BIOSCIENCE JOURNAL

APPLICATION OF SPECIAL FERTILIZERS AND THEIR EFFECTS ON THE AGRONOMIC ASPECTS OF MAIZE AND SOIL FERTILITY

Fabrício Resende DE AGUIAR[1], André Cabral FRANÇA[2], Miguel Henrique Rosa FRANCO[3], Douglas Pelegrini VAZ-TOSTES[4], Regina Maria Quintão LANA[3], Reginaldo DE CAMARGO[3]

[1] Postgraduate Program in Plant Production, Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina, Minas Gerais, Brazil.
[2] Agronomy Department, Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina, Minas Gerais, Brazil.
[3] Agronomy Department, Universidade Federal de Uberlândia, Uberlândia, Minas Gerais, Brazil.
[4] Agronomy Department, Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil.

Corresponding author:
Fabrício Resende de Aguiar
fabricio.resende@ufvjm.edu.br

How to cite: DE AGUIAR, F.R., et al. Application of special fertilizers and their effects on the agronomic aspects of maize and soil fertility. *Bioscience Journal*. 2023, **39**, e39074. https://doi.org/10.14393/BJ-v39n0a2023-66915

Abstract
Maize has a high nutritional requirement, especially regarding NPK fertilization. However, conventional fertilization with these nutrients presents a high loss potential, mainly by volatilization, leaching, adsorption, and fixation, which may reflect on the development and yield of maize plants. Using fertilizers with increased efficiency seeks to mitigate these limitations, reducing potential losses due to gradual nutrient release. This study aimed to compare the nutrition, growth, and production of maize plants subjected to different doses and special NPK fertilizers fully applied at planting and their residual effect on the soil. It was a randomized block design in a 3x4 factorial scheme with four replications. The first factor consisted of conventional mineral, polymer-coated, and organomineral + PGPB fertilizers. The second factor included doses of 0, 60, 90, and 120 kg ha^{-1} of NPK. The study evaluated vegetative growth, foliar nutrition (N, P, and K), yield growth components, productivity, profitability, and residual K content in the soil after cultivation. The conventional mineral fertilizer produced more dry biomass in the aerial part. Profitability was similar between conventional and special fertilizers. However, the latter performed better overall in vegetative and productive growth, showing a potential reduction of the applied doses without compromising grain yield, especially in organomineral + PGPB fertilization. This treatment also presented a higher residual effect of K on the soil.

Keywords: *Bacillus*. Controlled release. Organomineral. Polymer. Slow release. *Zea Mays*.

1. Introduction

Maize (*Zea mays* L.) is the most-produced cereal in the world (Contini et al. 2019). According to CONAB (2021), the 2021/2022 harvest yielded around 115,223.1 thousand tons of grains in 21,661.2 thousand hectares of the Brazilian territory, with an estimated national average yield of 5,319 kg ha^{-1} of grains. The technological factors required for developing maize yield include soil fertility, nutrition, and fertilization, which significantly represent the sustainability of the activity and profits. An adequate and efficient nutrient supply that is balanced and sufficient to meet the needs throughout the crop cycle is an alternative for maximizing production rates (Coelho et al. 2008).

However, using fertilizers on a large scale excessively and uncontrollably has significant environmental, economic, and energetic consequences. Approximately 40 to 70% of the nutrients applied via conventional soluble fertilizers are lost to the environment by leaching, volatilization, and fixation, causing ecosystem pollution, lower plant absorption, and consequently decreased productivity and financial loss (Valderrama and Buzetti 2017).

Given the high percentage of nutrient losses to the environment when using essentially mineral sources, polymer-coated mineral fertilizers represent an alternative to increase fertilization efficiency. Special fertilizers or even those with improved efficiency consist of a mineral matrix coated with one or more organic or inorganic polymers, delaying nutrient release (Shaviv 2001).

They are generally used in sources coated with inorganic polymers, impermeable or semi-permeable membranes with thin pores (polyurethanes, polyesters, and resins), and mostly slow-release polymers (Shaviv 2001). The higher efficiency, in this case, is due to the structure of the coated fertilizer particles, which solubilize the nutrients inside the capsules when absorbing water from the soil and are later released gradually and controllably through the porous structure in the root zone, according to plant demand (Tomaszewska et al. 2002).

Minerals coated with biodegradable organic polymers are called organominerals. They present a maximum of 20% moisture, at least 8% organic carbon, a minimum CEC of 80 $mmol_c$ kg^{-1}, and a sum of primary nutrients (N, P, and K) of at least 5% (MAPA 2020).

They show a lower rate of nutrient release according to time than conventional mineral sources, providing lower nutrient losses to the environment due to the shorter time of soluble nutrient exposure to elements that cause such potential losses.

They are of slow release, unlike mineral sources coated with inorganic polymers that have a controlled release. Thus, residual nutrients affect soils subjected to organomineral fertilizers, which favor succession crop development and yield (Aguiar et al. 2021).

Besides these fertilizer technologies, using bioinoculants based on plant growth-promoting microorganisms, such as fungi and bacteria, has gained space in the market over the last decade and has been extensively studied to enhance the development and production of different crops (Shen 2021). Studies with isolates (Aguiar et al. 2020) and compounds have been developed with various microbial strains associated with components, such as biochar (Rafique et al. 2019).

Introducing plant growth-promoting bacteria (PGPB) in the environment promoted the solubilization of organic or inorganic phosphorus unavailable to the plant and potassium; the production of phytohormones, enzymes, and siderophores; bioprotection against pathogens; and increased absorption of other nutrients and water by root system stimulation through secondary mechanisms (Radhakrishna et al. 2017; Ribeiro et al. 2018).

Bacillus genus species have stood out in this area by improving the vegetative development and production of different crops (Paiva et al. 2020). Besides the previous direct and indirect effects on plants, inoculants containing *Bacillus* strains are more stable in the environment. That is due to the formation of resistant endospores, allowing an adaptation to extreme climatic conditions, such as temperature, pH, or pesticide exposure. They can also transform exogenous DNA and synthesize enzymes and antibiotics (Bahadir et al. 2018).

The research by Delima et al. (2019) with the inoculation of *B. subtilis* showed beneficial results for bean and maize plants, contributing to vital photosynthetic characteristics under water stress. Furthermore, the responses of each plant species to inoculation were different. Considering the relevance of maize and the potential of these technologies to mitigate the low efficiency of conventional fertilizers, this study aimed to compare the nutritional status, growth, and production of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers with increased efficiency, estimating yield among treatments. The residual K content in the soil was also evaluated.

2. Material and Methods

The study was conducted in the field from November 30, 2020 to April 28, 2021, at Fazenda Santa Julieta, Entre-Ribeiros region, Paracatu, MG, Brazil (latitude -16.970023 and longitude -46.446399, average altitude of 450 m). The area has an Aw climate (savanna) according to the Köppen Geiger climate classification, and it is megathermal, meaning an average temperature above 18°C in all months of the year, with dry winters and rainy summers. The average annual rainfall is approximately 1,400 mm. Figure 1 presents the temperature and average precipitation data for the location during the experiment, using the interval means of the variables for every ten days.

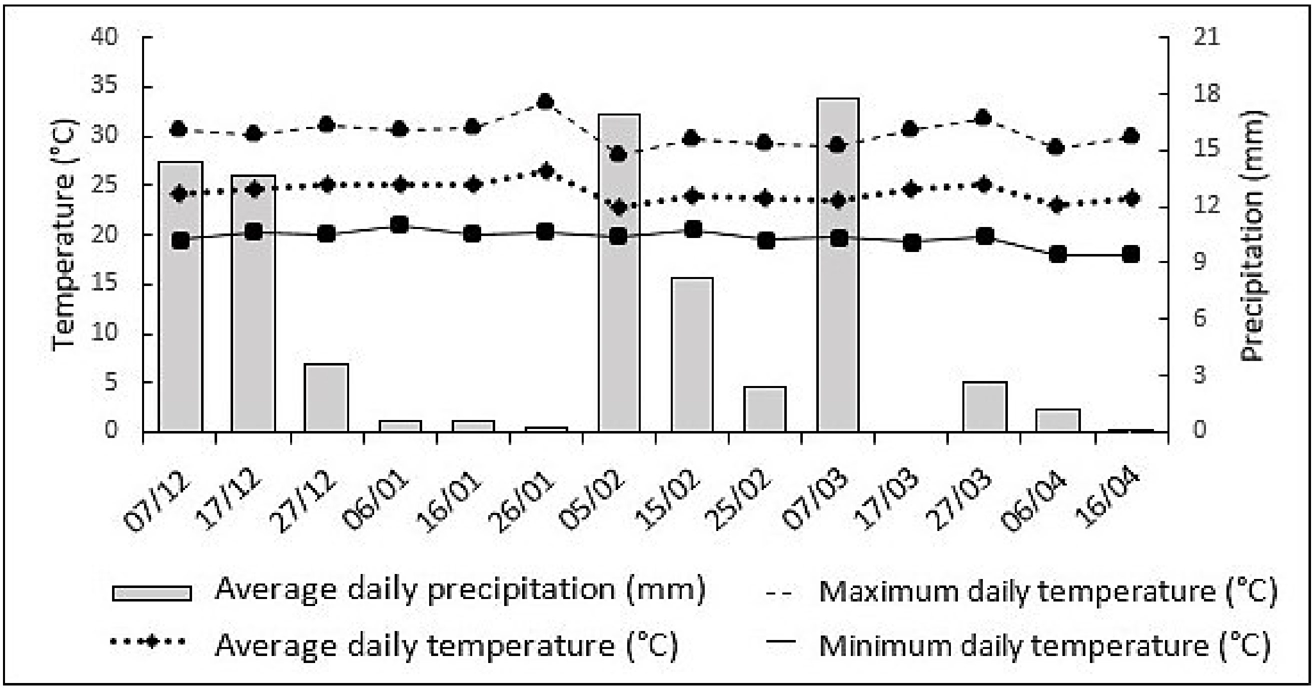

Figure 1. Precipitation (mm) and averages every ten days of maximum temperatures, minimum and average (°C) for the months from Oct./20 to Apr./21 in Paracatu, Minas Gerais.

The soil classification was dystrophic Red-Yellow Latosol (EMBRAPA 2009). Table 1 shows the chemical characterization of the soil before implementing the experiment in the 0-20 cm depth layer.

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

				Chemical					
pH (H_2O)	pH ($CaCl_2$)	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	CEC	SB	K^+	P
----- 01:02.5 -----				----------------------cmol$_c$ dm^{-3}----------------------					mg dm^{-3}
5.7	5.4	3.6	1.18	0.0	2.22	7.23	5.01	0.23	6.3
t	O.M.	O.C.	B	Cu	Fe	Mn	Zn	V	m
cmol$_c$ dm^{-3}	-----dag kg^{-1}-----			----------------mg dm^{-3}----------------				---- % ----	
5.01	2.2	1,3	0,27	0,67	20,0	9,6	1,12	69	0
				Physical					
	Sand			Silt				Clay	
				------------------------- g kg^{-1}-------------------------					
	400			180				420	

CEC: cation exchange capacity (pH 7.0); SB: sum of Bases; t: cation exchange capacity; O.M.: organic matter; O.C.: organic Carbon; V: base saturation; m: aluminum saturation.

The methodologies used for soil analysis were pH (H2O); Ca, Mg, Al, (KCl 1 mol L^{-1}); P, K (HCl 0.05 mol L^{-1} + H2SO4 0.0125 mol L^{-1}); available P (extractor Mehlich-1); H + Al (Buffer Solution – SMP - pH 7.5); and Cu, Fe, Mn, Zn (DTPA 0.005 mol L^{-1} + TEA 0.1 mol^{-1} + CaCl2 0.01 mol L^{-1} - pH 7.3). The texture was analyzed with the pipette method, and chemical analyses were based on EMBRAPA (2009).

The experimental design was randomized blocks in a 3x4 factorial scheme with four replications. The first factor corresponds to three fertilizers: organomineral 08-08-08 plus plant growth-promoting bacteria (OM + PGPB), conventional mineral 18-18-18, and mineral-coated with three layers of special inorganic additives (KimCoat) 15-15-15. The second factor includes the doses of 0, 60, 90, and 120 kg ha^{-1} of NPK based on the volumes practiced by regional maize producers. The organomineral fertilizer contains 14.56% of organic carbon and 408 mmolc kg^{-1} of cation exchange capacity (CTC).

The organomineral source was previously inoculated with bioinoculant spraying based on *Bacillus subtilis* and *Bacillus licheniformis*, at 700 mL of bioinoculant for each ton of organomineral fertilizer and a concentration of $1x10^{11}$ colony-forming units per mL (CFU mL^{-1}).

Nitrogen, phosphorus, and potassium were fully applied to the planting furrow. Maize was cultivated in a row, with a spacing of 0.5 cm, and population density adjusted to approximately 70,000 plants per hectare. The study used the Morgan 30A37PWU transgenic maize cultivar. The experimental units consisted of 30 m² (3 x 10 m) with a spacing of 1 meter between blocks. Micronutrients and phytosanitary management were applied equally across the experimental area.

Forty-eight days after sowing (DAS), at the time of female inflorescence, the entire leaf opposite and below the first upper ear, excluding the midrib (Malavolta et al. 1997), was collected from each plant for foliar chemical analysis of macronutrients. The samples were packed in paper bags and sent to the laboratory to determine the foliar content of N, P, and K, following the methodology by EMBRAPA (2009).

Fifty-eight DAS, the vegetative growth of maize plants was analyzed, removing ten plants per experimental plot to measure average plant height (cm) with a graduated ruler. The SPAD index was determined with the portable SPAD-502 meter (Minolta Corporation Ltda.) and by sampling the center of the newly expanded and physiologically mature leaf without reaching the midrib. The stem diameter was measured with a digital caliper, and the shoot fresh mass was determined by weighing the stem and leaves on a scale.

The plant samples were packed in paper bags and sent to the laboratory to determine the shoot dry mass. At the end of the crop cycle, during senescence, the ears of 54 plants were removed, corresponding to the three central lines of each plot in 5 meters of length. The following data were extracted from a useful area of 7.5 m² per experimental subplot: the number of maize rows per ear (NRE); the length of ears; the number of grains per row (QGR); grain yield in ten plants; the weight of a thousand seeds (WTS), determined from eight count replicates of 100 seeds weighed on a precision scale (0.001g), following the criteria by RAS (Brasil 2009) and subsequent 13% moisture correction; and yield and the sieve retention test (SRT) from a sample of 100 gram of seeds distributed over the set of sieves from 18 to 24 meshes, following the criteria by RAS (Brasil 2009) and expressed in percentages.

The profitability related to each level and type of tested fertilization was calculated from the difference between productivity gains and costs of the evaluated fertilizers. The price of mineral fertilizer was obtained from the price list of March 2022 based on the average of two companies. The organomineral value was provided by AgroCP, and the polymer-coated mineral by Kimberlit, also according to the same list. The cost of fertilizer application to all treatments and the planting furrow was not calculated.

The selling price of maize grains in bulk (60 kg bags) was considered for the revenue difference of maize produced at different doses of the tested sources. Profitability was represented by the difference between gross profit and the cost of the respective treatment.

Finally, to evaluate the influence of fertilizer application on the chemical characteristics of the cultivated soil, a sample was collected from each plot and sent to the laboratory to perform chemical soil analyses according to the methodology by EMBRAPA (2009).

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

3. Results

There was a significant effect for the interaction between fertilizers and NPK doses for plant height, shoot dry mass, leaf N content, the number of grains in an ear row, and grain yield. Then, the interaction was unfolded, investigating NPK doses for each fertilizer. As for the other characteristics (SPAD index, leaf P and K content, shoot fresh biomass, cob length, stem diameter, rows per cob, WTG, SRT, and residual K/T), there was a significant effect only for NPK doses, regardless of the analyzed fertilizer.

Plant height

Plant height increased as fertilizer doses increased to 93, 97, and 110 kg ha-¹ of NPK through polymer-coated, OM + PGPB, and conventional mineral fertilizers, respectively, measuring between 192 and 198 cm (Figure 2).

There were gains of around 45, 46, and 56% in the height of plants fertilized with conventional mineral, polymer-coated, and OM + PGPB fertilizers compared to the respective unfertilized controls.

Shoot dry mass

Conventional mineral fertilization provided higher shoot dry mass production from maize plants than special fertilizers, particularly when applying the recommended NPK dose, producing up to 192.3 g per plant (Figure 3).

Similarly, the plants responded positively to organomineral fertilization inoculated with PGPB up to the highest tested dose, producing 142.5 g of shoot dry biomass. The polymer-coated mineral fertilizer, in turn, was beneficial up to 89 kg ha-¹ of NPK, producing around 145.5 g of shoot dry mass.

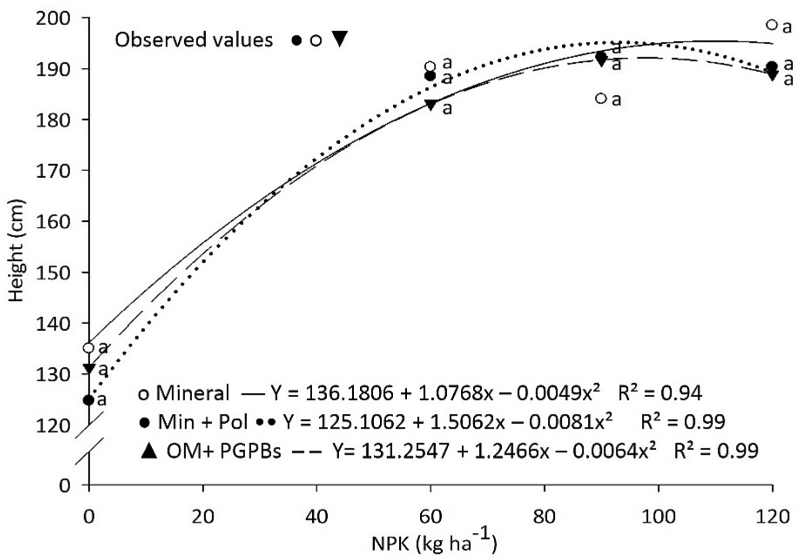

Figure 2. Height of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers. * Means followed by the same letter do not differ statistically by Tukey's test at 5% probability. (cv = 3.68%).

However, the tested fertilizers did not significantly affect the trait at 0, 60, and 90 kg ha-¹ of NPK. Conventional mineral, polymer-coated, and OM + PGPB fertilizers showed 15, 24, and 67% increments compared to unfertilized plots.

Yield

Regarding maize grain yield, there was a positive response from plants up to 77, 106, and 120kg ha^{-1} of NPK applied through polymer-coated, conventional mineral, and OM + PGPB fertilizers, reflecting maximum yields of 96, 97, and 106 bags of grain (60 kg) per hectare, respectively (Figure 4). Grain yield increased by around 33, 44, and 54% for mineral, polymer-coated, and organomineral treatments compared to unfertilized plots.

Organomineral fertilizer application with microorganisms showed higher productivity than conventional or coated treatments at 120 and 90 kg ha-¹ of NPK. The gains represented 10 and 11%, respectively, compared to coated and conventional fertilizers.

There was no significant difference among treatments at applications of 60 kg ha-¹ of NPK. However, when comparing coated and uncoated mineral sources in absolute terms, the grain yield of the conventional mineral fertilizer was 70 kg ha-¹ higher than the polymer-coated source. However, the NPK dose corresponding to the maximum yield from the special fertilizer was 27.4% lower than the uncoated source. Thus, this index represents savings of 29 kg of NPK ha-¹, approximately 1/4 of the recommended NPK amount for the crop, with an approximate difference of one bag of grain (60 kg) using the polymer-coated treatment.

It is worth noting that, when reducing the dose, OM + PGPB yielded approximately 102 bags of grains (60 kg), representing a potential dose reduction without compromising grain yield, as with the polymer-coated mineral fertilizer.

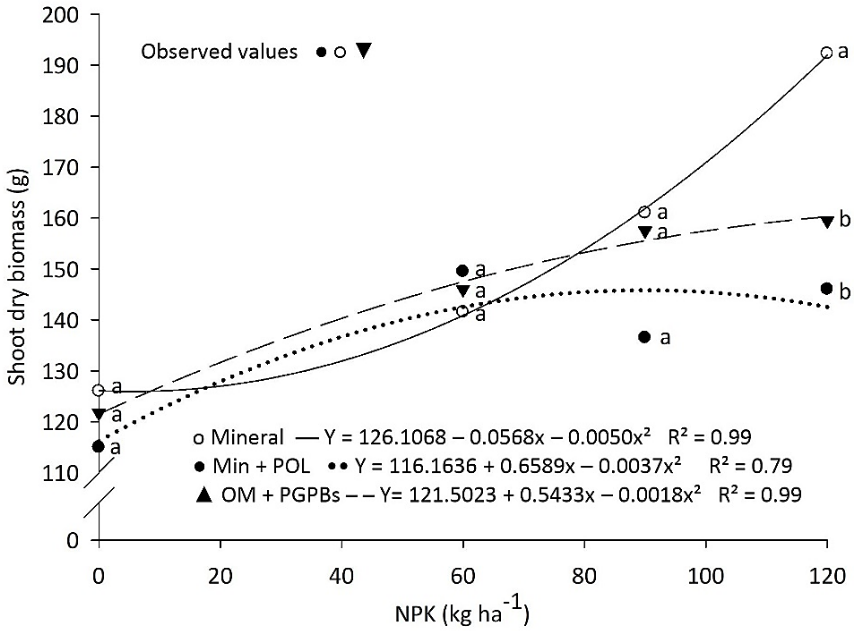

Figure 3. Shoot dry biomass of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers. * Means followed by the same letter do not differ statistically by Tukey's test at 5% probability. (cv = 10.24%).

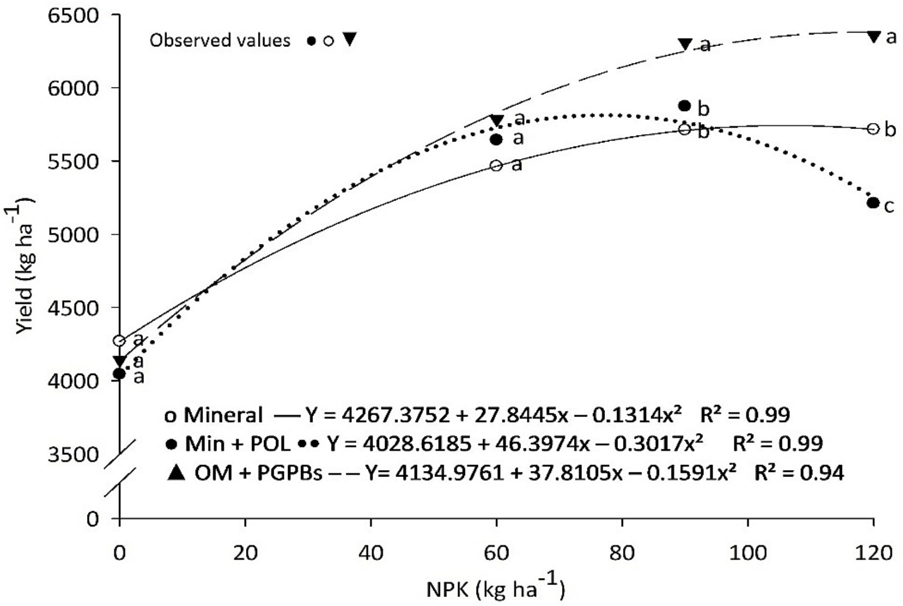

Figure 4. Grain yield of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers. * Means followed by the same letter do not differ statistically by Tukey's test at 5% probability (cv = 3.74%).

Profitability

Although special fertilizers have increased crop harvest rates and gross financial returns, the profitability was similar among the fertilizers, considering their prices in March 2022 (Table 2).

Among the studied NPK doses, applying the recommended amount (120 kg ha^{-1}) of nutrients for the crop provided profits higher than 0, 60, and 90 kg ha-^{1} for all tested fertilizers. However, the maximum estimated profitability for each treatment resulted from the application of 11, 19, and 28 kg ha-^{1} of NPK through mineral, polymer-coated, and OM + PGPB fertilizers, referring to the production of 76, 80, and 85 bags (60 kg) of maize grains, with estimated returns of R$6,486.00, R$6,452.00, and R$6,347.00, respectively. Therefore, the highest yield did not reflect higher profitability, regardless of fertilizer.

Residual potassium

The studied sources and doses significantly affected residual potassium (K) in the soil (Figure 5). The nutrient concentration in the medium increased in response to higher doses, with a quadratic trend for the three analyzed sources.

Table 2. Gross profit and estimated net profit from the cultivation of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers.

Fertilizer	Dose	Dose NPK	Cost	A	B	C
	Kg ha^{-1}	Kg ha^{-1}	R$ ha^{-1}	Bag (60 kg) ha^{-1}	-----R$ ha^{-1}-----	
Mineral (18-18-18)	2269	60	2269	91.1	8210	5941
	3403	90	3403	95.2	8581	5178
	4537	120	4537	95.3	8588	4051
	4008	106*	4008	95.7	8628	4620
	416	2**	416	76.0	6902	6486
Min + Pol (15-15-15)	2696	60	2696	94.0	8478	5782
	4044	90	4044	97.9	8824	4780
	5392	120	5392	86.8	7828	2436
	3458	77*	3458	96.9	8737	5279
	1258	4**	1258	84.9	7710	6452
OM + PGPRs (08-08-08)	2891	60	2891	96.4	8693	5802
	4336	90	4336	105.2	9482	5146
	5781	120	5781	106.0	9554	3773
	5735	119*	5735	106.4	9593	3858
	915	2**	915	79.9	7262	6347

* Dose corresponding to higher estimated productivity; ** Dose corresponding to higher estimated profitability; A - Productivity obtained in the experiment (sc. 60 kg); B - Gross profit per hectare: Price of the grain sack of 60 kg (R$90.16, price sold in March 2022) * Number of bags produced; C - Profitability: (B - cost).

The organomineral fertilizer with PGPB presented higher residual K content in the soil than the conventional mineral treatment at 120 kg ha-^{1} of NPK. However, there was no statistically significant difference for the polymer-coated source. Polymer-coated and uncoated mineral fertilizers presented similar residual K content at all tested doses.

There was up to 0.19, 0.23, and 0.31 cmol$_c$ dm^{-3} of residual K in the soil for conventional mineral, polymer-coated, and organomineral + PGPB fertilization, respectively. The slow-release organomineral fertilizer had a residual effect on the soil compared to the initial content in the soil analysis (0.23 cmol$_c$ dm^{-3} of K), conditioning the replacement of 0.08 cmol$_c$ dm^{-3} of K.

Compared to the previous crop, the slow-release fertilizer promoted plant nutrition and added approximately 62 kg ha-^{1} of K to the soil for succession crop cultivation. The polymer-coated mineral fertilizer, in turn, showed no residual effect because the K content remained the same as the initial one. The amount of K remaining in the uncoated mineral fertilizer was relatively lower than the initial soil condition.

The comparison of residual K content in the soil after maize cultivation to the control plots that were not fertilized but subjected to mineralization of nutritional reserves of the medium throughout the experiment showed increases of around 0.02, 0.06, and 0.11 $cmol_c\,dm^{-3}$ of residual K in the soil at 120 kg of NPK in mineral, polymer-coated, and OM + PGPB treatments. These values represent an additional 16, 47, and 86 kg of residual K ha^{-1} in the soil available for supplying the subsequent crop.

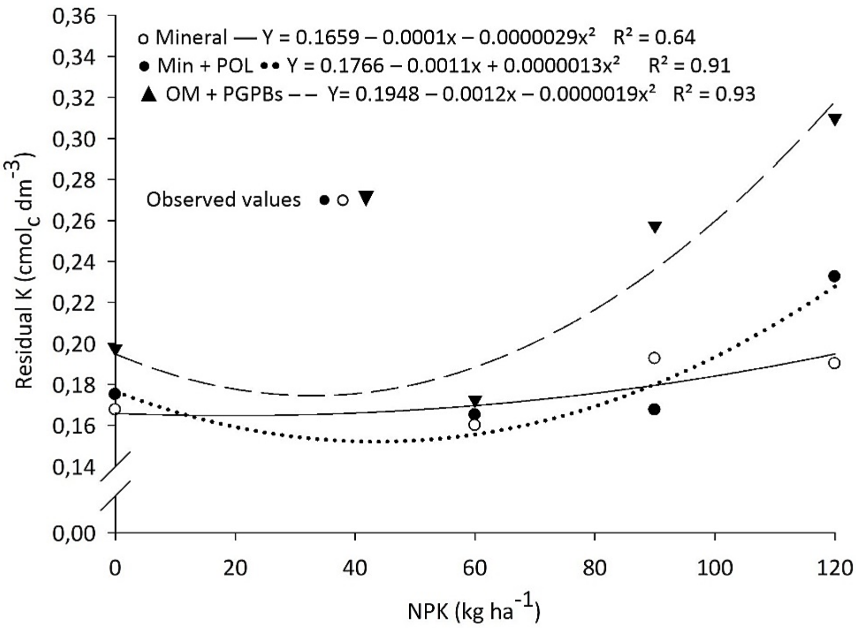

Figure 5. Residual potassium content in soil after cultivation with of maize plants subjected to fertilization applied to the planting furrow at different doses of NPK and mineral fertilizers. * Means followed by the same letter do not differ statistically by Tukey's test at 5% probability (cv = 33.23%).

4. Discussion

The characteristic height of maize plants responded similarly to the tested fertilizations, and variable values increased as NPK fertilization increased to 93, 97, and 110 kg ha^{-1} for polymer-coated, organomineral + PGPB, and conventional mineral treatments, in that order.

Regarding the vegetative development of plants, the fertilizers did not affect fresh biomass production, but the doses did. However, the shoot dry biomass production of plants submitted to mineral fertilization at the recommended dose showed better results than special fertilizer treatments. It is worth noting that vegetative characteristics did not directly reflect on grain yield.

Coelho (2008) points out that N and P nutrient absorption has two phases: maximum absorption during vegetative and reproductive development or ear formation and a lower absorption at tassel emergence and the start of ear formation. Potassium, in turn, has a different pattern than these nutrients, with higher absorption in the vegetative phase and a high accumulation rate (higher than N and P) in the first 30 to 40 days of development. Potassium is a start-up element because the crop requires it at the earliest stages.

The same author also indicates that maize has different periods of intense absorption, with the first occurring in the vegetative stage (V12 - V18) and the second during the reproductive phase or ear formation when reaching the productive potential.

The tested NPK sources were fully applied to the planting furrow. Therefore, the higher accumulation of shoot dry biomass of maize plants in the mineral treatment compared to special fertilizers might have occurred at the expense of the higher nutrient amounts released at the start of crop development. Therefore, applying highly soluble mineral fertilizers to the planting furrow caused fast nutrient availability until the first stage of maximum absorption.

However, special fertilizers present a gradual nutrient availability depending on coating technology. Even though N and K supplies were applied at planting, maximum use may not have occurred in the first phase of maximum nutrient absorption, thus presenting lower shoot dry biomass accumulation than the mineral fertilizer of high solubility. The gradual supply throughout the crop cycle ensured plant nutrition even in later stages, such as in the reproductive period, which showed a second peak of maximum nutrient absorption, promoting higher grain yield at the end of the crop cycle.

Freitas et al. (2021) evaluated maize plant development and yield in response to organomineral and mineral fertilizer applications in planting and coverage. They also found higher production values per area in the organomineral fertilizer treatment in planting and coverage. Similarly, Pereira, Diniz, and Rezende (2020) showed higher ear length and diameter, grains per row, and grain yield of maize plants subjected to organomineral fertilization than soluble fertilizers.

Overall, coated and uncoated mineral treatments and organominerals obtained similar yield responses in this experiment. When comparing the special sources, there was a higher maize grain yield in plots fertilized with organomineral fertilizer inoculated with PGPB than with the polymer-coated mineral treatment, at 90 and 120 kg ha^{-1} of NPK. Although the nutrient release to the soil has not been directly evaluated, Figure 1 shows, from mid-December to the evaluation period, a reduction in nutrient release from the source in question due to low rainfall during that time. Thus, the potential exploitation of grain yield was compromised, presenting results up to 77 kg ha^{-1} of NPK.

Furthermore, a potentiating fertilization effect occurred when introducing PGPB in the environment, using the organomineral fertilizer as a vehicle. Microorganisms use organic carbon (14.56%) composing the organic fraction as a partial energy matrix (Aguiar et al. 2022).

Mazzuchelli, Sossai, and Araujo (2014) found positive effects of *B. subtilis* and *A. braziliense* inoculation on maize growth and production in northern Paraná (Brazil), with a yield increase of up to 17% when applied to the planting furrow. Plant fresh mass increased by approximately 15% in the *B. subtilis* treatment.

The tested PGPB is multifunctional and includes enzymes, hormones, and substances that favor plant development and protection, promote plant growth, and increase the tolerance to abiotic stresses, such as water stress and high temperatures.

Several microorganisms produce chemicals that can improve plant development and production (Scudelleti et al. 2021; Sagar et al. 2022). *Bacillus* genus species promote the biosynthesis of phytohormones and work as biocontrol agents by inducing systemic plant resistance (Radhakrishnan et al. 2017; Lastochkina et al. 2020).

Among the plant growth-promoting phytohormones, indole-3-acetic acids (IAA) production by these microorganisms is more efficient for plant use when synthesized by microbial isolates than the pure IAA solution (Puente et al. 2018).

Additionally, there is the effect of the *Bacillus* species on phosphate solubilization, in which organic and inorganic acid exudation by microorganisms makes the organic P in the soil available. Other mechanisms that make P available are the production of phytase and phosphatase enzymes and low molecular weight molecules called siderophores, which capture Fe associated with the element. Thus, P converts into an ionic form that is plant-absorbable, resulting in better nutrition (Sobral, Oliveira, and Santos 2018).

Paiva et al. (2017) proved the feasibility of spraying inoculants in the planting furrow associated with the organomineral source in a greenhouse. This study showed increments of around 8.9% in maize grain yield compared to organomineral fertilization without microorganisms.

Pereira et al. (2020) showed a grain yield increase of around 39.5% in plants submitted to *Bacillus subtilis* inoculation in the seeds compared to those with uninoculated seeds.

Similar to this study, Paiva et al. (2020) analyzed the effects of pelleting maize seeds with *B. subtilis* and *B. megaterium* strains associated with organomineral phosphate fertilization on plants grown in different locations. There was a significantly higher grain yield in the plots with previously treated seeds, in Sete Lagoas (13.7%) and Santo Antônio do Itambé (6.5%), than the uninoculated ones, reaching 50% compared to the treatment without fertilization.

The maximum estimated profitability for each fertilizer provided better results at low NPK doses (Table 2). This behavior is justified by the high initial chemical soil fertility, as verified in the chemical characterization of the medium (Table 1).

Although special fertilizers promoted higher maize grain yields than conventional chemical sources, their net revenue was lower than conventional mineral treatments. The coating technology of the conventional mineral matrix requires investments, which reflects in the final price of commercialized special fertilizers, with higher costs of these products per hectare.

However, when comparing the residual K content in the soil, the plots fertilized with organomineral + PGPB sources showed better results than with conventional mineral fertilizers at the recommended nutrient amounts for the crop. Therefore, further studies in this area are required, exploring the residual effect of special fertilizers on subsequent crops.

Overall, fully applying NPK nutrients to the planting furrow through special fertilizers was better than conventional mineral fertilizers, even at lower doses, without compromising yield, dismissing coverage fertilization, and reducing operational expenses.

5. Conclusions

Maize producers may use any of the tested fertilizers, as profitability was equal among the sources compared to the dose for maximum estimated profitability.

The organomineral + PGPB fertilizer promoted higher grain yield than the other treatments at all tested NPK doses, except for 60 kg ha^{-1}, which showed no difference for conventional and polymer-coated mineral fertilizers.

There was potential for a reduction of up to 60 kg ha^{-1} of NPK when using polymer-coated and organomineral + PGPB fertilizers without further coverage fertilization or grain yield compromises.

The organomineral + PGPB fertilizer expressed higher residual K content in the soil than conventional and polymer-coated mineral fertilizers.

Authors' Contributions: DE AGUIAR, F.R.: acquisition of data, analysis and interpretation of data, and drafting the article; FRANÇA, A.C.: analysis and interpretation of data and critical review of important intellectual content; FRANCO, M.H.R.: acquisition of data and critical review of important intellectual content; VAZ-TOSTES, D.P.: critical review of important intellectual content; LANA, R.M.Q.: conception and design and critical review of important intellectual content; DE CAMARGO, R.: conception and design and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: The authors would like to thank UFVJM for granting the scholarship and AgroCP for encouraging the research.

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Received: 6 September 2022 | **Accepted:** 13 February 2023 | **Published:** 5 May 2023