

Biochar, Filter-Cake, and Polymer-Based Special Fertilizers for Maize Cultivation

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Abstract

This investigation assessed the effects of special fertilizers on maize. The experiment was performed according to a randomized block design, with four replications in a $7 \times 4 + 1$ factorial scheme, representing seven sources (filter-cake-based organic compound, biochar-based organic compound, organic-mineral (OM) filter-cake, OM biochar, OM filter cake + humic substances (HS), mineral fertilizer with polymers, and conventional mineral) and four fertilizer levels based on the nitrogen (N) contents (60, 120, 180, and 240 kg/ha). An absolute control, without any fertilizer application, was used. At 60 days after sowing (DAS), the plant growth parameters, nutritional status, and residual nutrients in the soil were evaluated. The mineral fertilizer with polymers and OM filter-cake + HS showed better results for the dry matter of the shoot of the plant and plant height. When considering the leaf area, the OM filter-cake and OM filter-cake + HS fertilizers stood out. The accumulation of N and potassium (K) in the shoot of the plants was higher when the OM filter-cake + HS and mineral fertilizer with polymers were applied. With respect to the accumulated phosphorus (P), treatment with the OM filter-cake, OM filter-cake + HS, and mineral with polymers showed better results. On the other hand, for the analysis of P and residual K in the soil, the treatments based on filter-cake and biochar organic compost were better. Treatment with the OM filter-cake + HS and mineral with polymers stood out when considering the plant growth parameters and nutritional aspects of the maize crop.

Keywords: efficiency, humic substances, organic-mineral

1. Introduction

The use of organic-mineral and organic fertilizers is an alternative to counter increasing national grain production (Polidoro, 2013) and structural deficiencies of Brazilian soils.

Organic-mineral fertilizers are formulated from organic waste, such as manure, peat, residues from the sugar industry, residues from the alcohol industry, bone meal, different cakes, agribusiness waste, and sewage sludge. Therefore, the use of these residues to produce organic-mineral fertilizers can immediately eliminate 50 percent of the environmental liabilities generated by these production processes by 2020 (Benites et al., 2010).

Another way to enhance this market and the technology involved in the manufacture of fertilizers is related to the study of alternatives capable of improving the physicochemical characteristics of these products. Some alternatives, such as the addition of isolated humic substances (humic and fulvic acids), introduction of the organic matrix pyrolysis process, biochar production, and manufacture of special fertilizers with the addition of polymers, have been studied with the aim to improve the agronomic features of these fertilizers.

According to Rocha et al. (2003), humic substances can modify plant metabolism due to their effects on the soil, such as metal complexation, increased cation exchange capacity, nutrient supply, and moisture retention. These substances can also influence ion transport, respiratory activity, chlorophyll content, nucleic acid synthesis, and the activity of various enzymes in plants, thus favouring better plant development (Nannipieri et al., 1983).

Studies have found that the application of biochar to the soil makes a significant contribution to the physical nature of the system, influencing the structure, texture, porosity, depth, and consistency of soils, due to changes

in the surface area density and pore and particle distribution, density, and size (Van Zwietwn et al., 2010).

The major advantages of polymer-coated fertilizers are the use of this protective layer against agents that cause nutrient loss and the behavioural change of these encapsulated fertilizers in relation to conventional sources, which promote a gradual availability of mineral elements to the system (Silva et al., 2012).

In this study, the objective was to evaluate the use of different types of special fertilizers for maize compared to the use of a conventional mineral fertilizer.

2. Materials and Methods

The experiment was performed in a greenhouse at the Federal University of Uberlândia, Umuarama campus, from January to April 2018, in plastic pots with approximately 18 kg of soil. Dystrophic Red Latosol (LVd), collected from the experimental farm of Gloria, Uberlândia-MG, was used. The soil was sieved through a 4 mm mesh, and dolomitic limestone with 90% relative power of total neutralization (PRNT), containing approximately 460 mg/g calcium oxide (CaO) and 80 mg/g magnesium oxide (MgO), was added at 18 g per pot. The samples were subsequently incubated for a period of 60 days, to correct the acidity and increase the base saturation to 60%. The chemical and physical compositions of the soil used in the experiment after the limestone application and incubation are described in Table 1, the analyses being carried out according to the methodologies proposed by Embrapa (2009) and Embrapa (1997).

Table 1. Chemical and physical characterization of the soil after limestone application and incubation for 60 days

<i>Chemical analysis</i>								
pH (H ₂ O)	Ca	Mg	Al	P	K	H + Al	CTC	S-SO ₄
1-2.5	-----	cmol _c /dm ³ -----	-----	-----	mg/dm ³ -----	-----	cmol _c /dm ³ -----	mg/dm ³
6.7	1	0.5	0	1	20	1.7	3.25	41
M.O.	C.O.	B	Cu	Fe	Mn	Zn	V	m
-----	dag/kg -----	-----	-----	mg/dm ³ -----	-----	-----	-----	% -----
0.6	0.4	0	0.7	9	2.4	0.5	58	0
<i>Textural Analysis</i>								
Soil	Coarse sand		Fine sand		Silt		Clay	
	-----		-----		g/kg -----		-----	
LVd	297		250		54		400	

Note. Ca, Mg, and Al = 1 mol KCl/L; P and K = HCl 0.05 mol/L HCl + H₂SO₄ 0.0125 mol/L; Available-P (Mehlich-1 extractor); S = calcium phosphate 0.01 mol/L; H + Al = Buffer Solution—SMP at pH 7.5; Cu, Fe, Mn, and Zn = DTPA 0.005 mol/L + TEA 0.1 mol⁻¹ + CaCl₂ 0.01 mol/L at pH 7.3, cmol_c/dm³ × 10 = (mmol_c/dm³)/(mg/dm³) = ppm/dag/kg = % CTC at pH 7.0; V = Base saturation; m = Aluminum saturation; M.O. = Colorimetric Method; Methodologies based on EMBRAPA (2009). Textual Analysis conducted using the Pipette Method (EMBRAPA, 1997).

The experiment was performed according to a randomized block design with four replications in a 7 × 4 + 1 factorial scheme, corresponding to seven sources (filter-cake-based organic compound, biochar-based organic compound, organic-mineral (OM) filter-cake, OM biochar, OM filter-cake + humic substances (HS), mineral fertilizer with polymers, and conventional mineral) and 4 fertilizer levels based on the nitrogen (N) contents (60, 120, 180, and 240 kg/ha). An absolute control, without any fertilizer application, was used. Due to the similarity between phosphorus (P) and potassium (K) levels in organic-mineral and mineral fertilizers, treatments with these fertilizers received the same doses of these nutrients. However, the doses of P and K in organic fertilizers were different. Thus, the doses of the biochar and cake treatments were calculated considering the N content (%) present in these organic materials, fixing this element as a basis for calculating the dose to be applied and presenting variations in the P and K doses, as shown in Table 2.

Table 2. Type of fertilizer, amount of nutrients, and sources of each treatment

Source	Doses			Dose in the soil	Source dose	Source dose
	P ₂ O ₅	N	K ₂ O			
No fertilizer added	0	0	0	0	0	0
Organic meal-based filter-cake (cake)	96	60	48	12000	108.0*	6.0
	192	120	96	24000	216.0*	12.0
	288	180	144	36000	324.0*	18.0
	384	240	192	48000	432.0*	24.0
Organic meal-based biochar (biochar)	75	60	45	15000	135.0*	7.5
	150	120	90	30000	270.0*	15.0
	225	180	135	45000	405.0*	22.5
	300	240	180	60000	540.0*	30.0
Organic-mineral pellet-based filter-cake (OM cake)	60	60	60	500	4.5	0.3
	120	120	120	1000	9.0	0.5
	180	180	180	1500	13.5	0.8
	240	240	240	2000	18.0	1.0
Organic-mineral pellet-based biochar (OM biochar)	60	60	60	500	4.5	0.3
	120	120	120	1000	9.0	0.5
	180	180	180	1500	13.5	0.8
	240	240	240	2000	18.0	1.0
Organic-mineral pellet-based filter-cake + humic substances (OM cake + HS)	60	60	60	500	4.5	0.3
	120	120	120	1000	9.0	0.5
	180	180	180	1500	13.5	0.8
	240	240	240	2000	18.0	1.0
Mineral with polymers (mineral w/pol)	60	60	60	375	3.3	0.2
	120	120	120	750	6.7	0.4
	180	180	180	1125	10.1	0.6
	240	240	240	1500	13.4	0.8
Conventional mineral (mineral)	60	60	60	333.33	3.0	0.2
	120	120	120	666.66	6.0	0.3
	180	180	180	999.99	9.0	0.5
	240	240	240	1333.32	12.0	0.7

Note. Dose applied in g per plant, based on the N contents (Table 1) present in the raw materials used.

The filter-cake, a by-product of sugarcane activity, was used as an organic base for the formation of organic-mineral and biochar fertilizers.

Sixty days after the limestone application, the fertilizers were applied, and five seeds of maize were cultivated in each pot (cultivar DKB 310 Pro 2). Thinning was carried out at 15 days after sowing (DAS), with only one plant left per pot. At 20 DAS, liquid macro- and micro-nutrient supplementation was performed by adding sulphur, zinc, boron, copper, and manganese (S, Zn, B, Cu, and Mn) to the pots in the proportions of 60.0, 6.0, 2.2, 1.5, and 2.0 kg/ha, respectively. Throughout the experiment, the irrigation of the pots was constant, with a field capacity of approximately 80% for all treatments.

At 60 DAS, when the plants had nine fully developed leaves, the plant height (cm), leaf area of the plants (cm²), root dry mass (g), and shoot dry mass (g) measures were estimated. The plants were removed, placed in paper bags, and taken to the soil fertility laboratory, where determination of the dry mass of the shoot of the plants (leaves and stems) and roots was conducted using a forced air circulation drying oven at 65 °C.

After determining the dry mass, the samples were ground in a Wiley mill (2 mm) and stored in paper bags. Subsequently, the macro-nutrient concentrations of the shoot of the plants (Embrapa, 2009) were determined. On the basis of the nutrient content values in the plant and the dry matter mass of the shoot, the accumulation (extraction) of nutrients in the maize plants was calculated by multiplying the dry mass of the shoot (DMS) in g

by the nutrient content in g per kg.

On the basis of the plant dry mass values and the use of conventional mineral fertilization as the standard source, the equivalent fertilizer dose was calculated following Equation 1:

$$Eq_{\text{Mineral fertilization}}(\%) = \frac{\sum[(x_{f180} - xt) + (x_{f240} - xt)]}{\sum[(x_{k180} - xt) + (x_{k240} - xt)]} \times 100\% \quad (1)$$

where, $Eq_{\text{Mineral fertilization}}(\%)$: equivalent in mineral fertilizer; x_{f180} : dry matter production of the shoot of the source tested—dose of 180 kg/ha; x_{f240} : dry matter production from the shoot of the source tested—240 kg/ha dose; x_{k180} : dry matter production from the shoot of the standard source—dose of 180 kg/ha; x_{k240} : dry matter production from the shoot of the standard source—240 kg/ha dose; and xt : dry matter production of the control. The $Eq_{\text{Mineral fertilization}}(\%)$ calculation is described by Geodert et al. (1986).

To determine the effects of fertilizer application on the soil chemical characteristics after root and plant removal, soil samples were collected from each pot to determine the P and K levels (Embrapa, 2009).

Data were initially tested for residual normality assumptions (the Shapiro-Wilk test), variance homogeneity (Levene's test), and block additivity (Tukey's test for additivity) using the SPSS version 20.0 software. All data were analysed at 0.01 significance level. Later, an analysis of variance was conducted using the statistical software SISVAR (Ferreira, 2011), and the averages were compared using the Scott-Knott (0.05 significance) and Dunnett (0.05 significance) tests. To evaluate the effects of fertilizer doses, polynomial regressions were used at a 5% significance.

3. Results and Discussion

The highest values for the DMS were observed when using the mineral fertilizer with polymers and OM cake + HS (Figure 1A). The maximum response points were determined at the doses of 216 and 190 kg/ha for the OM cake + HS and mineral fertilizer with polymers, which corresponded to 33.7 and 33.6 g of dry mass, respectively (Figure 1A).

Similarly, for the plant height, the highest values were determined when the mineral fertilizer with polymers and OM cake + HS were used. The maximum response values were observed at doses of 180 and 177 kg/ha for the mineral fertilizer with polymers and OM cake + HS, respectively (Figure 1B).

The leaf area of the maize plants presented the best results when using the OM cake and OM cake + HS fertilizers. In this treatment, increments with maximum response points were found at the doses of 208 and 258 kg/ha for the OM cake and OM cake + HS fertilizers, which correspond to 7465 and 7478 cm², respectively (Figure 1C). In contrast with these results, Valderrama et al. (2011), upon evaluating the effects of N and P doses and sources (coated or not coated with polymers) on the production components of irrigated maize in the Cerrado region, did not find significant differences between the sources with respect to the plant height or stem diameter of maize plants. The best results observed for the OM cake and OM cake + HS treatments may be explained by the gradual release of both fertilizers, which provide a more adequate nutrition for maize plants.

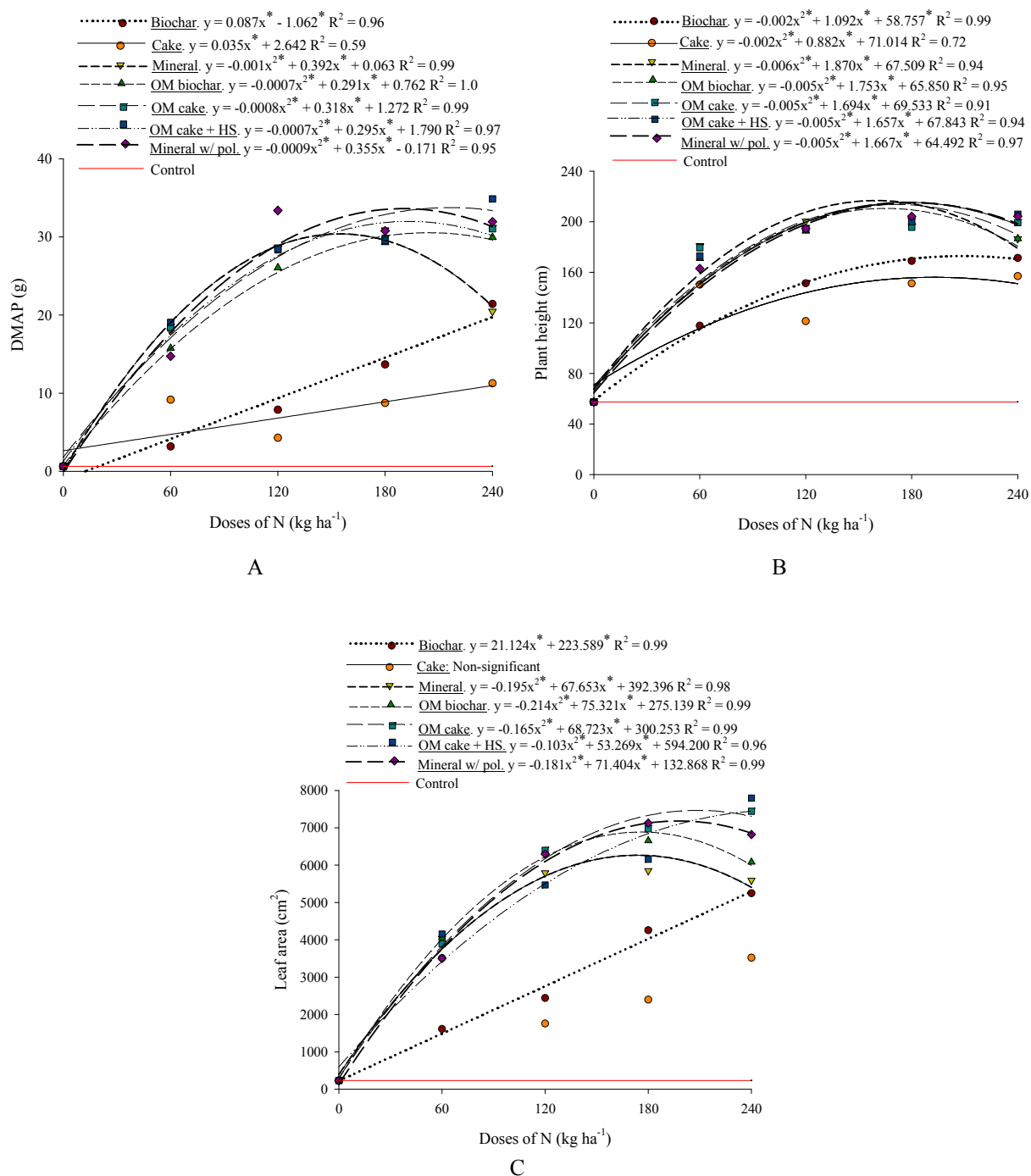


Figure 1. Dry matter mass of the shoot of the plant—DMAP (g) (A); Height (cm) (B) and leaf area (cm²) (C) in maize plants under different fertilizers and doses of N (kg/ha) 60 days after sowing. Red lines refer to the value of the control, in which no fertilizer was applied to the soil

A greater efficiency was observed for treatments with the OM cake, OM biochar, OM cake + HS, and mineral fertilizer with polymers with respect to the percentages observed based on the 'Eq_{Mineral fertilization}' equation, relative to the equivalent values of each product in relation to the mineral fertilizer. For the cake and biochar fertilizers, a reduction in efficiency was observed when compared to the mineral fertilizer (Table 3). These results demonstrate that the protection against loss factors (volatilization, fixation, and leaching) and the gradual release provided by organic-mineral and mineral fertilizers with polymers played a fundamental role in the greater efficiency of these treatments. Thus, strategies aimed at the application of lower doses of these fertilizers

can be used in the field without the risk of productivity losses, whilst maintaining the profitability for the producer.

Table 3. Equivalent values and efficiency of different types of fertilizers compared to a standard mineral fertilizer

Source	Equivalent in mineral fertilizer* (%)	Efficiency (%)
OM cake	118.97	18.97
OM biochar	115.71	15.71
OM cake + HS	126.04	26.04
Cake	37.40	-62.60
Mineral w/ pol	122.70	22.70
Biochar	67.49	-32.51

Note. Calculations were performed according to the efficiency equation ($Eq_{\text{Mineral fertilization}}$) based on the applied doses of mineral fertilizer.

Regarding the accumulated N and K contents, it was observed that the OM cake, OM biochar, OM cake + HS, and mineral fertilizer with polymers at a dose of 240 kg/ha presented the best results (Figure 2). For these treatments, the accumulated N content in the shoot of the plant increased linearly, and every 10 kg of nutrients applied to the soil increased the N content by 38.9, 38.1, 41.5, and 36.4 mg/pot with the OM cake, OM biochar, OM cake + HS, and mineral fertilizer with polymers, respectively (Figure 2A).

As for the K content accumulated in the shoot, it was found that every 10 kg of nutrients applied to the soil increased the K content by 59.8, 56.0, 63.6, and 60.0 mg/pot with the OM cake, OM biochar, OM cake + HS, and mineral with polymers treatments, respectively (Figure 2B).

Unlike the results obtained in the current study, when evaluating the effectiveness of a polymer-coated K fertilizer compared to conventional KCl on maize plant nutrition in two soil types (sandy and clayey), Bley (2015) found that independent of the soil and doses, K absorption was higher in plants under the conventional treatment compared to those given the coated-KCl treatment.

When the accumulated P content in the maize plants was analyzed, it was found that the OM cake, OM cake + HS, and mineral fertilizer with polymers, at a dose of 240 kg/ha, presented the highest values. Linear increases were observed as the applied dose to the soil increased; for every 10 kg of nutrients applied, there was an increase in the P of 7.3, 6.4, and 6.8 mg/pot for the OM cake, OM cake + HS, and mineral fertilizer with polymers, respectively (Figure 2C).

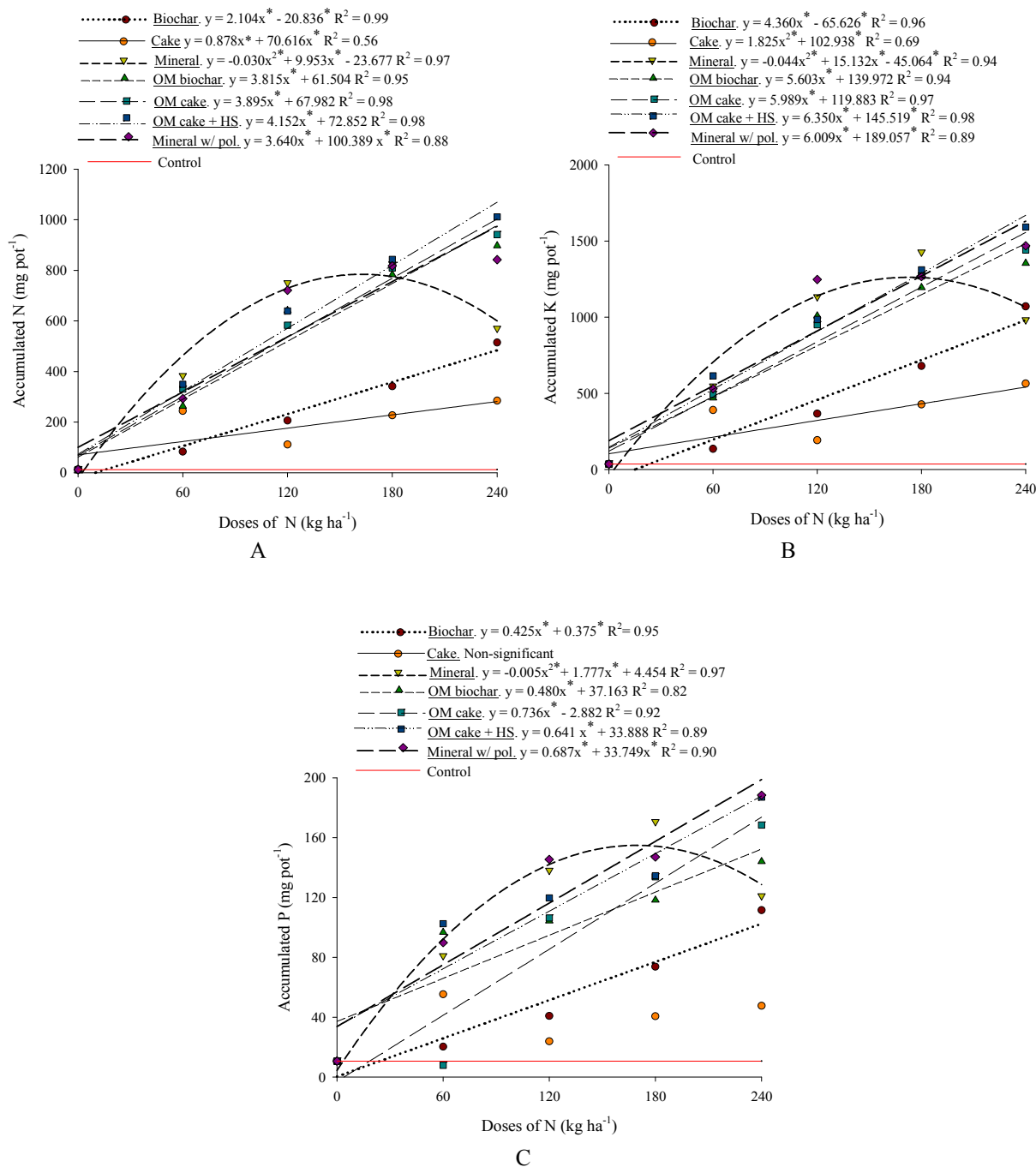


Figure 2. Nitrogen-N (A), Potassium-K (B), and Phosphorus-P (C) accumulated in the shoot of maize plants (mg/pot) under different fertilizers and doses of N (kg/ha) 60 days after sowing. Red lines refer to the value of the control, in which no fertilizer was applied to the soil

According to Pinton et al. (1999), the beneficial effects of humic substances on plant nutrition are linked to better root development. Moreover, humic substances increase the emergence of lateral roots in the plant, which induces the production of smaller but more branched secondary roots, thus improving the absorption of nutrients by the plant (Canellas et al., 2002). Therefore, the higher accumulation of N, P, and K in the shoot of the maize plants when the OM cake + HS treatment was applied may be related to better absorption efficiency of these nutrients, due to the addition of organic acids to the organic-mineral fertilizer.

There was no significant difference in the soil P content with most of the fertilizers studied, when compared to the control, except for the 120 kg/ha dose of filter-cake and the 180 and 240 kg/ha doses of biochar (Figure 3A).

The highest values for the residual P content in the soil were obtained when applying the organic filter-cake and biochar fertilizers. The P content in the soil was adjusted to a quadratic equation for the filter-cake organic compost, with the maximum value at a dose of 137 kg/ha, which corresponded to 36.23 mg/dm³. Regarding the biochar treatment, the highest value for this variable was observed when the fertilizer was applied at a dose of 240 kg/ha. For each 10 kg of fertilizer applied, there was an increase of 1.1 mg/dm³ in the P in the soil (Figure 3A).

The higher residual P content in the soil, resulting from the application of organic fertilizers, can be explained by the decreased adsorption of this element in the soil colloids, provided by the application of organic matter. Regarding the residual K levels in the soil, it was observed that regardless of the treatment used, there were linear increases in the content of this element with the application of higher dosages of fertilizers to the soil (Figure 3B).

Considering the mineral fertilizer, it was observed that compared with the applied dose of 180 kg/ha, all applied fertilizers showed a significant difference in the K levels of the soil for, except for the organic compound biochar and filter-cake, in which the results were superior to the control even at lower dosages (Figure 3B).

The highest K content in the soil was obtained when biochar and filter-cake were applied, where for each 10 kg of nutrients applied to the soil there was an increase of 15.4 and 15.11 mg/dm³ for biochar and filter-cake, respectively (Figure 3B).

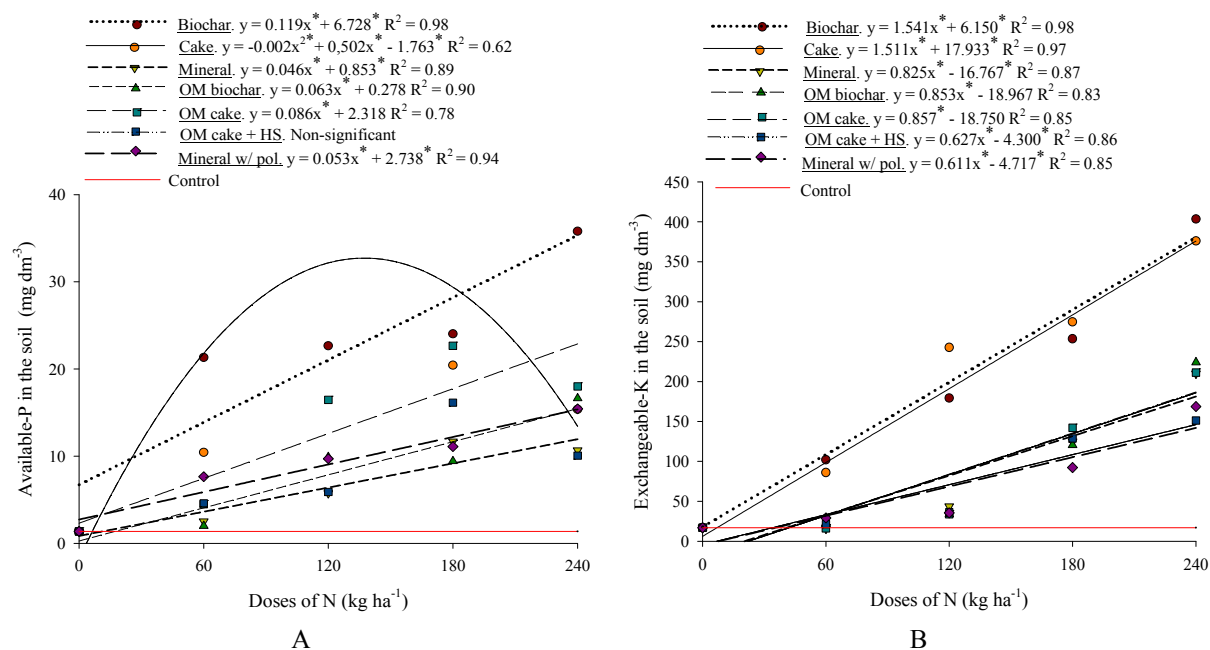


Figure 3. Phosphorus-P (Mehlich-1) (A) and Potassium-K (B) contents in the soil (mg/dm³) as a function of increasing doses of N rates (kg/ha) using different fertilizers. Red lines refer to the value of the control, in which no fertilizer was applied to the soil

Similar results to the current investigation were obtained by Junior et al. (2011), when studying the effects of different doses of organic and mineral fertilizers on sugarcane and soil chemical attributes. They verified significant increases in the soil P content when compared to the use of mineral fertilizer, thus indicating the efficiency of the compound to supply P to the soil. The same occurred for K in the soil, where increasing doses of cake provided significant increments in the content of this element in the soil.

4. Conclusion

Mineral fertilizers with polymers, OM cake + HS, and OM cake were the most efficient in increasing the growth of maize plants.

The OM cake + HS fertilizer was revealed as the most efficient for the maize crop, and it was able to replace the mineral fertilizer, by demonstrating up to 26% greater efficiency in the production of the dry mass of the plants.

The accumulation of N, P, and K was higher in the shoot of maize plants when the OM cake + HS, mineral fertilizer with polymers, and OM cake were applied.

The treatments based on filter-cake and biochar produced better results for the P content and residual K in the soil.

References

- Benites, V. N., Correa, J. C., Menezes, J. F. S., & Polidoro, J. C. (2010). *Produção de fertilizante organomineral granulado a partir de dejetos de suínos e aves no Brasil*. Congresso FertBio 4, *Anais...* Guarapari-ES.
- Bley, H. (2015). *Liberção, nutrição de plantas e lixiviação de potássio de fertilizante revestido* (68f., Dissertação (Mestrado em ciência do solo), Universidade Federal de Santa Maria, Porto Alegre, RS, Brasil).
- Canellas, L. P., Oliavres, F. L., Façanha, A. L. O., & Façanha, A. R. (2002). Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H⁺-ATPase activity in maize root. *Plant Physiol*, *130*, 1951-1957. <https://doi.org/10.1104/pp.007088>
- EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (2009) *Manual de análises químicas de solos, plantas e fertilizantes* (2nd ed., p. 628). Informação Tecnológica, Brasília.
- EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (1997). *Manual de métodos de análise de solo* (2nd ed., p. 212). EMBRAPA-CNPS, Rio de Janeiro, RJ.
- Ferreira, D. F. (2011). Sisvar: A computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039-1042. <https://doi.org/10.1590/S1413-70542011000600001>
- Junior, A. B. A., Nascimento, C. W. A., Sobral, M. F., Silva, F. B. V., & Gomes, W. A. (2011). Fertilidade do solo e absorção de nutrientes em cana-de-acucar fertilizada com torta de filtro. *Revista Brasileira Engenharia Agrícola Ambiental*, *15*(10), 1004-1013. <https://doi.org/10.1590/S1415-43662011001000003>
- Geodert, W. J., Souza, D. M. G., & Rein, T. A. (1986). *Princípios metodológicos para avaliação agrônômica de fontes de fosforo* (Documentos 22, p. 23). Planaltina, DF: EMBRAPA.
- Nannipieri, P., Muccini, L., & Ciardi, C. (1983). Microbial Biomass and Enzyme Activities: Production and Persistence. *Soil Biology and Biochemistry*, *15*, 679-685. [https://doi.org/10.1016/0038-0717\(83\)90032-9](https://doi.org/10.1016/0038-0717(83)90032-9)
- Pinton, R., Cesco, S., Lacoletig, G., Astolfi, S., & Varanini, Z. (1999). Modulation of NO₃⁻ uptake by water-extractable humic substances: Involvement of root plasma membranes H⁺-ATPase. *Plant and Soil*, *215*, 155-161. <https://doi.org/10.1023/A:1004752531903>
- Polidoro, J. C. (2013). *Fertilizantes Organominerais: Aspectos Mercadológicos e Tecnológicos—Rede FertBrasil*. Ribeirão Preto, São Paulo, Brasil: V Fórum Abisolo.
- Rocha, J. C., & Rosa, A. H. (2003). *Substâncias húmicas aquáticas: interações com espécies metálicas* (p. 120). São Paulo, UNESP.
- Silva, A. A., Silva, T. S., Vasconcelos, A. C. P., & Lana, R. M. Q. (2012). Aplicação de diferentes fontes de ureia de liberação gradual na cultura do milho. *Bioscience Journal*, *28*, 104-111.
- Van Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., ... Cowie, A. (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant Soil*, *327*, 235-246. <https://doi.org/10.1007/s11104-009-0050-x>
- Valderrama, M., Buzetti, S., Benett, C. G. S., Andreotti, M., & Filho, M. C. M. T. (2011). Fontes e doses de NPK em milho irrigado sob plantio direto. *Pesquisa Agropecuária Tropical*, *41*(2), 254-263. <https://doi.org/10.5216/pat.v41i2.8390>

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