International Journal of Recycling of Organic Waste in Agriculture (2023) Special Issue: 159-177
Doi: 10.30486/IJROWA.2023.1973162.1559

ORIGINAL RESEARCH

Effect of sugarcane filter cake-based organomineral fertilizers on sweet maize growth

Arkan Setiaji [1*], **Budi Santoso** [1], **Hendrawan Wibisono** [2]

Received: 20 November 2022 / Accepted: 03 August 2023 /

Abstract

Purpose: One of the primary wastes of the sugar industry that has the potential to be converted into fertilizer is filter cake. Organomineral fertilizer is proposed as a promising approach. Therefore, this research evaluated the efficiency of various filter cake-based organomineral formulations for sweet maize growth under different fertilization rates.

Method: The treatments comprised of seven formulations of filter cake-based fertilizers (filter cake (F), biochar (B), organomineral filter cake, organomineral biochar (OB), organomineral filter cake + humic acid, organomineral biochar + humic acid, and conventional mineral fertilizer (M)) and four rates (40, 80, 120, and 160 kg N ha^{-1}) based on the nitrogen (N) contents of each fertilizer. Furthermore, fertilizers applied to maize, and growth performance, nutrient use efficiency (NUE), and soil quality were assessed.

Results: Maize fertilization using F, B, and OB at different rates resulted in the highest vegetative growth performance, NUE, and residual soil status. F fertilizer produced the optimal plant height, leaf area, and stem diameter for maize. The application of OB fertilizer was most efficient in N uptake, potassium uptake, and potassium recovery, demonstrating values of 42.56%, 91.8%, and 115.4%, respectively. B fertilizer provided a better residual of P (93.4%) than M and a higher organic matter content (224.7%) than the negative control. As per our findings, OB is the best treatment for increasing growth performance, NUE, and soil quality with an optimal dose of 0.96 t ha^{-1}.

Conclusion: Fertilization using OB has significantly improved sweet maize agronomic traits and soil quality.

Keywords: Maize growth, Nutrient use efficiency, Organomineral fertilizer, Sugar industry waste

Introduction

Agribusiness is a growing market worldwide and is highly responsible for moving the Indonesian economy, with the fertilizer market being one of the highlighted elements in this chain. According to Allied Market Research® reports, the market size was worth USD 184.60 billion in 2021 and is projected to reach USD 251.57 billion by 2030, with the dry fertilizer subsegment dominating the growth (Pankaj and Vitika 2022). In 2021, 8.1 million tons of fertilizers were delivered to the Indonesian market, representing a growth of 22.8% compared to the previous year

✉ A Setiaji: arkansetiaji@apps.ipb.ac.id

1 Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, Indonesia
2 Division of Corn and Rice Research, ANR Co., Ltd., Ponorogo, Indonesia

(BPS-Statistics Indonesia 2022). Fertilizer consumption has been gradually increasing in volume, mainly due to the demand for sophisticated products, causing significant gains in agricultural productivity.

Organomineral fertilization can be applied as a strategy to meet the high nutrient demand required by the agricultural industry. This strategy as an alternative contributes to the sustainability by acting as a fertilizer and soil conditioner, improving chemical and physical attributes, and promoting substantial diversity of beneficial microorganisms (Ginting 2019; Wang et al. 2021), and lowering production costs with minimal dependence on mineral fertilizers (Fallah et al. 2018). Organomineral fertilizers consist of a mixture of organic raw materials (bone meal, peat, manure, sewage sludge, and industrial sugar waste) and mineral fractions (nitrogen (N), phosphorus (P), potassium (K), sulfur, and zinc) bound by chemical or adsorption technology (Smith et al. 2020). This organic waste emerges as an alternative to improve the efficiency of organomineral fertilizers without compromising crop productivity or reducing the selling price by up to 50% for environmental obligations (Crusciol et al. 2020; Bouhia et al. 2022; Carpanez et al. 2022).

Sugar factories in Indonesia produce a large amount of waste, such as molasses, bagasse, boiler ash, and filter cake, which are the main economically important byproducts for fertilizers. An Indonesian sugar factory with a milling capacity of 2400 tons per day can produce an average of 2960 liters of liquid waste and 60 tons of filter cake (Kurniasari et al. 2019). For each sugarcane processing unit, only 13% produces sugar, while the remaining 87% waste comprises 3% molasses, 4% filter cake, 28% bagasse, and 52% liquid effluents (Ochoa George et al. 2010). Various organic materials have been used to produce organomineral fertilizers, from which sugarcane filter cake is obtained from the mixture between ground bagasse and decantation sludge during the juice treatment production process of sugar (Purwono et al. 2011; Solomon 2011). The amount of filter cake byproduct depends on the extraction system; approximately 18–22 kg t^{-1} sugarcane is produced by the mill system, and the diffusion system is highly efficient, producing 5–6 kg t^{-1} (Santos et al. 2019). Junior et al. (2011) revealed that filter cake leaves the production process with 75%–80% moisture, and due to its organic composition, it is an excellent product for the recovery of low-fertility soils. Pressmud cake (PMC) or filter cake is one such source of organic matter and nutrients (rich in P and K), which can be profitably utilized for crop production. Like other organic manures, in addition to its favorable effects on the physicochemical and biological properties of soil, PMC has a great potential to supply nutrients for rice growth (Kalaivanan and Omar Hattab 2016).

Improving the chemical and physical characteristics of fertilizers is also essential to meeting the demand for high-quality products. The application of the pyrolysis process for filter cakes through biochar production and the addition of humic acids and polymers to produce organominerals have been studied in the current research.

This material can also be used to obtain biochar byproducts from the slow pyrolysis process in the total or partial absence of oxygen and at a temperature between 300ºC and 600ºC due to the high content of organic matter in the filter cake (Tripathi et al. 2016). This product increases N, P, K, Ca, Mg, and Fe levels and can also be considered as an excellent source of organic matter for the formulation of organomineral fertilizers (Puga et al. 2020; Sornhiran et al. 2021). The results of previous works indicate that biochar application significantly contributes to soil structure and consistency due to the changes in surface area density, distribution, and size of pores and particles (Atkinson et al. 2010; Xu et al. 2012; Shaaban et al. 2018). According to Hussain et al.

(2017), because of the solid aromatic structure characterized in biochar, it has a high resistance to degradation compared to other types of organic matter applied to the soil, thereby facilitating the formation of negative functional groups on its surface and slowing down soil oxidation. Furthermore, biochar retains ions from the soil through electrostatic phenomena, complexation, and capillary forces on its surface and pores (Ajema 2018). However, the influence of biochar on soils can vary differently because its properties depend on heterogeneity in the soil status and the quality and quantity of added biomass.

Fertilizers with the addition of humic substances also appear in special fertilizers. Humic acid may increase fertilizer efficiency due to its ability to compete for P adsorption sites and prevent nutrient adsorption by iron oxides and aluminum, maintaining the availability of the element for plants (Maluf et al. 2018; Xing et al. 2020). Another technology that has a high ability to be used is polymer coating which is produced from polyurethane and polyolefin. Polymer coats have been used to increase the efficiency of fertilization by fixing problems of nutrients immobilization in the soil, lost by leaching, volatilization, and denitrification through the gradual release of nutrients, which is the so-called slow-release fertilizer (Li et al. 2021; Sim et al. 2021).

A few studies have shown that organomineral fertilizers could improve plant growth and yield (Kominko et al. 2017; Smith et al. 2020; Bouhia et al. 2022; Carpanez et al. 2022). Using organomineral fertilizers, the productivity of potatoes and melons have been reported to be increased by 22% and 100% over mineral fertilizers, respectively (Makinde et al. 2007; Cardoso et al. 2017). Kominko et al. (2017) reported that organominerals derived from sewage sludge were potentially superior to mineral fertilizers due to the gradual release of nutrients and the optimal N, P, and K ratio. Furthermore, organomineral fertilizers could mitigate tomato salinity (Rady 2012) and water stress in cucumbers (Abd El-Mageed and Semida 2015). Therefore, this research analyzed the efficiency of agricultural production of mashed organomineral fertilizers from filter cake or its biochar, with their mixture with humic substances, and comparison of them to other types of mineral fertilizer in sweet maize growth.

Materials and methods

Production of fertilizers

The fertilizers were produced at the Kebumen village-owned enterprises (BUMDes) based in the Kendal regency, with fertilizer production facilities at the factory. Filter cake from Industri Gula Nusantara Co. Ltd. assisted composting until stabilization with subsequent drying and reaching a water content of around 25%. Then, the composted filter cake was separated into organic fertilizer or mixed with soluble mineral fertilizers (urea, monoammonium phosphate (MAP), and KCl) to obtain the mashed organomineral fertilizer. In other processes, the filter cake was added to a pyrolysis reactor at a constant temperature of 400°C. After carbonization of this material, the final product was biochar, whose ash content was about 77%. . Biochar was also separated into organic fertilizer or used to manufacture organomineral fertilizer. After the production of organomineral fertilizers obtained from the composting and pyrolysis of the filter cake, samples derived from this product were separated for adding humic acids in the proportion of 15 kg ton^{-1} of organomineral fertilizer produced. Conventional mineral fertilizer was obtained as a positive control by mixing granules from urea, MAP, and KCl-soluble minerals. The chemical composition of the fertilizers used in the experiment is described in Table 1.

Table 1. Treatments and chemical composition of the fertilizers used in the experiment

Parameters	F	B	OF	OB	OFH	OBH	M
MC (%)	22.6	6.6	4.4	4.3	10.5	4.1	0.9
C (%)	16.6	16.0	8.2	8.1	7.67	7.9	-
N (%)	0.5	0.4	12.0	12.0	12.0	12.0	18.0
P (%)	0.8	0.5	12.0	12.0	12.0	12.0	18.0
K (%)	0.4	0.3	12.0	12.0	12.0	12.0	18.0
CEC (mmol kg^{-1})	366.1	221.9	110.2	116.3	187.5	198.8	-
pH	6.2	6.6	7.2	6.8	6.5	6.7	5.8
EC (dS m^{-1})	0.7	0.3	1.1	1.1	1.7	1.3	2.0

MC: moisture content, C: organic carbon, N: total nitrogen, P: total P_2O_5, K: potassium, CEC: cation exchange capacity, EC: electrical conductivity, F: filter cake, B: biochar, OF: organomineral filter cake, OB: organomineral biochar, OFH: organomineral filter cake + humic acid, OBH: organomineral biochar + humic acid, M: conventional mineral fertilizer

Growing media

The experiment was conducted in a screenhouse from July to October 2022 in plastic polybags with approximately 18 kg of oxysol-type soil. After collecting, the soil was sieved using a 4 mm mesh and received the application of dolomitic limestone (Kapur Pertanian Kebomas™), with a plaque reduction neutralization test of 90%, CaO content around 46%, and MgO of 8% under 18 g per pot proportion, considering subsequent incubation for 60 days for increased acidity (pH 6.5–7) and base saturation to 60%. The chemical and physical characteristics of the soil after incubation are as follows: pH (H_2O) 6.7, Ca 0.74 $cmol_c$ kg^{-1}, Mg 0.37 $cmol_c$ kg^{-1}, P 0.74 $cmol_c$ kg^{-1}, K 14.81 $cmol_c$ kg^{-1}, H^+Al 1.7 $cmol_c$ kg^{-1}, CTC 1.26 $cmol_c$ kg^{-1}, S-SO_4 41 mg kg^{-1}, organic matter 6.0 g kg^{-1}, organic carbon 4.0 g kg^{-1}, Cu 0.7 mg kg^{-1}, Fe 9 mg kg^{-1}, Mn 2.4 mg kg^{-1}, Zn 0.5 mg kg^{-1}, base saturation 58%, coarse sand 297 g kg^{-1}, thin sand 250 g kg^{-1}, thin sand silt 54 g kg^{-1}, and clay 400 g kg^{-1}.

Experimental design

The experiment was carried out in a completely randomized design with two factors (7 × 4) (n = 5). The first factor was included seven different formulas of fertilizers all applied at the base 5 cm below the sowing spot, and the second factor was also different doses based on the N contents of the fertilizers (40, 80, 120, and 160 kg N ha^{-1}). Except for filter cake and biochar fertilizers with different doses of P and K, the experimental pots received the same doses of these nutrients due to the equality of P and K contents in organomineral and mineral fertilizers. Therefore, the dosage of both treatments was calculated considering the N content, fixing this element as the basis for calculating the application dosage, as shown in Table 2. Finally, an additional negative control (without fertilizer application) was added to the experimental pots.

Maize seed sowing and fertilizer performance analysis

Sixty days after soil incubation, fertilizers were included and two seeds of maize (Tamara sweet maize variety) were sown in each pot.

Table 2. Fertilizers, amount of nutrients, and doses provided for each treatment

Fertilizers	NPK content (kg ha^{-1})			Equivalent of doses applied		
	P_2O_5	N	K_2O	t ha^{-1}	g kg^{-1} soil	g plant^{-1}
Control	0	0	0	0	0	0
F	64	40	32	8	4	72
	128	80	64	16	8	144
	192	120	96	24	12	216
	256	160	128	32	16	288
B	50	40	30	10	5	90
	100	80	60	20	10	180
	150	120	90	30	15	270
	200	160	120	40	20	360
OF	40	40	40	0.33	0.17	3
	80	80	80	0.66	0.33	6
	120	120	120	1.00	0.50	9
	160	160	160	1.33	0.67	12
OB	40	40	40	0.33	0.17	3
	80	80	80	0.66	0.33	6
	120	120	120	1.00	0.50	9
	160	160	160	1.33	0.67	12
OFH	40	40	40	0.33	0.17	3
	80	80	80	0.66	0.33	6
	120	120	120	1.00	0.50	9
	160	160	160	1.33	0.67	12
OBH	40	40	40	0.33	0.17	3
	80	80	80	0.66	0.33	6
	120	120	120	1.00	0.50	9
	160	160	160	1.33	0.67	12
M	40	40	40	0.22	0.11	2
	80	80	80	0.44	0.22	4
	120	120	120	0.66	0.33	6
	160	160	160	0.88	0.44	8

F: filter cake, B: biochar, OF: organomineral filter cake, OB: organomineral biochar, OFH: organomineral filter cake + humic acid, OBH: organomineral biochar + humic acid, M: conventional mineral fertilizer

Thinning was performed fifteen days after planting (DAP), leaving only one plant per pot. Meanwhile, at 20 DAP, micronutrients (S, Zn, B, Cu, and Mn) in liquid form were applied to the pots in a proportion of 60, 6.0, 2.2, 1.5, and 2.0 kg ha^{-1}, respectively.

At 45 DAP, when the plants had five fully developed leaves, the soil plant analysis development (SPAD) index was measured using a portable SPAD-502 plus chlorophyll meter (Minolta Co., Ltd.). Measurements were taken from the central parts of newly expanded but physiologically mature leaves. Using the SPAD indirectly facilitates the status assessment of plant N in real time (Hou et al. 2021). At 70 DAP, plant height (cm), stem diameter (mm), and leaf area (cm^2) were measured when the plants had 10 fully developed leaves:. Dry mass (g) of the aerial part of the plants (leaves and stems) and roots were determined after these evaluations. The samples were then initially ground in a Willey-type mill (2 mm) and sent to the Sucofindo Laboratory, where chemical analyses followed the methodology described by Motsara (2015). The accumulation of nutrients in the shoot was calculated by multiplying the shoot's dry weight (g) by the nutrient content in grams per kg. The percentage of P and K recovered for each treatment was calculated in accordance with the methodology described in the document efficiency of use of nutrients in plants based on the results (Baligar et al. 2001).

$$ARE\ (\%) = \frac{\mathrm{NUF} - \mathrm{NUC}}{QNA} \times 100$$

where ARE denotes apparent recovery efficiency; NUF is the nutrient uptake fertilizer: Accumulated P or K at a dose of 160 kg N ha^{-1}; NUC is the nutrient uptake control: Accumulated P or K at a dose of 160 kg N ha^{-1}; QNA is the quantity of P or K at an applied dose of 160 kg N ha^{-1} (column 2 and 4 in Table 1). The dose equivalence of fertilizers was calculated using equation 2 based on the dry mass results and mineral fertilizer as a definitive source. The calculation of the mineral fertilizer equivalent (MFE) and nutrient use efficiency (NUE) was described in the document as methodological principles for the agronomic evaluation of P sources.

$$MFE(\%) = \frac{[(xf_{120} - xt) + (xf_{160} - xt)]}{[(xm_{120} - \mathrm{xt}) + (xm_{160} - \mathrm{xt})]} \times 100\%$$

where xf$_{120}$ is the shoot dry weight (SDW) in tested fertilizer 120 kg N ha^{-1}; xf$_{160}$ is the SDW in tested fertilizer 160 kg N ha^{-1}; xm$_{120}$ is the SDW in mineral fertilizer 120 kg N ha^{-1}; xm$_{160}$ is the SDW in mineral fertilizer 160 kg N ha^{-1}; xt is the SDW of the negative control.

Meanwhile, agronomic efficiency (AE) was calculated in the following equations:

$$AE(kg\ kg^{-1}) = \frac{SDW\ of\ fertilized\ plot - SDW\ of\ control}{QNA}$$

Chemical analysis (P, K, and organic matter) of soil sample was performed in accordance with the method described by Motsara (2015) to determine the effect of fertilizer on the improvement of soil chemical characteristics.

Statistical analysis

Statistical analysis was performed using the SmartstatXl ver. 3.0.05 software program. The data were submitted to analysis of variance, and the means were compared by the Scott–Knott test (0.05 of significance) for specific comparison.

Results and discussion

Effects of fertilizer rates and types on maize growth

The results showed that applying fertilizers generally increased the SPAD index in maize. Apart from the mineral (M), biochar (B), and organomineral filter cake (OF) treatments, a decrease in the SPAD index was observed with the application of the highest doses (Table 3). The maximum results (35.99) were observed with the treatments using OF at doses of 120 kg N ha^{-1}, where the result was not significantly different from the filter cake (F) and OF at 160 kg N ha^{-1}. No significant difference ($p \leq 0.05$) was observed in the control for all doses of the B treatments, 120 kg N ha^{-1} organomineral biochar + humic acid (OBH), and M fertilizer at doses of 120 and 160 kg N ha^{-1}. Rocha et al. (2005) observed positive correlations between N content and SPAD index in maize at the stages of four and eight leaves and silking. The SPAD index has a high relationship with maize grain yield, and this correlation is like that between N content in the leaf index (first leaf below the ear) and grain yield (Szulc et al. 2021). Dong et al. (2015) indicated that the chlorophyll meter determined the intensity of the leaf's green color (the amount of light absorbed by the chlorophyll) and increased the possibility of obtaining indirect values of chlorophyll present in the leaves. In practice, using the SPAD index facilitated the indirect evaluation of the N content of the plant in real time. This device was characterized by rapid, handheld spectral tools and nondestructive reading material.

All types and fertilization doses significantly affected plant height (Table 3). The optimal height of maize was obtained after applications of 160 kg N ha^{-1} F fertilizer and organomineral biochar (OB), with a height of 163.86 and 161.57 cm, respectively. A decrease in this variable was observed when OBH and M fertilizers (120 and 160 kg N ha^{-1}, respectively) were applied to the soil. Widodo et al. (2018) found the best formulation of organomineral fertilizer, by comprising the mixture of 15% chicken manure, 20% mineral, and 65% straw. This fertilizer enhanced the height and dry weight of maize. In general, the use of organominerals increases the plant height and the number of corn leaves, which correlate with the results obtained during the harvest (Anetor and Omueti 2014; Subiksa and Husnain 2019). Considering the leaf area, treatments F, OB, organomineral filter cake + humic acid (OFH), and OBH were observed to increase with increasing doses of fertilizers (Table 3). The treatments B, OF, and M obtained maximum responses when applied at 80, 120, and 160 kg N ha^{-1}, respectively, with a decrease in this variable when applied to higher doses. The highest value for leaf area was recorded with the treatment based on F, OF, and OB fertilizers at a dose of 160 kg N ha^{-1}. Fertilization with filter cake is widely used in sugarcane plantations because the location between the processing plant and the estate is generally close together; thus, this fertilizer provided optimal results. The increase in the leaf area of sugarcane was consistent with that in the dose of filter cake used (Civiero et al. 2014). The leaf area parameter is mostly affected significantly due to the application of cake filters (Santos et al. 2014; Wibisana et al. 2020).

Analyzing the effect of fertilizer on stem diameter, the highest values (16.73 mm) were found for the treatments using OB at a dose of 160 kg N ha^{-1}, followed by F at 120 and 160 kg N ha^{-1} (Table 3). The treatment of OB and OBH at 40 and 120 kg N ha^{-1}, respectively, did not show significant difference when compared to the control. Analysis of stem diameter analysis is essential because it not only indicates the plant's ability to collect nutrients and redistribute them to the grains at the time of filling, but also reduces plant lodging and breakage in the field (Ebrahimi et al. 2011). Mendes et al. (2011) demonstrated that maize stem diameter at 45 DAP was highest when organomineral fertilizer was applied; however, 75 DAP mineral fertilization showed better results.

In other studies, maize growth performance (plant height, stem diameter, number of leaves, and first insertion of the ear) did not show significant differences in various organomineral fertilizer formulations but differed significantly from control and mineral-only fertilizers (Santana 2012; Martins et al. 2017; Wulansari et al. 2022). These findings confirmed the importance of combining mineral substances with organic matter to increase the agronomic potential of maize.

The F and OF treatments showed the optimum shoot dry mass results, with emphasis on the application of filter cake at 120 and 160 kg N ha^{-1} and OF at 160 kg N ha^{-1}, with the production of 24.52, 23.20, and 23.10 g of dry mass, respectively (Table 3).

Table 3. Growth performance of maize subjected to different fertilizers

Fertilizers	N rate (kg ha^{-1})	SPAD	Height (cm)	Leaf area (cm^{2})	Stem diameter (mm)	Shoot dry weight (g)	Root dry weight (g)
Control	0	21.89	57.85	464.78	4.59	0.92	0.38
F	40	28.04^{c}	122.12^{f}	1562.9^{j}	10.40^{d}	8.92^{f}	2.48^{f}
	80	30.37^{b}	133.42^{d}	2623.3^{e}	11.70^{c}	17.23^{c}	5.74^{c}
	120	34.30^{a}	149.65^{b}	3100.2^{c}	15.07^{b}	23.20^{a}	8.88^{a}
	160	35.71^{a}	163.86^{a}	3660.6^{a}	15.22^{b}	24.52^{a}	5.75^{a}
B	40	24.64^{ns}	97.93^{h}	1179.7^{l}	9.46^{d}	6.76^{g}	3.88^{g}
	80	24.37^{ns}	123.84^{f}	1911.8^{h}	11.92^{c}	10.07^{e}	4.02^{e}
	120	23.64^{ns}	130.63^{d}	1636.1^{j}	12.37^{c}	13.51^{d}	4.43^{d}
	160	22.19^{ns}	136.35^{d}	1650.1^{j}	13.32^{c}	13.85^{d}	4.96^{d}
OF	40	28.92^{c}	132.35^{d}	2148.5^{g}	9.85^{d}	8.88^{f}	4.16^{f}
	80	33.15^{a}	139.48^{c}	2327.5^{f}	11.98^{c}	10.64^{e}	4.58^{e}
	120	35.99^{a}	149.19^{b}	3384.5^{b}	14.47^{b}	15.62^{c}	8.03^{c}
	160	34.41^{a}	145.04^{c}	2525.7^{e}	12.87^{c}	23.10^{a}	10.19^{a}
OB	40	30.65^{b}	116.38^{g}	1377.6^{k}	7.03^{ns}	5.49^{g}	1.66^{g}
	80	31.85^{b}	136.94^{d}	2217.2^{g}	13.57^{c}	19.59^{b}	7.87^{b}
	120	34.40^{a}	137.29^{d}	2409.2^{f}	14.15^{b}	24.21^{a}	7.89^{a}
	160	36.62^{a}	161.57^{a}	3365.0^{b}	16.73^{a}	16.77^{c}	8.11^{c}
OFH	40	27.80^{c}	111.72^{g}	1629.4^{j}	8.75^{e}	6.41^{g}	4.49^{g}
	80	27.83^{c}	112.30^{g}	1826.5^{i}	10.93^{d}	7.86^{f}	4.53^{f}
	120	29.55^{b}	113.66^{g}	2143.9^{g}	10.38^{d}	9.42^{f}	6.08^{f}
	160	32.96^{a}	135.16^{d}	2979.9^{d}	13.76^{b}	19.77^{b}	6.53^{b}
OBH	40	31.70^{b}	128.36^{e}	1678.1^{j}	9.93^{d}	7.24^{g}	4.77^{g}
	80	33.58^{a}	141.55^{c}	1907.4^{h}	12.82^{c}	11.29^{e}	4.91^{e}
	120	26.22^{ns}	109.36^{g}	2215.1^{g}	7.90^{ns}	12.63^{d}	7.08^{d}
	160	34.94^{a}	127.68^{e}	2871.9^{d}	12.82^{c}	17.39^{c}	7.95^{c}
M	40	32.13^{b}	110.73^{g}	1321.6^{k}	8.65^{e}	6.03^{g}	3.19^{g}
	80	33.66^{a}	133.32^{d}	2968.5^{d}	12.41^{c}	13.36^{d}	8.89^{d}
	120	21.89^{ns}	144.98^{c}	3173.0^{c}	14.57^{b}	12.31^{d}	3.36^{d}
	160	20.81^{ns}	120.87^{f}	2361.3^{f}	11.98^{c}	9.34^{f}	4.15^{f}

Means followed by distinct letters in the same column differ from each other by the Scott–Knott test at 0.05 of significance, ns: not significant to control. F: filter cake, B: biochar, OF: organomineral filter cake, OB: organomineral biochar, OFH: organomineral filter cake + humic acid, OBH: organomineral biochar + humic acid, M: conventional mineral fertilizer

The use of organomineral fertilizers increases the dry weight of shoots at least six times compared to the control. Similarly, considering the organomineral fertilizer NPK 5-15-5 in maize and comparing it with mineral fertilizer NPK 10-30-10, Teixeira et al. (2011) verified a 20% increase in plant dry weight with the application of organomineral fertilizer. These results demonstrated that the association of organic and mineral fertilizers could increase the efficiency of mineral use, providing better results in the field (Kaur et al. 2005; Herencia et al. 2008). In contrast, Lana et al. (2014), working with two types of soil (red-yellow argisol and eutroferric red latosol) and evaluating the SDW of maize after applying the organomineral fertilizer Umostart™ and mineral MAP, found high levels of P in soil and shoots when using the mineral fertilizer compared to the organomineral fertilizer. The authors revealed that the results may be related to the excellent solubility of the MAP mineral fertilizer and its consequent high availability for the plants in the soil.

Silva et al. (2011) studied the effect of humic substances isolated from a peat bog in the Serra do Espinhaço, Brazil, on the root growth promotion of tomato seedlings and found that humic acids possessed a high capacity to induce lateral roots in the initial stage of tomato development, promoting the appearance of root hairs on seedlings. However, in this study, optimum root dry weight was obtained on fertilization using OF, F, and M at 160, 120, and 80 kg N ha^{-1}, respectively (Table 3). Fertilizer added with humic acid only produces a maximum dry weight of root (7.95 g) in the OBH treatment. Applying a filter cake as fertilizer that contains 16.6% organic carbon could promote optimal biomass accumulation in maize.

Effects of fertilizers on NPK accumulation in shoot

Different types and fertilization rates significantly affected the concentration of N, P, and K in the shoot (Table 4). The fertilization using OF, OB, and OFH had a definite effect at the concentrations of 120 and 160 kg N ha^{-1} for the accumulation of N, P, and K. Except for biochar treatment, accumulated N was comparable with an increase in the fertilization dose. The use of biochar as a soil amendment improved N uptake, which resulted in 1.76 times higher N accumulation at 120 kg N ha^{-1} OB treatment compared to the 160 kg N ha^{-1} mineral treatment. These results are consistent with those obtained by other studies (Huang et al. 2019; Khan et al. 2021). A study on two sugarcane varieties showed that additional biochar led to an increase of up to 24% and 30% in N uptake (Chen et al. 2022). The positive effect of OB is probably due to the adequacy of N (12%) contained in fertilizer; the presence of biochar can also improve nutrient holding capacity, reduce water evaporation, minimize nutrient leaching, and thus improve N availability for roots. Notably, the effect of biochar cannot be compared to compost or manure, which increases soil fertility in different ways. Thus, combining compost and manure is the best fertilization option. The highest increase in P concentration (102.90 mg plant^{-1}) was observed in the treatment with OB. The treatment resulting in the lowest P concentration was detected in 40 kg N ha^{-1} filter cake. The interaction of N and P with biochar can improve the performance of symbiont microbes in soybean (Egamberdieva et al. 2022). The meta-analysis study by Glaser and Lehr (2019) predicted an increase in soil P availability of 4.6 times when the soil was ameliorated with biochar. Availability increased 2.4 times when applied to soil pH 6.5–7.5 and continued to increase in acid soils (Ahmed et al. 2021). The optimal value for the K accumulation showed no significant difference between OB (1295.38 mg plant^{-1}) and OFH (1298.59 mg plant^{-1}) treatments at a dose of 160 kg N ha^{-1}. K is absorbed by roots in the form of K^{+}, which is facilitated by high-affinity transporters and ion channels. In pots with limited soil volume, K transport generally follows the mass flow; therefore, air circulation and soil moisture play an important role (Mackay and Barber 1985; Rosolem et al. 2003). de Mello-Prado (2021) found that K absorbed from soils with sufficient humidity (approximately 33 kPa) was 1.72 times higher than soils with deficient humidity (−170 kPa). High

K absorption after the application of fertilizers containing biochar and filter cake compost enhances nutrient and water-holding capacity in the root area. However, this phenomenon needs further confirmation, especially in terms of the water-holding capacity of media and soil nutrient content after fertilization. Mahmood et al. (2019) observed that the increase in the absorption of nutrients by plants after the application of humic acids was promoted by the rise in the plasma membrane (PM) permeability through their surfactant action and the activation of PM H^+-ATPase. Notably, the electrochemical gradient generated by H^+-ATPase is directly involved in mechanisms responsible for plant development, such as the energization of secondary systems responsible for the absorption of nutrients by plants and the increase in cellular plasticity accountable for plant growth. Considering acid growth theory, which induces an increase in proton extrusion mediated by H^+-ATPase, the latter promotes apoplast acidification, activating specific enzymes that act on the cell wall and thus allowing plant cell elongation (Shao et al. 2021).

Most of the research revealed that humic acid significantly enhanced the activity of nitrate reductase, nitrite reductase, and glutamine synthetase enzymes involved in the reduction and assimilation of N (Ampong et al. 2022). However, the present research revealed that adding humic acid in formulations of OFH and OBH in overall rates did not significantly increase NPK uptake. This finding might be due to the interaction between humic acid and other ingredients under concentrated conditions. The relative content of carboxyl groups in humic acid combined with high PO_4-based fertilizers and low O/C and (O+N)/N atomic ratios was previously reported to enhance the hydrophilicity for nutrient release (Jing et al. 2020). However, additional research is necessary to obtain a clear picture. Different from the observed results, Costa et al. (2011) evaluated the effects of the use of cover crops and the application of three different fertilizers (mineral, organomineral, and organic) for the maize plants and found high levels of foliar N with the application of mineral treatment. The mineral fertilizer presented large N solubility concerning the organomineral and organic sources due to the differences in the solubility during fertilization. This finding could be due to the low immediate availability dependent on the mineralization of the organic matter present in the sources containing organic matter in their structure. Numerous studies have been conducted on N, P, and K accumulation in different organs; however, the critical concentration of these nutrients has been unavailable.

ARE, MFE, and AE value of different types of fertilizers

ARE represented the contents of nutrients recovered from the soil and accumulated in the aerial part of the plants. High efficiency of potassium (K) recovery was observed for the treatment OFH (Fig. 1A). The treatments OF and OB demonstrated the best results for phosphorus (P) (Fig. 1B). ARE demonstrated the difference between the contribution of the original P and K from within the soil and that accumulated in the plant tissues with fertilizer. The physical and chemical protection provided by the addition of organic matter to organomineral fertilizers, with a consequent improvement in the supply efficiency of nutrients to the maize, was attributed to a high content of P and K recovered from the soil and translocated to the aerial part of the maize. The MFE revealed a large value of all fertilizers, mainly highlighting the fertilization using F (227.55%), OB (198.84%), and OF (155.07%) (Fig. 1C). A value of more than 100% indicated that the use of organic fertilizer was not only equivalent but the nutrient content was also substantially better than mineral fertilizer.

Table 4. Nitrogen (N), phosphorus (P), and potassium (K) accumulated in shoot maize

Fertilizers	N rate (kg ha^{-1})	N (mg plant^{-1})	P (mg plant^{-1})	K (mg plant^{-1})
Control	0	18.81	2.81	70.71
F	40	54.51^{r}	6.93^{ns}	170.14^{r}
	80	116.94^{o}	40.91^{g}	388.90^{j}
	120	142.79^{l}	56.26^{d}	506.04^{h}
	160	225.36^{i}	63.69^{c}	808.04^{d}
B	40	28.46^{ns}	15.67^{l}	147.58^{s}
	80	47.17^{s}	20.92^{j}	234.69^{p}
	120	68.93^{q}	27.17^{i}	336.86^{m}
	160	64.35^{q}	30.10^{h}	416.42^{i}
OF	40	86.74^{p}	18.13^{k}	230.88^{p}
	80	132.72^{m}	24.68^{i}	311.74^{n}
	120	354.25^{d}	48.78^{e}	689.83^{e}
	160	443.42^{b}	74.56^{b}	1064.95^{b}
OB	40	69.33^{q}	15.79^{l}	187.56^{q}
	80	187.25^{k}	63.54^{c}	294.24^{o}
	120	482.44^{a}	102.90^{a}	635.97^{f}
	160	328.61^{e}	77.78^{b}	1295.38^{a}
OFH	40	57.40^{r}	18.89^{k}	187.84^{q}
	80	126.87^{n}	18.31^{k}	293.27^{o}
	120	216.72^{j}	28.88^{h}	640.59^{f}
	160	363.02^{c}	63.65^{c}	1298.59^{a}
OBH	40	57.68^{r}	11.41^{m}	197.39^{q}
	80	123.34^{n}	25.86^{i}	374.87^{k}
	120	234.16^{n}	38.62^{g}	381.26^{k}
	160	264.43^{g}	46.08^{f}	926.84^{c}
M	40	71.04^{q}	14.52^{l}	188.61^{q}
	80	181.10^{k}	39.86^{g}	806.74^{d}
	120	222.97^{i}	43.70^{f}	578.36^{g}
	160	273.79^{f}	37.47^{g}	364.22^{l}

Means followed by distinct letters in the same column differ from each other based on the Scott–Knott test at 0.05 of significance, ns: not significant to control. F: filter cake, B: biochar, OF: organomineral filter cake, OB: organomineral biochar, OFH: organomineral filter cake + humic acid, OBH: organomineral biochar + humic acid, M: conventional mineral fertilizer

The application of 100 kg N through a cake compost filter with an MFE value of 227.55% will resulted in the same N uptake of corn as 227.55 kg of N mineral fertilizer. Terms, such as NUE, AE, and partial nutrient balance, also refer to the same description (Syers et al. 2008; Masclaux-Daubresse et al. 2010; Dreschsel et al. 2015), which showed the capability of crops to consume and utilize the N or other specific nutrients for optimum growth. AE could also be expressed as the ratio between the output of biomass and the input of fertilizers. The highest AE values were obtained in the OB (198.84%), F (127.55%), and OF (55.07%) (Fig. 1D). Plants with a high AE value could maximize the conversion of absorbed nutrients to form plant biomass. Some studies conducted in the field to evaluate the AE of using organomineral fertilizer in the cultivation of sugarcane demonstrate that the organomineral fertilizer was more efficient than the conventional mineral fertilizer in cane plants and ratoon cane. This efficiency could be due to the capability of the organomineral fertilizer to replace the mineral fertilizer and offer up to 23.8% more efficiency in the production of sugarcane stalks, thus providing high profitability for the segment (Souza et al. 2014). Fertilization using biochar did not obtain higher AE compared with conventional mineral fertilizer application. The high recalcitrance of this material affected insufficient time for the total release of the nutrients, thereby revealing a low biomass accumulation.

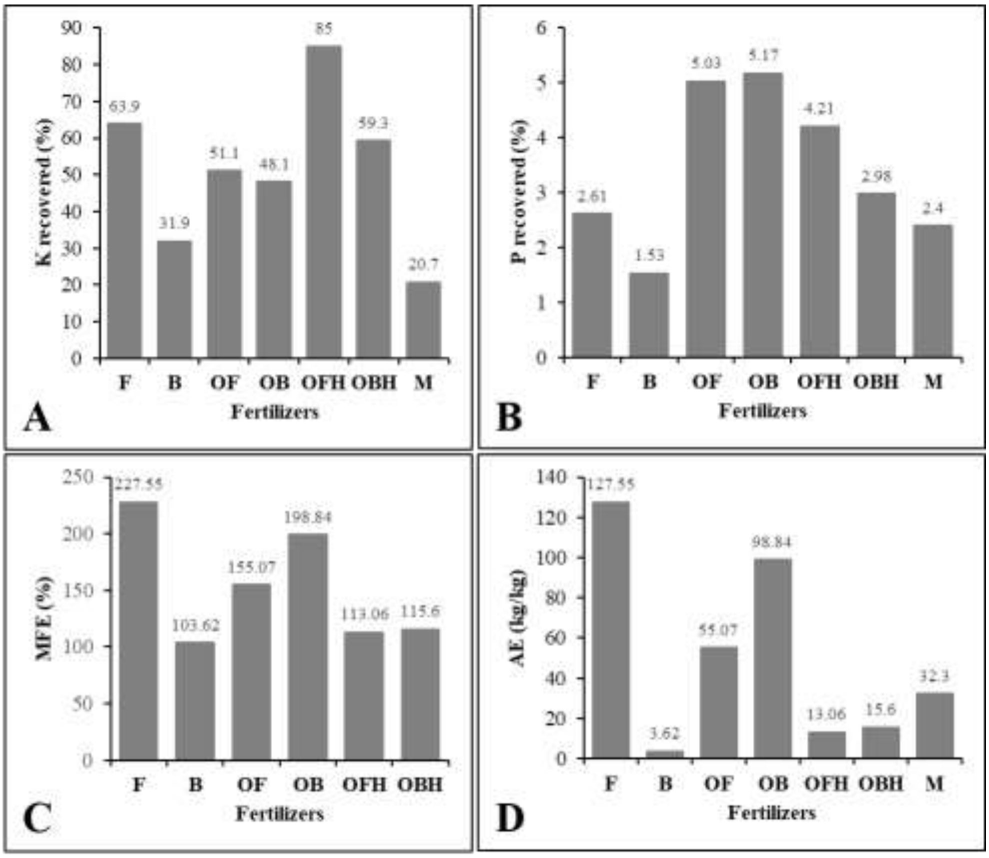

Fig. 1 Apparent recovery of K (A) and P (B) efficiency, mineral fertilizer equivalent (C), and Agronomic efficiency (D) of different types of tested fertilizers

Effects of fertilizers on P, K, and organic matter content in the soil

Evaluating the levels of P and K present in the soil at 70 DAP, an increase of these nutrients was observed along with an increase in the applied fertilizer dose. The application starting from 40 kg N ha^{-1} caused a significant difference in P content compared to the control (Table 5). The maximum available P present in the soil, approximately 252.14 mg kg^{-1}, was observed in the application of 160 kg N ha^{-1} of OF fertilizer. P in the soil was only 3.54 mg kg^{-1} in the untreated control. The increase of P available in the soil provided by organomineral fertilizers might be linked to the organic matter in these fertilizers. The effect of the organic matter present in the organomineral fertilizer might have contributed to reducing the fixation of P, thus favoring the presence of high levels of this element in soil (Borges et al. 2019). Martins et al. (2017) evaluated the residual effect of P after the application of mineral and organomineral phosphate fertilizers and found a tendency for better results when associated with the application of organomineral fertilizers compared with super triple phosphate despite the absence of statistical differences in the levels of available P in the soil depending on the applied fertilizers. The organic functional groups in the filter cake coukd fill the P fixation sites, increasing the availability of this element to plants due to decreased P reaction with clay minerals and iron oxides. When mineral fertilizers were applied, mixed with an organic source, the present organic carriers can improve the solubility of P compounds in the soil, gradually releasing this element to the plants. The soil available K was significantly affected by fertilizers (Table 5). B treatment at doses of 120 and 160 kg N ha^{-1} and M and OF treatments at 160 kg N ha^{-1} showed the best increments of this element compared to the other fertilizers. The highest K content (312.98 mg kg^{-1}) in soil was obtained from B treatment at doses of 160 kg N ha^{-1}. Teixeira (2013) verified the AE of the organomineral fertilizer in the sugarcane crop and analyzed the data on the residual effect of K in the soil 133 days after the application of the organomineral and mineral fertilizer. This verification revealed that the application of organomineral fertilizer provided an average increase of 18% in the K content in the soil in relation to mineral fertilizer. This result might be related to the low release of K due to the gradual release of the nutrient provided by the organic fraction of the fertilizer and the consequent decrease in leaching and loss of K in the soil. By contrast, Wietholter et al. (1994) analyzed the effect of fertilization with conventional mineral, organomineral fertilizers, and the direct application of organic compost based on poultry litter in the soil and found no significant difference in the K content regardless of the fertilizers used. The availability of organic matter in soil plays an important role in the provision of N, where mineralization can provide 54%–78% of total N compared to N from mineral fertilizers, which are easily denitrified and leached (Intansari and Subiksa 2022). All doses of OF, OB, OFH, OBH, M, and F 40 kg N ha^{-1} did not differ markedly from the control (Table 5). The application of B fertilizer at 120 kg N ha^{-1} significantly increased soil organic matter (SOM) four times more than the control (from 8.5 g kg^{-1} to 37.0 g kg^{-1}). Except for filter cake treatment, 160 kg N ha^{-1} applications lowered the SOM content. Research suggested that the application of biochar in the soil could lead to a stabilization of SOM (Chen et al. 2020). Thus, in soils with modern agrosystems, the net carbon gain from applying biochar based on soil management strategies would be considerably improved, favoring the fixation of organic carbon. Filter cake fertilizer (160 kg N ha^{-1}) also has a beneficial effect on SOM, by enhancing its concentration 1.8 times higher than the control. Another study by Ossom et al. (2012) in Swaziland reported that the high application of filter cake (40 t ha^{-1}) in maize fields markedly improved SOM and P concentration by nine times. The P content in the soil increased by 78% when a combination of filter cake and rice husk ashes was applied. This treatment also increased plant biomass by 11.9% and P uptake by 2.7 folds compared with the untreated soil (Utami et al. 2012). Different results were found in a study conducted by Costa et al. (2011). They evaluated the rotation effect of cover crops associated with three sources of fertilization (mineral, organic, and organomineral) on the chemical attributes of a eutroferric red latosol and found better results in 0–10 cm soil samples where the application of organic fertilizer was better than other treatments.

Table 5. P, K, and organic matter in the soil after application of different doses of fertilizers

Fertilizers	N rate (kg ha^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Soil organic matter (g kg^{-1})
Control	0	3.54	14.8	8.5
F	40	49.62^{q}	57.92^{l}	8.8^{ns}
	80	147.86^{i}	158.36^{f}	13.5^{e}
	120	75.82^{m}	95.64^{j}	10.5^{f}
	160	206.92^{c}	98.62^{j}	15.5^{d}
B	40	88.18^{l}	66.44^{k}	11.3^{f}
	80	148.98^{i}	142.12^{g}	28.2^{c}
	120	242.80^{b}	212.86^{c}	37.0^{a}
	160	252.14^{a}	312.98^{a}	33.7^{b}
OF	40	41.56^{r}	29.60^{o}	7.1^{ns}
	80	136.92^{j}	60.18^{l}	6.6^{ns}
	120	134.28^{j}	174.98^{e}	8.4^{ns}
	160	199.96^{d}	176.68^{e}	8.2^{ns}
OB	40	57.50^{p}	39.92^{n}	6.5^{ns}
	80	58.06^{p}	52.38^{m}	7.1^{ns}
	120	113.20^{k}	55.68^{m}	8.4^{ns}
	160	170.08^{f}	160.62^{f}	8.1^{ns}
OFH	40	42.50^{r}	15.44^{ns}	6.0^{ns}
	80	61.94^{o}	28.24^{o}	5.4^{ns}
	120	164.72^{g}	70.32^{k}	7.6^{ns}
	160	159.68^{h}	102.58^{i}	7.0^{ns}
OBH	40	42.68^{r}	17.66^{ns}	7.2^{ns}
	80	33.70^{s}	$18,20^{ns}$	7.0^{ns}
	120	65.82^{n}	113.68^{h}	5.5^{ns}
	160	159.76^{h}	115.94^{h}	6.8^{ns}
M	40	14.80^{t}	11.74^{ns}	6.5^{ns}
	80	15.08^{t}	13.66^{ns}	6.6^{ns}
	120	171.18^{f}	202.38^{d}	7.0^{ns}
	160	177.36^{e}	219.42^{b}	8.3^{ns}

Means followed by distinct letters in the same column differ from each other by the Scott–Knott test at 0.05 of significance, ns: not significant to control. F: filter cake, B: biochar, OF: organomineral filter cake, OB: organomineral biochar, OFH: organomineral filter cake + humic acid, OBH: organomineral biochar + humic acid, M: conventional mineral fertilizer

Determination of the optimal rate of OB fertilizer

The availability of nutrients in the planting medium determined the response of plants to fertilization. This response was also affected by the type and original nutrient status of the media. Plants will not show a significant response to N fertilization in soils with high or remarkably high N availability classes; therefore, determining the optimal dose is necessary. Based on the regression equation X = −25.695 +

$120.71X - 62.289X^2$ (Fig. 2) with a correlation value (r) of 0.989 and a coefficient of determination (R^2) of 97.87%, the optimal dose of fertilization with OB was 0.96 t ha^{-1}, with optimal biomass reaching 32.79 g.

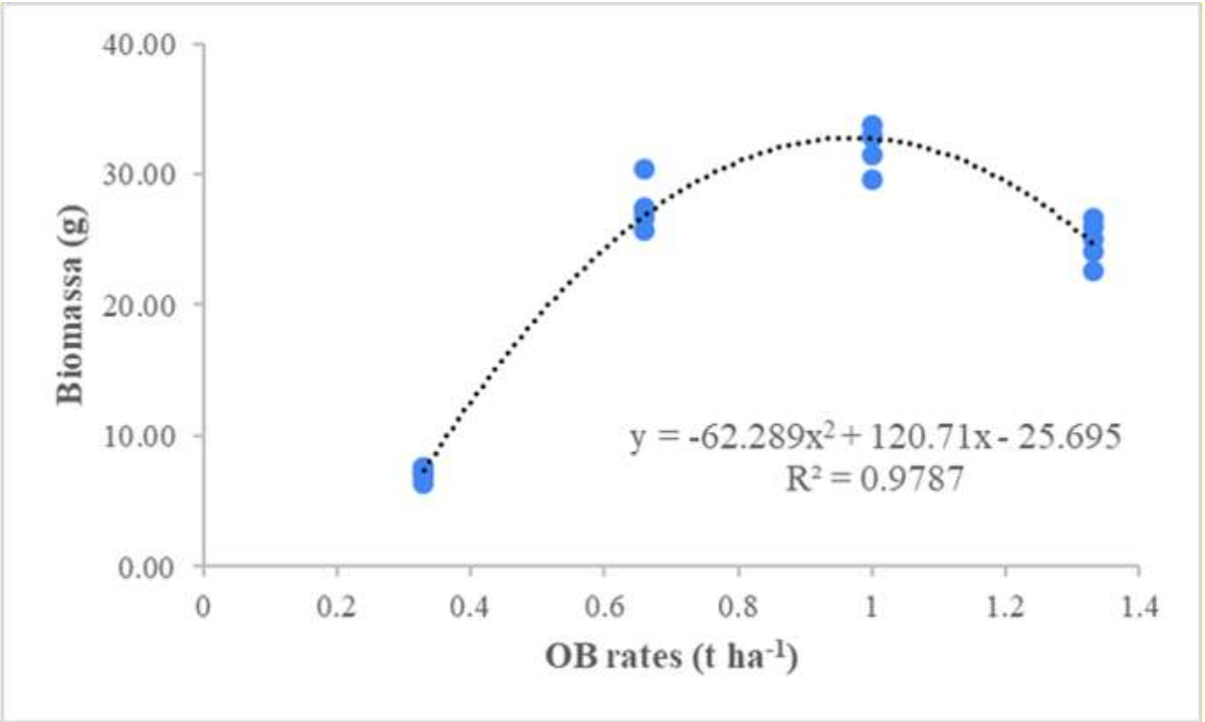

Fig. 2 Relative biomass response to OB fertilizer rate*

*to facilitate application suggestions in the field, units of t ha^{-1} were used instead of kg N ha^{-1} (see Table 2 column 5)

Practical implications of filter cake-based organomineral products

A single formulation of sugarcane filter cake compost was not considered. The material availability was limited only during the harvest season, which also had an unbalanced nutrient concentration and lack solubility (excessively slow nutrient release). If the composting process is incomplete and the compost gains a long decomposition period, then these phenomena could raise unpleasant odors in the field. Other reports suggest a potential for phytotoxicity and immobilization of nutrients due to undegradable residues (Butler et al. 2001; Sen and Chandra 2007). Therefore, the use of this process must be combined with other materials to achieve sustainable organomineral fertilizer production. Organomineral fertilizer production technology is currently comparable to conventional mineral fertilizers. This condition was proven by the research of Deeks et al. (2013), which compared the performance of the two types of fertilizers to the productivity of wheat, rape, oleaginous plants, barley, beans, and maize for three years of testing. The use of organic fertilizers is not to replace conventional mineral fertilizers but as a complement to improve soil quality and crop productivity in a sustainable way. The combination of organomineral and filter cake or biochar has been demonstrated to improve these wastes.

Conclusion

The higher AE provided by the application of filter cake and organomineral fertilizers compared to mineral fertilizers could be explained by the physical protection and gradual release of the nutrients contained in these fertilizers, thus providing highly balanced nutrition and consequently the highest biomass production. Treatment of biochar from filter cake (B fertilizer) provided a better residual P of 93.4% than mineral fertilizer as well as organic matter, which was 224.7% more than the negative control. Optimal vegetative growth, especially in plant height, leaf area, and stem diameter, was obtained via filter cake fertilization. The highest accumulation of N was 482.44 mg plant^{-1} and P was 102.96 mg plant^{-1}, and P recovery of 5.17% was obtained from fertilization using OB. Therefore, OB was the best treatment for increasing growth performance, NUE, and soil quality with an optimal dose of 0.96 t ha^{-1}. The SOM analysis revealed that the organomineral and mineral fertilizers did not exhibit significant differences in relation to the control. These results proved that the high efficiency of organomineral fertilizers was not linked to an increase in the content of organic matter in the soil but to the direct effects of the organic fraction in protecting against losses of the existing mineral part in the fertilizer.

Acknowledgment: This study was financially supported by BPPT Kemendikbudristek and LPDP through the Indonesian Education Scholarships (BPI). The authors thank the bio lab staff of ANR Co. for monitoring plant growth and the head of the Kebumen village for assisting in compost production.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

Abd El-mageed TA, Semida WM (2015) Organo mineral fertilizer can mitigate water stress for cucumber production (*Cucumis sativus* L.). Agric Water Manag 159: 1-10. https://doi.org/10.1016/j.agwat.2015.05.020

Ahmed N, Basit A, Bashir S, Bashir S, Bibi I, Haider Z, Ali MA, Aslam Z, Aon M, Alotaibi SS, El-Shehawi AM (2021) Effect of acidified biochar on soil phosphorus availability and fertilizer use efficiency of maize (*Zea mays* L.). J King Saud Univ Sci 33:101635. https://doi.org/10.1016/j.jksus.2021.101635

Ajema L (2018) Effects of biochar application on beneficial soil organism. Int J Eng Res Technol 5:9-18

Ampong K, Thilakaranthna MS, Gorim LY (2022) Understanding the role of humic acids on crop performance and soil health. Front Agron 4:848621. https://doi.org/10.3389/fagro.2022.848621

Anetor MO, Omueti JAI (2014) Organo-mineral fertilizer effects in some phosphorus-unresponsive soils of southwestern Nigeria: 1. Effects on maize growth response and soil properties. Agric Biol J North Am 5:265-280. https://doi.org/10.5251/abjna.2014.5.6.265.280

Atkinson CJ, Fitzgerald JD, Hipps NA (2010) Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. Plant Soil 337: 1-18. https://doi.org/10.1007/s11104-010-0464-5

Baligar VC, Fageria NK, He ZL (2001) Nutrient use efficiency in plants. Commun Soil Sci Plant Anal 32:921-50. https://doi.org/10.1081/CSS-100104098

Borges BMMN, Abdala DB, de Souza MF, Viglio LM, Coelho MJA, Pavinato PS, Franco HCJ (2019) Organomineral phosphate fertilizer from sugarcane by-product and its effects on soil phosphorus availability and sugarcane yield. Geoderma 339: 20-30. https://doi.org/10.1016/j.geoderma.2018.12.036

Bouhia Y, Hafidi M, Ouhdouch Y, Boukhari MEME, Mphatso C, Zeroual Y, Lyamlouli K (2022) Conversion of waste into organo-mineral fertilizers: current technological trends and prospects. Rev Environ Sci Biotechnol 21: 425-446. https://doi.org/10.1007/s11157-022-09619-y

Butler TA, Sikora LJ, Steinhilber PM, Douglass LW (2001) Compost age and sample storage effects on maturity indicators of biosolids compost. J Environ Qual 30: 2141-2148. https://doi.org/10.2134/jeq2001.2141

Cardoso AF, Lana RMQ, Soares W, Peixoto JVM, Luz JMQ (2017) Performance of organomineral fertilizer in winter and rainy potato crop. Biosci J 33: 861-870. https://doi.org/10.14393/BJ-v33n4a2017-36709

Carpanez TG, Moreira VR, Assis IR, Amaral MCS (2022) Sugarcane vinasse as organo-mineral fertilizers feedstock: Opportunities and environmental risks. Sci Total Environ 832:154998. https://doi.org/10.1016/j.scitotenv.2022.154998

Chen G, Gui J, Qing C-X, Huang D-L, Liao F, Yang L (2022) Evaluating the impact of biochar on biomass and nitrogen use efficiency of sugarcane using 15N tracer method. Front Agron 4:989993. https://doi.org/10.3389/fagro.2022.989993

Chen K, Peng J, Li J, Yang Q, Zhan X, Liu N, Han X (2020) Stabilization of soil aggregate and organic matter under the application of three organic resources and biochar-based compound fertilizer. J Soils Sediments 20: 3633-43. https://doi.org/10.1007/s11368-020-02693-1

Civiero JC, Daros E, Melo LJOT, Weber H, Mógor AF, Figueiredo GGO (2014) Application of humic substance and L-glutamic amino acid in different sizes of 1-bud set of sugarcane. Rev Cienc Agrar 37: 340-347

Costa MS, Steiner F, Costa LA, Castoldi G, Pivetta LA (2011) Nutrition and yield of maize under different cropping systems and nutrient sources. Rev Ceres 58:249-255. https://doi.org/10.1590/S0034-737X2011000200018

Crusciol CAC, Campos MD, Martello JM, Alves CJ, Nascimento CAC, Pereira JCDR, Cantarella H (2020) Organomineral fertilizer as source of P and K for sugarcane. Sci Rep 10: 5398. https://doi.org/10.1038/s41598-020-62315-1

de Mello Prado R (2021) Mineral nutrition of tropical plants. Springer Nature, Cham

Deeks LK, Chaney K, Murray C, Sakrabani R, Gedara S, Le MS, Tyrrel S, Pawlett M, Read R, Smith GH (2013) A new sludge-derived organo-mineral fertilizer gives similar crop yields as conventional fertilizers. Agron Sustain Dev 33: 539-549. https://doi.org/10.1007/s13593-013-0135-z

Dong T, Shang J, Chen JM, Liu J, Qian B, Ma B, Morrison MJ, Zhang C, Liu Y, Shi Y, Pan H (2019) Assessment of portable chlorophyll meters for measuring crop leaf chlorophyll concentration. Remote Sens 11: 2706. https://doi.org/10.3390/rs11222706

Drechsel P, Heffer P, Magen H, Mikkelsen R, Wichelns D (Eds.) (2015) Managing water and fertilizer for sustainable agricultural intensification. International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI), Paris

Ebrahimi ST, Yarnia M, Benam MK, Tabrizi EF (2011) Effect of potassium fertilizer on maize yield (Jeta cv.) under drought stress condition. Am Eurasian J Agric Environ Sci 10: 257-263

Egamberdieva D, Ma H, Reckling M, Omari RA, Wirth S, Bellingrath-Kimura SD (2022) Interactive effects of biochar, nitrogen, and phosphorous on the symbiotic performance, growth, and nutrient uptake of soybean (*Glycine max* L.). Agronomy 12: 27. https://doi.org/10.3390/agronomy12010027

Fallah S, Rostaei M, Lorigooini Z, Abbasi Surki AA (2018) Chemical compositions of essential oil and antioxidant activity of dragonhead (*Dracocephalum moldavica*) in sole crop and dragonhead-soybean (*Glycine max*) intercropping system under organic manure and chemical fertilizers. Ind Crops Prod 115:158-165. https://doi.org/10.1016/j.indcrop.2018.02.003

Ginting S (2019) Promoting bokashi as an organic fertilizer in Indonesia: A mini review. Horticulture 27: 189-203. https://doi.org/10.19080/IJESNR.2019.21.556070

Glaser B, Lehr VI (2019) Biochar effects on phosphorus availability in agricultural soils: A meta-analysis. Sci Rep 9: 9338. https://doi.org/10.1038/s41598-019-45693-z

Herencia JF, Ruiz JC, Morillo E, Melero S, Villaverde J, Maqueda C (2008) The effect of organic and mineral fertilization on micronutrient availability in soil. Soil Sci 173:69-80. https://doi.org/10.1097/ss.0b013e31815a6676

Hou W, Shen J, Xu W, Khan MR, Wang Y, Zhou X, Gao Q, Murtaza B, Zhang Z (2021) Recommended nitrogen rates and the verification of effects based on leaf SPAD readings of rice. Peer J 9:e12107. https://doi.org/10.7717/peerj.12107

Huang M, Fan L, Jiang L-G, Yang S-Y, Zou Y-B, Uphoff N (2019) Continuous applications of biochar to rice: Effects on grain yield and yield attributes. J Integr Agric 18:563-570. https://doi.org/10.1016/S2095-3119(18)61993-8

Hussain M, Farooq M, Nawaz A, Al-Sadi AM, Solaiman ZM, Alghamdi SS, Ammara U, Ok YS, Siddique KHM (2017) Biochar for crop production: Potential benefits and risks. J Soils Sediments 17:685-716. https://doi.org/10.1007/s11368-016-1360-2

Intansari RSR, Subiksa IGM (2022) The effectiveness of organic fertilizer granules for increasing sweet maize production on acid dryland in Bogor district. JSA 1: 40-52. https://doi.org/10.19184/jsa.v1i1.127

Jing J, Zhang S, Yuan L, Li Y, Lin Z, Xiong Q, Zhao B (2020) Combining humic acid with phosphate fertilizer affects humic acid structure and its stimulating efficacy on the growth and nutrient uptake of maize seedlings. Sci Rep 10: 17502. https://doi.org/10.1038/s41598-020-74349-6

Junior ABA, Nascimento CWA, Sobral MF, Silva FBV, Gomes WA (2011) Soil fertility and uptake of nutrients by sugarcane fertilized with filter cake. Rev Bras Eng Agríc Ambient 15:1004-1013. https://doi.org/10.1590/S1415-43662011001000003

Kalaivanan D, Omar Hattab K (2016) Recycling of sugarcane industries by-products for preparation of enriched pressmud compost and its influence on growth and yield of rice (*Oryza sativa* L.). Int J Recycl Org Waste Agric 5: 263-272. https://doi.org/10.1007/s40093-016-0136-4

Kaur K, Kapoor KK, Gupta AP (2005) Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. J Plant Nutr Soil Sci 168:117-122. https://doi.org/10.1002/jpln.200421442

Khan Z, Nauman Khan MN, Luo T, Zhang K, Zhu K, Rana MS, Hu L, Jiang Y (2021) Compensation of high nitrogen toxicity and nitrogen deficiency with biochar amendment through enhancement of soil fertility and nitrogen use efficiency promoted rice growth and yield. GCB Bioenergy 13:1765-1784. https://doi.org/10.1111/gcbb.12884

Kominko H, Gorazda K, Wzorek Z (2017) The possibility of organo-mineral fertilizer production from sewage sludge. Waste Biomass Valor 8: 1781-1791. https://doi.org/10.1007/s12649-016-9805-9

Kurniasari HD, Fatma RA, Aldomoro SRJ (2019) Analisis karakteristik limbah pabrik gula (blotong) dalam produksi bahan bakar gas (BBG) dengan teknologi anaerob biodigester sebagai sumber energi alternatif nasional [Analysis of the sugar factory waste (molasses) characteristics in gasoline fuel production (GFP) using anaerobic biodigester technology as a national alternative energy source]. JSTL 11: 102-113. https://doi.org/10.20885/jstl.vol11.iss2.art2

Lana MC, Rampim L, Schulz LR, Kaefer JE, Schmidt MH, Ruppenthal V (2014) Disponibilidade de fosforo para plantas de milho cultivadas com fertilizante organomineral e fosfato monoamônico [Phosphorus availability for maize plants grown with organomineral fertilizer and monoammonium phosphate]. SAP 13: 198-209. https://doi.org/10.18188/sap.v13i3.7659

Li L, Wang M, Wu X, Yi W, Xiao Q (2021) Bio-based polyurethane nanocomposite thin coatings from two comparable POSS with eight same vertex groups for controlled release urea. Sci Rep 11: 9917. https://doi.org/10.1038/s41598-021-89254-9

Mackay AD, Barber SA (1985) Soil moisture effects on potassium uptake by corn. Agron J 77: 524-527

Mahmood YA, Ahmed FW, Juma SS, Al-Arazah AA (2019) Effect of solid and liquid organic fertilizer and spray with humic acid and nutrient uptake of nitrogen, phosphorus and potassium on growth, yield of cauliflower. Plant Arch 19: 1504-1509

Makinde EA, Ayoola OT, Akande MO (2007) Effects of organo-mineral fertilizer application on the growth and yield of egusi melon. Aust J Basic Appl Sci 1: 15-19

Maluf HJGM, Silva CA, Curi N, Norton LD, Rosa SD (2018) Adsorption and availability of phosphorus in response to humic acid rates in soils limed with $CaCO_3$ or $MgCO_3$. Ciênc Agrotec 42:7-20. https://doi.org/10.1590/1413-70542018421014518

Martins DC, Resende ÁVD, Galvão JCC, Simão EDP, Ferreira JPDC, Almeida GDO (2017) Organomineral phosphorus fertilization in the production of corn, soybean and bean cultivated in succession. Am J Plant Sci 8: 2407-2421. https://doi.org/10.4236/ajps.2017.810163

Masclaux-Daubresse C, Daniel-Vedele F, Dechorgnat J, Chardon F, Gaufichon L, Suzuki A (2010) Nitrogen uptake, assimilation and remobilization in plants: Challenges for sustainable and productive agriculture. Ann Bot 105: 1141-1157. https://doi.org/10.1093/aob/mcq028

Mendes P, Rodrigues E, Rodrigues Filho F (2011) Use of biosolids for maize crop (*Zea mays* L.): Soil physical and chemical properties evaluation and its growth plant influence. Cad Agroeco 6: 1-5

Motsara MR (2015) Guide to laboratory establishment for plant nutrient analysis. Scientific Publishing, Rome

Ochoa George PA, Eras JJC, Gutierrez AS, Hens L, Vandecasteele C (2010) Residue from sugarcane juice filtration (filter cake): Energy use at the sugar factory. Waste Biomass Valor 1:407-413. https://doi.org/10.1007/s12649-010-9046-2

Ossom EM, Dlamini FT, Rhykerd RL (2012) Effects of filter cake on soil mineral nutrients and maize (*Zea mays* L.) agronomy. J Trop Agric 89: 141-150

Pankaj J, Vitika V (2022) Fertilizer market by type (organic, inorganic), by form (dry, liquid), by application (agriculture, horticulture, gardening, others): Global Opportunity Analysis and Industry Forecast, 2021-2030. https://www.alliedmarketresearch.com/fertilizer-market-A16556. Accessed 03/03/2023

Puga AP, Queiroz MCDA, Ligo MAV, Carvalho CS, Pires AMM, Marcatto JDOS, Andrade CAD (2020) Nitrogen availability and ammonia volatilization in biochar-based fertilizers. Arch Agron Soil Sci 66: 992-1004. https://doi.org/10.1080/03650340.2019.1650916

Purwono P, Sopandie D, Harjadi SS, Mulyanto B (2011) Application of filter cake on growth of upland sugarcanes. Indonesian J Agron 39: 79-84. https://doi.org/10.24831/jai.v39i2.13197

Rady MM (2012) A novel organo-mineral fertilizer can mitigate salinity stress effects for tomato production on reclaimed saline soil. S Afr J Bot 81: 8-14. https://doi.org/10.1016/j.sajb.2012.03.013

Rocha RNC, Galvão JCC, Teixeira PC, Miranda GV, Agnes EL, Pereira PRG, Leite UT (2005) Relação do índice SPAD, determinado pelo clorofilômetro, com teor de nitrogênio na folha e rendimento de grãos em três genótipos de milho [Relationship of SPAD index, determined by chlorophyll meter, with leaf nitrogen content and grain yield in three maize genotypes]. Rev Bras Milho Sorgo 4: 161-171. https://doi.org/10.18512/1980-6477/rbms.v4n2p161-171

Rosolem CA, Silva RH, Esteves JAF (2003) Potassium supply to cotton roots as affected by potassium fertilization and liming. Pesq Agropec Bras 38: 635-641. https://doi.org/10.1590/S0100-204X2003000500012

Santana CTC (2012) Comportamento de milho (*Zea mays* L.) e propriedades físicas do solo, no sistema plantio direto, em resposta a aplicação de fertilizante organomineral [The characteristics of corn (*Zea mays* L.) and soil physical properties, in no-tillage system, in response to application of organomineral fertilizer]. Dissertation. Unesp

Santos DH, Silva MA, Tiritan CS, Crusciol CAC (2014) The effect of filter cakes enriched with soluble phosphorus used as a fertilizer on the sugarcane ratoons. Acta Sci Agron 36:365-372. https://doi.org/10.4025/actasciagron.v36i3.17791

Santos F, Rabelo S, De Matos M, Eichler P (2019) Sugarcane biorefinery, technology and perspectives. Academic Press, London

Sen B, Chandra TS (2007) Chemolytic and solid-state spectroscopic evaluation of organic matter transformation during vermicomposting of sugar industry wastes. Bioresour Technol 98:1680-1683. https://doi.org/10.1016/j.biortech.2006.06.007

Shaaban M, Van Zwieten L, Bashir S, Younas A, Núñez-Delgado A, Chhajro MA, Kubar KA, Ali U, Rana MS, Mehmood MA, Hu R (2018) A concise review of biochar application to agricultural soils to improve soil conditions and fight pollution. J Environ Manag 228: 429-440. https://doi.org/10.1016/j.jenvman.2018.09.006

Shao Y, Feng X, Nakahara H, Irshad M, Eneji AE, Zheng Y, Fujimaki H, An P (2021) Apical- root apoplastic acidification affects cell wall extensibility in wheat under salinity stress. Physiol Plant 173:1850-1861. https://doi.org/10.1111/ppl.13527

Silva AC, Canellas LP, Olivares FL, Dobbss LB, Aguiar NO, Frade DAR, Rezende CE, Peres LEP (2011) Promoção do crescimento radicular de plântulas de tomateiro por substâncias húmicas isoladas de turfeira [Promotion of root growth of tomato seedlings by humic substances isolated from peat bog]. Rev Bras Ciên Solo, Viçosa 35: 1609-1617. https://doi.org/10.1590/S0100-06832011000500015

Sim DHH, Tan IAW, Lim LLP, Hameed BH (2021) Encapsulated biochar-based sustained release fertilizer for precision agriculture: A review. J Clean Prod 303: 127018. https://doi.org/10.1016/j.jclepro.2021.127018

Smith WB, Wilson M, Pagliari P (2020) Organomineral fertilizers and their application to field crops. Anim Manure Prod Characteristics Environ Concerns Manag 67: 229-243. https://doi.org/10.2134/asaspecpub67.c18

Solomon S (2011) Sugarcane by-products based industries in India. Sugar Technol 13:408-416. https://doi.org/10.1007/s12355-011-0114-0

Sornhiran N, Tuntrachanida J, Malachey P, Thongtuk P, Wisawapipat W, Aramrak S, Prakongkep N (2021) Aluminum-and iron-engineered biochar from sugarcane filter cake as phosphorus adsorbents and fertilizers. Science Asia 47: 220-227. http://doi.org/10.2306/scienceasia1513-1874.2021.032

Souza JR, Ribeiro BN, Raposo TP, Fiorin JE, Castro GS, Magalhães RS (2014) Eficiência do fósforo revestido com polímeros na cultura da soja [Efficiency of phosphorus coated with polymers in soybean culture]. Acta Iguazu 3: 1-9. https://doi.org/10.48075/actaiguaz.v3i4.11199

BPS-Statistics Indonesia.Statistical yearbook of Indonesia (2022).https://www.bps.go.id/publication/2022/02/25/0a2afea4fab72a5d052cb315/statistik-indonesia-2022.html. Accessed 21/11/2022

Subiksa IGM, Husnain (2019) Effect of organomineral soil amendment for acid upland on soil chemical properties and growth of maize. JPPTP 3: 23-30. http://doi.org/10.21082/jpptp.v3n1.2019.p23-30

Syers J, Johnston A, Curtin D (2008) FAO fertilizer and plant nutrition bulletin: efficiency of soil and fertilizer phosphorus use. In: reconciling changing concepts of soil phosphorus behavior with agronomic information 18. Food and Agriculture Organization of the United Nations, Rome

Szulc P, Bocianowski J, Nowosad K, Zielewicz W, Kobus-Cisowska J (2021) SPAD leaf greenness index: Green mass yield indicator of maize (*Zea mays* L.), genetic and agriculture practice relationship. Plants_(Basel) 10: 830. https://doi.org/10.3390/plants10050830

Teixeira WG (2013) Biodisponibilidade de fósforo e potássio provenientes de fertilizantes mineral e organomineral [Bioavailability of phosphorus and potassium from mineral and organomineral fertilizers]. Dissertation. Universidade Federal de Uberlândia

Teixeira WG, Sousa RT, Henrique HM, Kordorfer GH (2011) Produção de matéria seca, teor e acúmulo de nutrientes em plantas de milho submetidas à adubação mineral e organomineral [Dry matter production, nutrient content and accumulation in corn plants subjected to mineral and organomineral fertilization]. In: congresso brasileiro de ciência do solo, Uberlândia, XXXIII

Tripathi M, Sahu JN, Ganesan P (2016). Effect of process parameters on production of biochar from biomass waste through pyrolysis: A review. Renew Sustain Energy Rev 55:467-481. https://doi.org/10.1016/j.rser.2015.10.122

Utami SR, Kurniawan S, Situmorang B, Rositasari ND (2012) Increasing P-availability and P-uptake using sugarcane filter cake and rice husk ash to improve Chinesse cabbage (*Brassica* sp.) growth in Andisol, East Java. J Agric Sci 4: 153-160. http://doi.org/10.5539/jas.v4n10p153

Wang R, Hou T, Sun Q, Ji L, Lei J, Zhang J (2021) Organic fertilizers and soil conditioner recover chemical fertilizer-induced changes in soil bacterial community diversity in wine grape rhizosphere soil. Pol J Environ Stud 30: 1853-1863. https://doi.org/10.15244/pjoes/126236

Wibisana DL, Purwono P, Yahya S (2020) The application of filter cake compost to improve the efficiency of inorganic fertilizer in upland sugarcane (*Saccharum officinarum* L.) cultivation. Planta Tropika 8:93-102. https://doi.org/10.18196/pt.2020.119.93-102

Widodo RA, Saidi D, Mulyanto D (2018) The effect of bio-organo mineral fertilizers on availability of soil NPK and growth of maize plants. Soil Water J 15: 10-21. https://doi.org/10.31315/jta.v15i1.2722

Wietholter S, Siqueira OJF, Peruzzo G, Bem JR (1994) Efeito de fertilizantes minerais e organominerais nos rendimentos de culturas e em fatores de fertilidade do solo [Effect of mineral and organomineral fertilizers on crop yields and soil fertility factors]. Ver Pesqui Agropec Bras 29:713-724

Wulansari R, Maryono M, Darmawan DA, Athallah FN, Hakim FK (2022) Bio-organo mineral effect on soil fertility, nutrient uptake, and sweet maize (*Zea mays* L. *saccharata*) growth planted in inceptisols soils. Indonesian Min J 25: 49-58. https://doi.org/10.30556/imj

Xing B, Ouyang M, Graham N, Yu W (2020) Enhancement of phosphate adsorption during mineral transformation of natural siderite induced by humic acid: Mechanism and application. Chem Eng J 393: 124730. https://doi.org/10.1016/j.cej.2020.124730

Xu G, Lv Y, Sun J, Shao H, Wei L (2012) Recent advances in biochar applications in agricultural soils: Benefits and environmental implications. Clean Soil Air Water 40: 1093-1098. https://doi.org/10.1002/clen.201100738