under application of fertilizer containing plant growth-promoting microorganisms.

Figure 7. Yield of corn grains from plants grown in Patos de Minas - MG, in the 2020/21 harvest, under application of different doses and fertilizers containing P and K in the planting furrow. * Means followed by the same letter for fertilizers within each dose do not differ from each other by the Tukey test at 5% (cv = 6.98%).

4 DISCUSSION

In view of the exposed results, the organomineral source, inoculated or not with plant growth-promoting bacteria (PGPBs), proved to be more efficient compared to the conventional mineral with regard to final commercialization products such as grain and silage production. Taller plants were observed, with a greater contribution of fresh biomass from the shoot (silage), in addition to greater grain yield, in plots submitted to organomineral treatments in relation to conventional mineral.

The technology of coating the mineral matrix with biodegradable organic polymer constituent in the organomineral fertilizer promotes the reduction of the mineralization rate of the nutrients contained in the formulation, in this case P and K. In this way, the release of these nutrients is carried out gradually, reducing potential K losses to the environment by leaching, in addition to preventing the adsorption of phosphorus with oxides present in the soil, since the nutrients will have a shorter time of exposure to the factors that cause losses. In addition, the plant's better nutrition is also
added to the constant supply of nutrients in the face of these effects, increasing the synchronism between the supply and the request of these by the plant throughout its life cycle.

The inoculation of organomineral fertilizers with PGPBs potentiated the effects of fertilization, especially when compared to conventional mineral fertilization. However, significant effects of microorganisms on the production of fresh biomass of the shoot of the plants were also observed at doses of 120 and 90 kg ha\(^{-1}\) of P and K.

These microorganisms have effects on the solubilization of NPK nutrients, in addition to acting in a multifunctional way on the production of enzymes, synthesis of phytohormones and substances that favor the development and protection of plants, acting as plant growth promoters (BASHAN; KAMNEV; BASHAN, 2013).

In this work, a significant positive effect of microorganisms was observed to increase the chlorophyll content in the leaf. The results reinforce the effects of PGPBs in increasing the photosynthetic capacity of the corn plant and, consequently, in its development.

There are reports of an increase in the N content in the leaves of maize plants in detriment of the previous inoculation of the seeds with a bioinoculant based on *Bacillus subtilis*, noting an increase of about 150% when compared to the control. This behavior demonstrates that there is some microbial influence on the availability of this nutrient to the plant (ARAÚJO, 2008).

In addition, among the synthesized phytohormones, auxins constitute one of the main mechanisms in promoting plant growth, especially indole-3-acetic acid (IAA). The biosynthesis of this phytohormone by microbial isolates was found to be more efficient for the plant when compared to the supply of a pure solution of indole-3-acetic acid (PUENTE et al., 2017).

The synthesis of IAA promotes root growth, especially the initiation, elongation and proliferation of root hairs, resulting in greater root mass and, consequently, greater absorption of nutrients by the plant, given the stimulation of the root system (HUSSAIN et al., 2015; PUENTE et al., 2017). Thus, there is greater exploitation of soil volume by the roots and, consequently, greater absorption of water and nutrients by the plant.

In addition, the *Bacillus* species used are considered phosphate solubilizers, making organic phosphorus available through the release of organic and inorganic acids through the production of phosphatase enzymes. These bacteria also produce
siderophores, organic molecules of low molecular weight that act in the uptake of the iron element that is commonly present bound to P. In this way, these nutrients are released in the ionic form that can be assimilated by the plants and, consequently, in greater absorption, development and crop yield (SOBRAL; OLIVEIRA; SANTOS, 2018).

An increase of about 100.5% was observed in the efficiency of P use by corn plants submitted to microbiological treatment with *Bacillus subtilis* in the seeds, reflecting better results in terms of vegetative development and production components. Grain yield was increased by 39.5% when compared to the treatment without inoculation (PEREIRA et al., 2020).

Studies with off-season corn in northern Paraná, Brazil, demonstrated positive effects of inoculation with *Bacillus subtilis* and *Azospirillum brasilense* on growth and fresh biomass production and grain yield of the crop. An increase in fresh biomass of the shoot of the plants of approximately 15% was verified in the treatment under inoculation with *Bacillus subtilis*, in addition to an increase in productivity of approximately 17% and 14.6% under treatments with inoculation directed to the sowing furrow and in the corn seed, respectively (MAZZUCHELLI; SOSSAI; ARAÚJO, 2014).

The pelleting of corn seeds with strains of *B. subtilis* and *B. megaterium* associated with phosphate fertilization resulted in increases of 13.7% and 6.5% in corn grain yield conducted in Sete Lagoas and Santo Antônio do Itambé, in that order (OLIVEIRA-PAIVA et al., 2020).

In this context, it is assumed that the higher productivity, as well as the potential to reduce P and K doses observed in the OM+PGPBs treatment, is associated with the sum of the effects of the direct and indirect mechanisms of PGPBs together with the release characteristic of nutrients promoted by organomineral technology.

5 CONCLUSIONS

Thus, it is possible to conclude that the corn plants responded positively to the dose of P and K, either in the conventional mineral or organomineral form. The supply through organomineral fertilization promoted results similar to those obtained with the conventional mineral. However, organomineral fertilizer inoculated with plant growth-promoting bacteria (PGPBs) potentiated the effect of fertilization, especially in relation to conventional mineral, resulting in greater development and production of corn plants.
submitted to this treatment, showing a promising alternative to sustainability and reducing dependence on chemical fertilizers.
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