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Organomineral fertilizer as an alternative for increasing potato yield and quality[1]

Fertilizante organomineral como alternativa para aumentar a produtividade e qualidade da batata

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HIGHLIGHTS:

Organomineral fertilizer improves the potato quality and yield.
Potatoes accumulate higher contents of K > N > P in leaves, stems, and tubers.
Potato quality is correlated with nutrient accumulation in the plant.

ABSTRACT: Organomineral fertilizer has great potential to replace synthetic fertilizers. The goal of this study was to determine an optimal substitution rate of organomineral fertilizer for mineral fertilizer to increase potato yield and quality. The experimental design was a randomized complete block with four replicates and six treatments, namely four substitution rates of organomineral fertilizer application (25, 50, 75, and 100% of mineral fertilizer demand), one rate of mineral fertilizer application (100% of mineral fertilizer demand), and the control (no fertilizer application). The organomineral application rates were tested as an alternative to substitute 25 to 100% of mineral fertilizer. The potato yield (total and in-class) and quality and plant and soil nutrient contents were monitored. The pH and total soluble solid contents had positive correlations with yield. Potatoes accumulated higher contents of K > N > P in the leaves, stems, and tubers. The organomineral fertilizer application rate of 3.7 t ha^{-1} (equivalent to 100% of mineral fertilizer demand) was the optimal rate to increase potato yield and quality. Organomineral fertilizer is a viable alternative to increase potato quality and yield and to increase plant and soil nutrient contents.

Key words: organic matter, plant growth, nutrients, nitrogen, phosphorus, potassium

RESUMO: O uso do organomineral tem um alto potencial para substituir fertilizantes sintéticos. O objetivo do presente estudo foi encontrar uma taxa de substituição ideal do organomineral em comparação com o fertilizante mineral para aumentar a produtividade e a qualidade da batata. O delineamento experimental foi em blocos casualizados, com quatro repetições, utilizando seis tratamentos: quatro doses substitutas de fertilizante organomineral (25, 50, 75, e 100% da demanda de fertilizante mineral), uma dose de fertilizante mineral (100% de fertilizante mineral) e controle (sem aplicação de fertilizante). As doses do organomineral foram testadas como alternativas para substituir de 25 a 100% do fertilizante mineral. A produtividade e qualidade da batata (total e em classes) e o teor de nutrientes na planta e no solo foram monitorados. Houve correlação positiva entre pH e conteúdo de sólidos solúveis totais com a produtividade. A batata acumulou maiores teores de potássio > nitrogênio > fósforo nas folhas, caules e tubérculos. A dose de 3,7 t ha^{-1} do organomineral (equivalente a 100% de fertilizante mineral) foi a taxa ideal para aumentar a produtividade e qualidade da batata. O organomineral é uma alternativa viável para aumentar a qualidade e a produtividade da batata com um incremento positivo de nutrientes nas plantas e no solo.

Palavras-chave: matéria orgânica, nutrição de plantas, nitrogênio, fósforo, potássio

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Introduction

Potatoes (*Solanum tuberosum*) are consumed by approximately one billion people worldwide, with a planted area of 18 million hectares and production of 330 million tons (Pllana et al., 2018). In Brazil, most potato production is located in the south and southwest regions, covering approximately 130,000 hectares and producing 3.5 million tons (EMBRAPA, 2020).

The quality and quantity of potatoes are directly related to the supply and availability of nutrients owing to the high nutrient demand of tuber production. Potassium and nitrogen are the main nutrients extracted by the potato plant, followed by calcium, phosphorus, magnesium, sulfur, and micronutrients (i.e., iron, manganese, zinc, copper, and boron) (Fernandes et al., 2010).

The recommended nutrient application for potato farming is based on demand, with application of 160, 560, and 320 kg ha^{-1} of N, P, and K, respectively, in areas in the first year of planting, and 120, 420, and 240 kg ha^{-1}, respectively, in previously cultivated areas (Mallmann et al., 2011). Potato plants use 48-77% of the applied mineral nutrients; the rest is lost by immobilization (P), volatilization [nitrous oxide (N_2O) and ammonia (NH_3)], and leaching into groundwater [K^+ and nitrate (NO_3^-)] (Almeida et al., 2015). Thus, there is a high dependence of potato production on synthetic fertilizers with low nutrient use efficiency, thereby limiting potato production.

As an alternative to decrease the nutrient losses and synthetic fertilizer demand in the crop production system, organomineral fertilizer is presented as a mixture of mineral fertilizers and decomposed organic residues (Almeida et al., 2016). The hypothesis is that organomineral fertilizer is a better alternative to mineral fertilizers and has a positive impact on potato yield and quality of the Agata cultivar. The objective of this study was to determine an optimal substitution rate of organomineral fertilizer to increase potato yield and quality.

Materials and Methods

An experiment was conducted in a commercial potato area in Mucugê, Bahia, Brazil (13°08’36”S, 41°28’53”W; altitude: 983 m) in 2014. The region’s climate is classified as Cfb (high altitude tropical climate) in the Köppen and Geiger classification (Alvares et al., 2013), with an average temperature and precipitation of 20.3 °C and 932 mm, respectively. During the study, the temperature ranged from 15 to 27 °C with total precipitation of 200 mm and monthly average air humidity of 69 to 72%. The climate data were obtained from Hayashi station in the region (Figure 1).

Before beginning the experiment, soil samples were collected from four points at depths ranging from 0 to 0.40 m. The soil samples were homogenized and submitted to chemical and physical characterization. The soil was classified as a Latosol in the Brazilian Soil Classification (EMBRAPA, 2018), and corresponded to an Oxisol in the Soil Taxonomy. The pH and P, K, Ca, Mg, and Al contents were 5.7 (H_2O), 117 mg dm^{-3} (P: extraction in Mehlich I), 0.47 cmol$_c$ dm^{-3} (K: extraction in 0.05 M HCl + 0.0125 M H_2SO_4), 1.30, 0.40, and 0.11 cmol$_c$ dm^{-3} (Ca, Mg, and Al: extraction in 1.0 M KCl) (EMBRAPA, 2017).

The experimental design was a randomized complete block with four replicates and six treatments, namely four substitution rates of organomineral fertilizer application (25, 50, 75, and 100% of mineral fertilizer demand), one rate of mineral fertilizer application (100% of mineral fertilizer demand), and the control (no fertilizer application).

The rates of organomineral application were based on previous studies (Cardoso et al., 2015; Oliveira et al., 2021) and tested organomineral fertilizer as an alternative by substituting 25 to 100% of mineral fertilizer demand. Each experimental unit included eight lines of 10 m long with plant spacing of 0.80 × 0.28 m, thereby totaling 64 m^2 and 44,642 plants ha^{-1}.

Potato seeds (cultivar: Agata, size 3, III generation) were planted in September 2015. The Agata is characterized by high productive potential, precocity, and good appearance of tubers (EMBRAPA, 2020).

The area was prepared with lime (2 Mg ha^{-1}) and gypsum (1 Mg ha^{-1}) application 30 days before planting according to the soil analysis. Furrows were opened and manually fertilized with i) mineral fertilizer treatment at a rate of 2,700 kg ha^{-1} using the formulation 4-14-8 of N (urea), P (triple superphosphate), and K (potassium chloride), respectively; and ii) organomineral fertilizer rates of 947.7 (25%), 1,895.4 (50%), 2,843.1 (75%), and 3,790.8 kg ha^{-1} (100%) using the formulation 2-8-5 of N

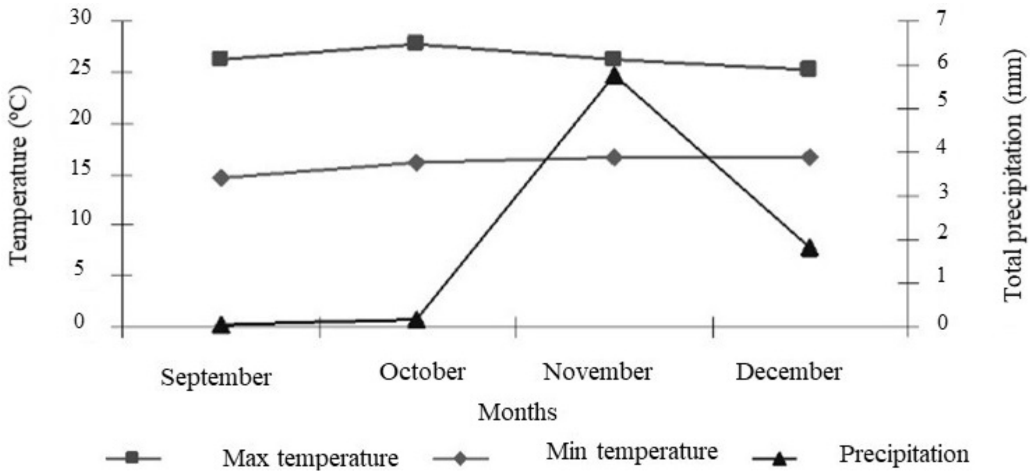


Figure 1. Temperature (Max: maximum; Min: minimum) and precipitation during the study period

(urea), P (simple superphosphate), and K (potassium chloride), respectively. Top-dressing fertilizer application was performed in all treatments using 1,000 kg ha^{-1} of commercial formulation 00-26-00, with P (26%), 19% Ca (simple superphosphate), and 6% S based on the recommendation of EMBRAPA (2020).

Organomineral fertilizer was produced by Geociclo Biotecnologia S/A (Geociclo, 2010) and was composed of N (2.00%) P (P_2O_5; 8.00%), K (K_2O; 5.00%), Ca (7.00%), Mg (1.20%), S (7.00%), B (0.05%), Zn (0.12%), Cu (0.05%), Mn (0.12%), and organic matter (8.00%). The mineral fertilizer was a commercial product containing N (urea; 4.00%), P (P_2O_5; 14.00%), K (K_2O; 8.00%), Ca (11.00%), S (9.00%), B (0.08%), Cu (0.08%), Mn (0.20%), Zn (0.20%), and Mg (2.00%).

Potato plants were grown under center-pivot irrigation and supplied with sufficient water for the full development of the crop (500-550 mm), as follows: i) 6 mm of water every 2 days from emergence to hilling up, ii) 10 mm of water every 3 days during vegetative development, and iii) 12 mm of water every 3 days during stolonization and tuberization.

According to pest, disease, and weed monitoring, products registered for potato cultivation were applied following the recommended rates when necessary. The plant development parameters were monitored 40, 56 and 65 days after emergence. A random sampling of two plants in each plot was performed to determine the dry matter and length of the stem, number and fresh weight of the tubers and leaf dry matter, and total plants. The data on days 40, 56 and 65 presented small variations, and the results were presented as the average of the three dates.

A random sampling of plants was performed by collecting two plants in each plot to determine the N, P and K contents 40 days after emergence. The nutrient contents were monitored in leaves, stems, and tubers according to EMBRAPA (2017). Samples were packed in paper bags and sent to the laboratory for sample preparation. Samples were washed and dried. After drying, the samples were disintegrated in a vegetable mill and chemically analyzed using the Kjeldahl method (N), the vanadate-molybdate-yellow method (P), and the emission flame spectrometry method (K). The plant dry matter and nutrient content data were used to calculate the nutrients exported by each part.

After 104 days of planting, the potato yield was determined by collecting all the tubers in the two central lines of each plot. The tubers were washed, weighed, and classified according to diameter into big (larger than 6 cm), special (5 to 6 cm), 1X (4 to 5 cm), 2X (smaller than 4 cm), diverse (tubers with small damages), and discard (tubers damaged by impact or disease).

Tuber samples were collected to monitor the quality parameters (hardness, pH, total soluble solid contents, and acidity). Hardness was determined by a texturometer (model W A68, Italy; 8 mm diameter tip), with two readings taken per tuber on opposite sides in the equatorial region. A pulp sample (20 g) diluted in distilled water (80 mL) was used to determine the pH in a pH meter (model MB-10). Diluted pulp samples were also prepared to determine the acidity using NaOH solution (0.5 M) by chemical titration using phenolphthalein as an indicator and to determine the total soluble solid contents using a refractometer. The results were expressed in °Brix.

After harvesting, soil was collected (0-0.20 m) from four points (between lines) to determine the pH in H_2O and the organic matter (colorimetric method), P (extraction in Mehlich 1), K (extraction in 0.05 M HCl + 0.0125 M H_2SO_4), Ca, Mg, and Al (extraction in 1 M KCl) contents according to EMBRAPA (2017).

Data were evaluated using descriptive statistics, namely the normality of the data (Shapiro-Wilk test) and the homogeneity of the variance (O'Neill and Mathew's test). The data were submitted to analysis of variance using the F-test ($p < 0.05$), and the rates of organomineral application were evaluated by regression analysis ($p < 0.05$). The means of 100% organomineral fertilizer and 100% mineral fertilizer application were compared using Student's t-test ($p < 0.05$). Variables were correlated by the Pearson test using a probability of 0.05. Statistical analysis was performed in R (version 4.0.0; R Foundation for Statistical Computing) and Python (version 3.8.3; Python Software Foundation), and the results were graphed in SigmaPlot (version 11.0; SYSTAT Software, Inc.).

Results and Discussion

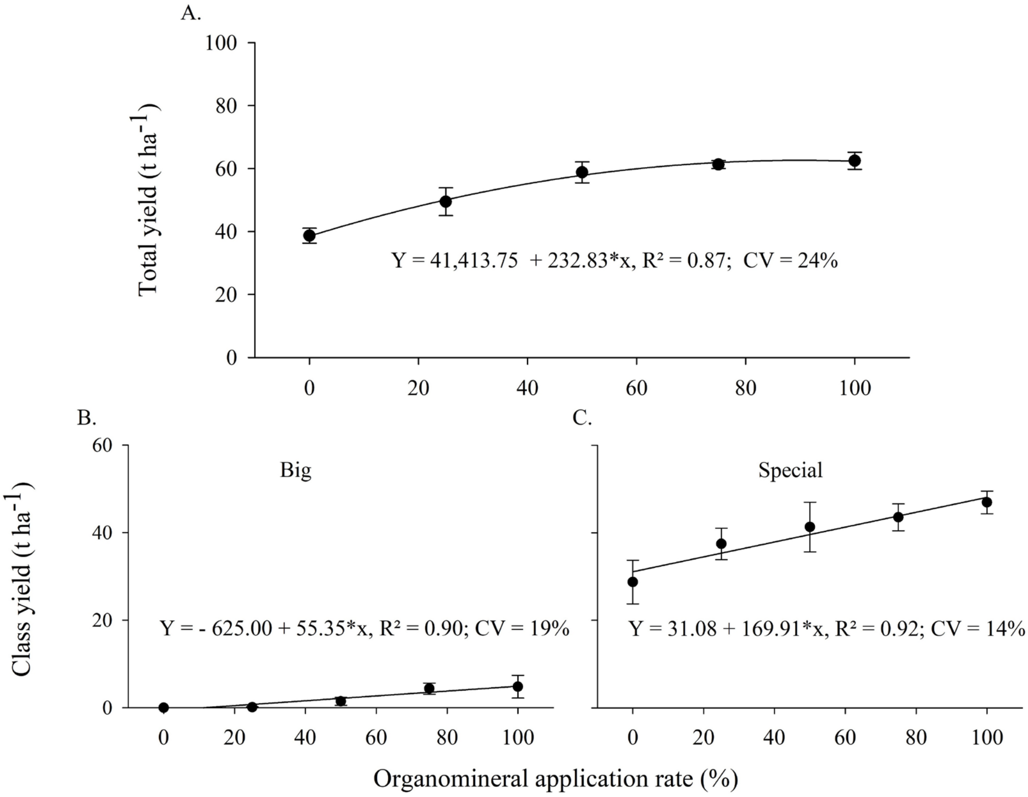
Organomineral application linearly increased the total potato yield from 38 to 62 t ha^{-1}, thereby representing an increase of 63% (Figure 2A). The potato yield classes were concentrated in big and special with averages of 2 and 40 t ha^{-1}, respectively (Figure 2).

The positive effect of organomineral fertilizer on potato yield is presented in the literature (Stertz et al., 2005; Cardoso et al., 2015). The total yield ranged from 40 to 60 t ha^{-1}, which is higher than that of recurrent Brazilian production (30 t ha^{-1}) (EMBRAPA, 2020). Silva et al. (2014) found that the Agata cultivar presented a late vegetative cycle and lower yield than BRS Ana and BRS Clara under tropical conditions. The adequate climate conditions explain the higher yield in our study, with temperatures ranging from 15 to 27 °C and optimal water available by irrigation. Cardoso et al. (2015) also found a positive climate effect on potato yield comparing planting in winter and summer at Cristalina, Goiás, Brazil. Adequate fertilization also was important to increase the performance of the Agata cultivar (Oliveira et al., 2021).

The organomineral fertilizer application rate of 3.7 t ha^{-1} (100%) was the best alternative to increase the potato yield, which is similar to the rate of 4.0 t ha^{-1} found by Cardoso et al. (2015). The organomineral fertilizer was a source of N (2.0%), P (P_2O_5; 8.0%), K (K_2O; 5.0%), and Ca (7.0%), which are essential elements for potato development.

Big and special classes were linearly impacted by the organomineral application rates with increases from 0 to 4 t ha^{-1} and 28 to 46 t ha^{-1}, respectively (Figure 2B and C). Souza et al. (2017) also found that soluble organomineral application (Acorda, Aminosan, and Fitofert) promoted the special potato yield of the Asterix cultivar. The positive effect of organomineral fertilizer is associated with the slow nutrient release caused by the high temperature and pressure used in transforming the compound into pellets.

The Agata cultivar is recommended for fresh consumption, and Class I (i.e., special and big) is more desired commercially by consumers and economically by producers (Fernandes et al.,



* Significant at $p < 0.05$ according to the F-test. Vertical bars represent the standard error of the mean (n = 4)

Figure 2. Effect of organomineral fertilizer application rates on potato yield and yield classes (t ha^{-1}; big and special)

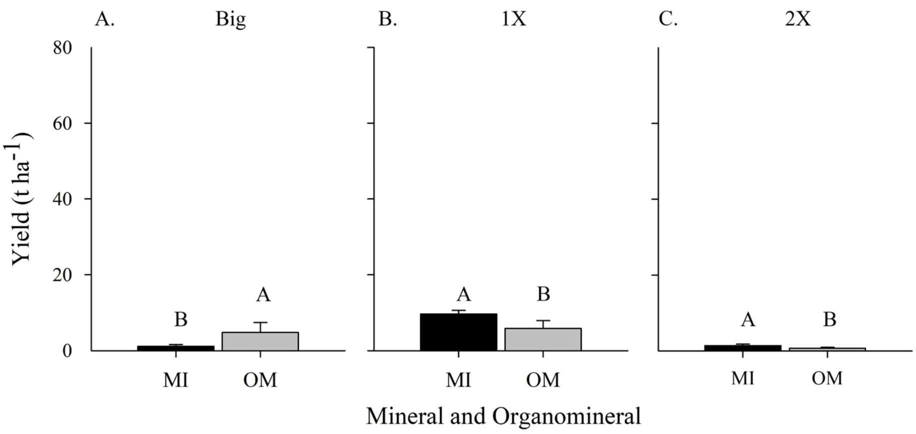
2010). Therefore, organomineral fertilizer was demonstrated to be a good substitute for mineral fertilizer for farmers.

There was no effect of different organomineral application rates on 1X, diverse, and 2X classes with average yields of 7.3, 1.3, and 1.3 t ha^{-1}, respectively. The discard class presented an average yield of 0.1 t ha^{-1} with no significant effect of organomineral application rates.

There was no clear difference in total yield between the 100% application rate of organomineral and mineral fertilizers with a small difference of 2 t ha^{-1}. Rós et al. (2014) also did not find a difference between organomineral and mineral fertilizers with respective average yields of 23.6 and 23.4 t ha^{-1}. In contrast, the 100% application rate of mineral fertilizer promoted a 40 and 47% increase in 1X and 2X classes, respectively, compared with that of organomineral fertilizer, whereas organomineral fertilizer promoted a 76% increase in the big class (Figure 3). Borchartt et al. (2011) found that organomineral fertilizer (cattle manure + N, P, and K) obtained a better potato yield than mineral fertilizers.

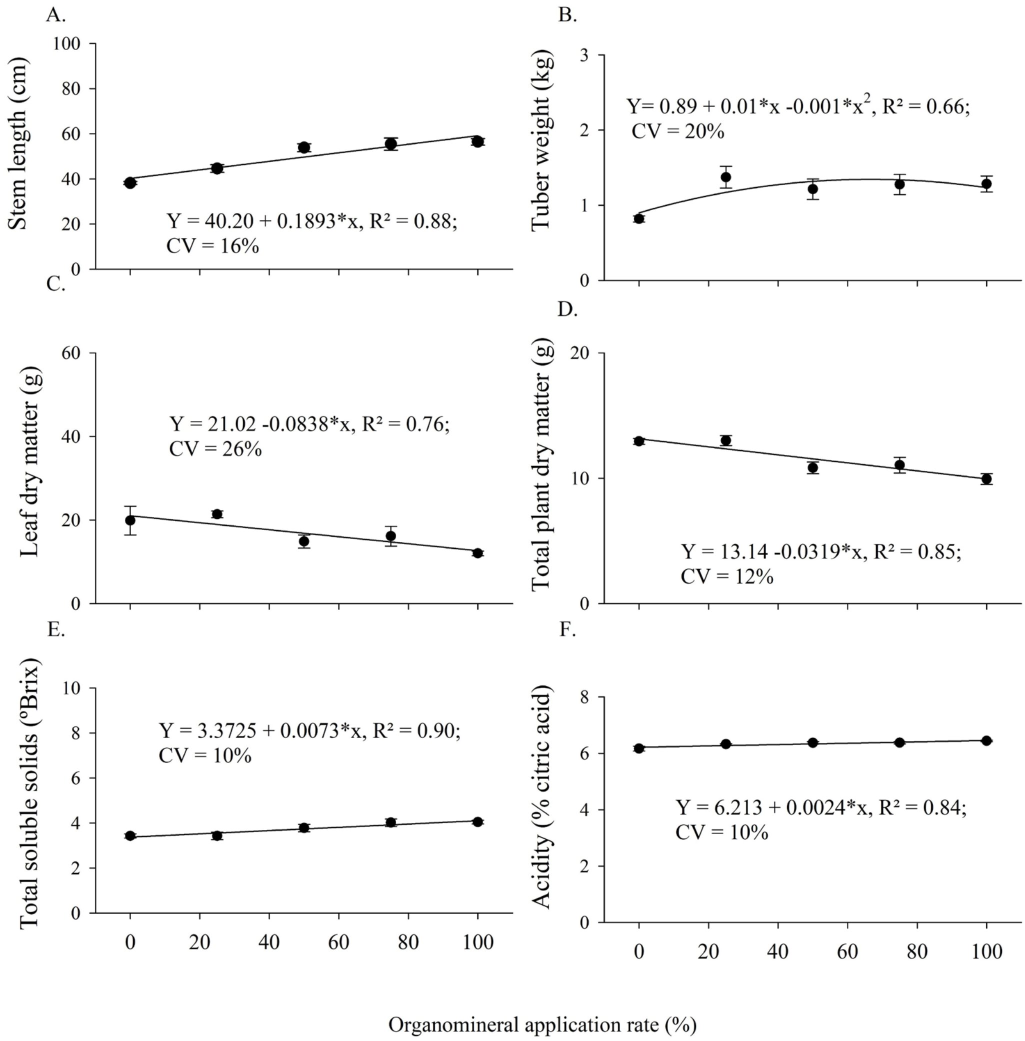
Organomineral application rates showed a positive linear response with stem length (R^2 = 88%), with an increase of 47.6% (Figure 4A). Jadoski et al. (2014) demonstrated that better agronomic characteristics were obtained with a stem length greater than 52.8 cm. The increase in stem length with fertilizer application (organomineral or mineral) is commonly found in the literature owing to adequate plant development conditions (Oliveira et al., 2021).

Tuber weight was also positively affected by organomineral application with a quadratic response (R^2 = 66%), and the optimal rate of organomineral application was fitted at 65%



* Significant at $p < 0.05$ according to the F-test. Means followed by different letters indicate significant differences at $p < 0.05$ according to the t-test. Vertical bars represent the standard error of the mean (n = 4)

Figure 3. Effects of organomineral fertilizer (OM) and mineral fertilizer (M) on the total potato yield and yield classes (t ha^{-1}; big, 1X, and 2X)



* Significant at $p < 0.05$ according to the F-test. Vertical bars represent the standard error of the mean (n = 4)

Figure 4. Effects of organomineral fertilizer rates on plant parameters (stem length, tuber weight, and leaf and total plant dry matter) and plant quality (total soluble solids and acidity)

(Figure 4B). In contrast, there was a significant reduction of 40 and 23% in leaf and plant dry matter, respectively, representing a decrease from 20 to 12 g and from 13 to 10 g, respectively (Figure 4C and D).

A reduction in leaf dry matter was also found by Fernandes et al. (2010), with a dry matter percentage between 14% and 16% for Agata cultivars. Generally, K can cause a reduction in leaf dry matter, as observed by Lopes et al. (2013). In our study, there was a K input of 947.7 (25%), 1,895.4 (50%), 2,843.1 (75%), and 3,790.8 kg ha^{-1} (100%) from organomineral fertilizer using the formulation 2-8-5, which corresponded to a K (K_2O) concentration of 5%.

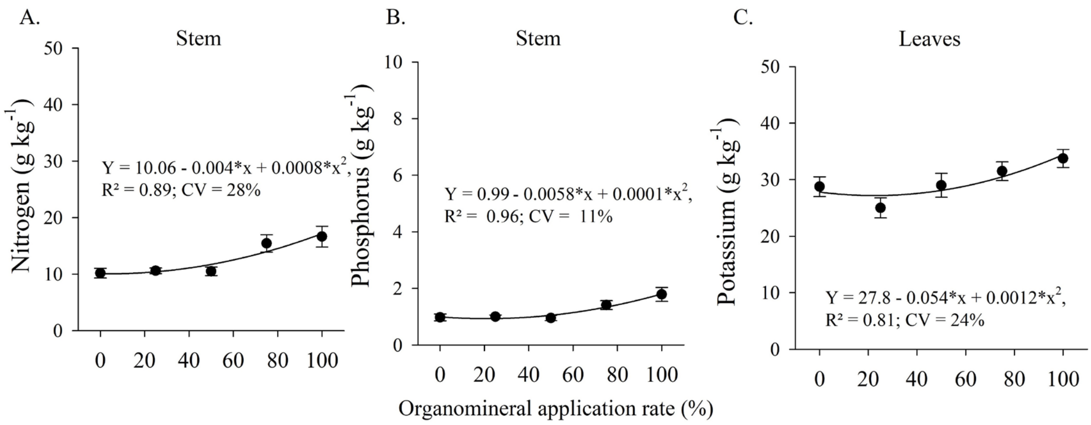
There was no effect of organomineral application on dry stem matter and the number of tubers with an overall average of 13 g and 7 tubers, respectively. There was also no difference in the stem, tuber, leaf, and plant dry matter between the organomineral and mineral fertilizer application rates of 100%.

The pH and soluble solid contents ranged from 6.1 to 6.4 and from 3.4 to 4.0 °Brix, respectively, and showed a positive correlation with total yield (pH: $r = 0.64$, $p < 0.05$; soluble solid content: $r = 0.54$, $p < 0.05$), thereby indicating an increase in tuber quantity and quality.

There were no differences in quality parameters between the organomineral and mineral fertilizer application rates of 100% with small differences of 3.7 Newton, 0.03, 0.4 °Brix, and 0.03 in citric acid in hardness, pH, soluble solid contents, and acidity, respectively.

No difference in plant parameters was also found by Borchartt et al. (2011) using mineral and organic fertilizers (bovine manure) supplemented with NPK. Stertz et al. (2005) observed a greater tuber dry matter content with organomineral application, representing an increase of 19% compared with that of mineral fertilization. The soluble solid contents increased with organomineral application with values ranging from 3.4 to 4.0 °Brix. Soluble solid contents close to 4.0 °Brix were observed by Evangelista et al. (2011) and Fernandes et al. (2010), who evaluated the physical and chemical characteristics of tubers grown in an organic system.

Soluble solids are classified as sugars (sucrose) in tubers and indicate an increase in the sucrose content. Soluble solids are an indirect measure of the sugar content and can vary from 2 to 25% depending on the species, maturation stage, and climate (Chitarra & Chitarra, 2005). The pH was also positively affected by organomineral applications with values ranging from 6.1 to 6.4. The highest pH value was observed



* Significant at $p < 0.05$ according to the F-test. Vertical bars represent the standard error of the mean (n = 4)

Figure 5. Effects of organomineral fertilizer application rates on the N, P, and K contents in stems and leaves

with the 100% organomineral dose, which was close to the pH value of 6.1 found by Fernandes et al. (2010).

Potatoes absorbed more K in the leaves, stems, and tubers, followed by N and P. Organomineral application increased the N and P contents in the stems with an R^2 higher than 89%, with the highest accumulation of N (16.6 g kg^{-1}) and P (1.8 g kg^{-1}) at the organomineral application rate of 100% (Figure 5A and B). There were no differences in N and P contents in all parts of the plant (stems, tubers, and leaves) between organomineral and mineral fertilizers.

The higher K accumulation in potatoes also was demonstrated by Luz et al. (2014) and Oliveira et al. (2021). Arrobas & Rodrigues (2009) also highlighted K as the nutrient most absorbed by potato plants, with an average of 114-143 kg ha^{-1}.

Organomineral application promoted a quadratic response with regard to K accumulation in leaves, with the highest K content of 33.7 g kg^{-1} at the organomineral application rate of 100% (Figure 5C). The use of organomineral fertilizer has been recommended as a source of P and K (Almeida et al., 2019), which explains the positive effect on K accumulation. The organic matter in the fertilizer adsorbed some of the applied K, thereby controlling its solubility and soil availability. Rosolem et al. (2018) showed that KCl coated with humic substances presents a higher efficiency than KCl owing to the slow K release caused by humic and fulvic acids.

An increase in leaf N and P with the application of organomineral fertilizer has commonly been observed in the literature. However, in our study, this result was not explained by linear or quadratic models. The N accumulation in potatoes was higher up to 30 days after planting, with a consecutive decrease due to the decrease in the plant's metabolism, which ended the vegetative growth cycle and began to enter the tuberization phase (Nobile et al., 2012). Luz et al. (2014) showed leaf N accumulation in the Asterix cultivar as the N dose increased owing to higher nutrient availability in the soil. Nitrogen input and accumulation are important to plant development because N is a fundamental component of organic molecules, such as amino acids, nucleic acids, chlorophyll, coenzymes, hormones, and other compounds that are involved in plant growth and development processes (van Raij et al., 2001).

Organic matter in soil increased with organomineral application (Table 1) owing to the presence of organic matter in fertilizer (Almeida et al., 2019). Organic matter is the main N reserve in soil, which is found as organic N.

Table 1. Chemical characterization of soil before potato planting and after potato harvesting under different rates of organomineral (OM) and mineral fertilizer application

Fertilizers	pH	OM	P	K	Ca	Mg
		(g dm^{-3})		(cmol$_c$ dm^{-3})		
Before potato planting						
Soil	5.7	8	117	0.47	1.3	0.4
After potato harvesting						
Control	4.9	10	175	0.22	1.6	0.5
100% (OM)	4.6	10	305	0.27	2.5	1.1
75% (OM)	4.9	10	320	0.26	1.7	0.6
50% (OM)	4.9	11	190	0.17	1.8	0.5
25% (OM)	4.9	10	195	0.21	1.8	0.5
Mineral (100%)	4.7	9	240	0.26	2.4	0.7

pH in H_2O; organic matter (colorimetric method); contents of P (extraction in Mehlich 1), K (extraction in 0.05 M HCl + 0.0125 M H_2SO_4), Ca, Mg, and Al (Ca and Mg extractions in 1 M KCl). n = 6

The soil P content increased as the organomineral application rate increased (Table 1). A superior performance of organomineral fertilizer in increasing P stocks in soil was expected owing to the high P content in mineral fertilizer (P_2O_5; 14.0%) and organomineral fertilizer (P_2O_5; 8.0%). Zavaschi et al. (2020) monitored the P availability in soil with P fertilizer and humic substances (organic matter), and showed an increase in labile P in the soil. Other studies have also presented a positive effect of organic matter in P fertilizers, which directly affected the crop yield (Maluf et al., 2018).

Organic substances that can alter the P dynamics in soil, e.g., sugars, phosphates, phospholipids, nucleic acids, hydrolysis esters, monoesters, and diesters. The K content decreased as the organomineral application rate increased owing to high K extraction by plants, thereby indicating that the K input by mineral fertilizer (P_2O_5: 14.0%; K_2O: 8.0%) and organomineral fertilizer (P_2O_5: 8.0%; K_2O: 5.0%) was not sufficient to maintain the high K content in the soil.

Conclusions

1. Organomineral application promoted an increase in potato yield and quality.

2. Organomineral application increased the total soluble solid contents and pH in potatoes.

3. Potatoes accumulated higher contents of K followed by N and P in the plant.

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