International Journal of Plant & Soil Science

Volume 35, Issue 22, Page 589-604, 2023; Article no.IJPSS.108961
ISSN: 2320-7035

The Use of the Ash from the Burning of Sugarcane Bagasse is Associated with Biosolid Application for Soil Fertility

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i224169

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/108961

Original Research Article

Received: 18/09/2023
Accepted: 22/11/2023
Published: 02/12/2023

ABSTRACT

The incorporation of agroindustrial wastes in the soil is an alternative practice for an adequate environmental destination, and it is a nutrient source. Purpose: This study evaluated the effects of incorporating biosolids associated with sugarcane ashes and their effect on bean crop production in

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a protected environment concerning nutritional chemical parameters. Methods: The experimental design was in randomised blocks in a 2x4+1 factorial scheme with four replications. The main factors consisted of two doses of ash (5 and 10 t ha^{-1}) and four doses of biosolid (0, 2.5, 5 and 10 t ha^{-1}) in two phenological stages, vegetative (V4) and reproductive (R7). Results: The results showed that adding both waste in the soil provided a better availability of secondary macronutrients and essential micronutrients for the bean crop but lower primary macronutrients. This way, the applied ash doses change the pH, considering its neutralising properties. Adding 10 t of SBA significantly reduced the pH compared to applying 5 t in the absence of biosolid. The soil organic matter content increased with the SBA application, mainly at the dose of 10 t ha-1 of the waste. Combining BS with the highest SBA dose ash (10 t ha -1) generally resulted in elevated P levels. About K contents, the 10 t SBA dose promoted the most significant increase in the content of this element. Conclusion: Regarding the effect of doses, considering the studied phenological stages (V4 and R7), the results were promising even at lower doses of applied waste. This result indicates a dose dependence to complement the crop's nutritional needs.

Keywords: sewage sludge; soil fertility; waste; ash.

1. INTRODUCTION

Due to the large generation of waste and the advancement in the debate on environmental issues, several segments have focused on finding alternatives to make their processes more sustainable. They mainly seek to meet environmental agendas and policies and reduce the use of their inputs.

Given the need to encourage these practices, the importance of sustainable development has been increasingly recognised. Therefore, in 2015, the member countries of the United Nations signed a new global policy, the 2030 Agenda for Sustainable Development, to increase global development and boost people's quality of life (United Nations, 2015).

Thus, 17 Sustainable Development Goals (SDGs) were established, among which 12 (consumption and sustainable production) aim to reduce waste generation through prevention, reduction, recycling, and reuse. The objective is to encourage companies, primarily large and transnational, to seek sustainable practices and integrate information about sustainability into their internal agendas (Brazil, 2021).

The use of waste has become a frequent and essential practice to reduce the environmental problems linked to the disposal of these materials. In addition, the waste of resources such as biomass and nutrients can be made available by these materials, indeed to the potential for contamination linked to inadequate disposal. This can lead to pollution of water resources through the leaching of these compounds and soil degradation.

In particular, the agro-industry sector has advanced in the use of waste, with cellulose, lignin, carbon, silica, silicon, inhibitors, adsorbents, and biofuels being used to provide nutrients, generate energy, and control abiotic stresses.

The application of waste in agriculture is a practice that can assist in the physic-chemical properties of soils, as well as being a nutrient source of agricultural crop interest, increasing the quality of production and economic viability of the system [1]. Using waste such as ash from burning sugarcane bagasse and biosolids (sewage sludge) changes the soil's physical, chemical, and biological properties. It can improve crop productivity, reduce the application of synthetic fertilisers, and be an exciting source of organic matter (OM). Notably, the carbon provided by these compounds plays an essential role in the balance of agricultural ecosystems, stimulating biological activity, nutrient levels, and water efficiency used by plants.

Favare et al. [2] argue that ash from the burning of sugarcane bagasse has provoked interest due to its potential as a fertiliser, conditioner, and possible use in the formulation of substrates. Among its advantages is the improvement of the soil's physical structure resulting from the organic contribution of the waste, which, in turn, increases the water and nutrient retention capacity, in addition to the supply of the macro and micronutrients, when compared to conventional fertilisers.

Kathpalia et al. (2018) report that the main nutrients found in ash are the primary macronutrients like phosphorus (P) and potassium (K) and the secondary macronutrients magnesium (Mg) and calcium (Ca). Corroborating with these authors reinforces that the ash application increases the availability of phosphorus (P) in the soil (Hale et al.,2020). It was also found that applying ash to the soil increased the P and K content, while the N level was lower than that of the treatment that did not receive ash application (Seleiman & Kheir, 2018).

Yamane [3] analysed the incorporation of sugarcane bagasse and its effect on the soil. The author has identified that this waste is beneficial as a K source, stimulating increased K levels. Furthermore, Yamane [3] points out that bagasse ash may have excess levels of micronutrients, as in the cases of Fe (8690 µg g^{-1} and Mn 192 µg g^{-1}).

According to Osinubi and Eberemu [4], the incorporation of ash (8% ash) in soils saturated with Fe and aluminium hydroxide influences its mechanics, with an increase in compaction and reduction of hydraulic conductivity.

According to Durgude et al. [5], wheat plants grown in moderately alkaline and low fertility soils (except for K) achieved higher biomass yields when incorporating sugarcane bagasse ash, comparing the treatments with other soil correctives.

Many studies have reported the effectiveness of ash combined with other organic waste and other by-products of the sugar and alcohol sector (vinasse, bagasse, straw, filter cake) or rice husk, peat, and biosolid when applied and disposed into the soil. Biosolids can also be used as organic fertilisers and substrate conditioners due to their organic composition [6].

The treated and stabilised sewage sludge is now called biosolid and is usually disposed of in sanitary landfills. Depending on its concentration in pathogens and metal content, it is intended for application in soils as a corrective or fertiliser in many crops [7]. Agronomic use has been widely researched as one of the most promising applications for several aspects, including incorporating organic matter, nitrogen (N), and P in the soil, improving the best characteristic of the substrate [7].

The United Nations Food and Agriculture Organization (FAO) guidelines and the European Directive 86/278/EEC establish the maximum acceptable concentration of /ECC) potentially toxic elements in the soil after biosolids application, with maximum annual rates [7, Krzyzanowaski et al., 2016). In Brazil, CONAMA resolution 375/2006 is the regulation that “Defines the criteria and procedures for the agricultural use of sewage sludge generated in sanitary sewage treatment plants and their derived products and the measures” [9].

The European directive regulates the maximum limits of heavy metals, cadmium (Cd), nickel (Ni), zinc (Zn), mercury (Hg), and lead (Pb) when for agricultural use; however, some of these values are dependent on the pH due to mobility, resulting in greater bioavailability for crops (Nunes et al., 2019). Sludge recycling is an advantageous alternative, both for the person responsible for generating the biosolid, which has a more sustainable waste destination and for those who will use this material, which is rich in nutrients and organic matter, in and low cost [10].

The composition of the biosolids will depend on the effluent type generated and the treatment, but they are generally rich in organic matter, around 50% of the dry matter, hydrocarbons, amino acids, or lipids, with a small presence of lignin or cellulose. Therefore, if applied to the soil, the organic matter of the waste can promote an increase in physical properties by improving the organisation of mineral particles. Thus, the soil structure is better organised with reducing surface runoff and erosion [7].

The biosolids used in substrates have the property of reducing the need and application of fertilisers [11] since its composition has high levels of N, P, and other macro and micronutrients, except for potassium [10]. Although ash and biosolids are recommended for application in agricultural soils, aiming at plant nutrition, little is known about their effects on soil chemical properties and their efficiency as an alternative fertiliser to commercial ones applied to the bean crop.

Thus, the present study aims to evaluate the isolated and combined effects of the ash application and biosolids on soil properties. The central hypothesis is that these wastes may provide important complementary physical-chemical characteristics about the availability of essential nutrients such as N, P, K and Si.

2 MATERIALS AND METHODS

2.1 Location of the Experimental Area

The assay was conducted in a greenhouse at the Biosciences Institute – São Paulo State University- Botucatu-SP, Brazil (22°53'42.4", 48°29'36.6" and altitude of 840 m) between May and September 2020. According to the classification of Köpppen - Geiger, the local climate is hot temperate, humid Cfa type, with rainy summers and dry winters. The annual average air temperature is 20.3ºC, with July being the coldest month of the year (average of 17.1°C) and January the warmest (average of 22°C), and relative humidity varies between 20% and 70% (Cunha & Martins, 2009).

The environmental control in the experimental period was recorded using a *datalogger model CR-1000,* installed in the greenhouse centre and programmed to do readings every 30 minutes. The average temperature during the trial was 23.13ºC, and the relative humidity was 61.74%, adequate for common bean development [12,13].

2.2 Experimental Development

The common bean (*Phaseolus vulgaris* L.) genotype was cultivar IAC Sintonia, medium cycle (88 days), and indeterminate growth. The experimental plots consisted of 21 L polyethene pots; the experimental design adopted was in randomised blocks (DBC) in a factorial scheme (2 x 4 + 1) with two doses of ash from the burning of sugarcane bagasse (5 and 10 t ha^{-1}), combined with four doses of sewage sludge (dry-biosolid basis, 0; 2.5; 5 and 10t ha^{-1}) and an additional treatment without dose of ash and sludge, only with recommended fertilisation for the crop (NPK – mineral fertiliser) with four replications per treatment.

The stipulated doses for each waste were based on the (individual) literature available, aiming to find the best dose response for association [14,15,16].

Treatments defined: T1: 5 t; T2: 5 t SBA+2.5 BS; T3: 5 t SBA + 5 t BS; T4: 5 t SBA +10 BS; T5: 10 t SBA; T6: 10 t SBA +2.5 BS; T7: 10 t (SBA: Sugarcane bagasse ash and BS: Biosolid).

2.3 Physical and Chemical Characteristics of the Soil Correction

Before the experiment began, a soil sample was collected to characterise the soil attributes' chemical and physics.

The soil used was characterised as a dystrophic red latosol with a sandy loam texture, with 755 g dm^{-3} sand, 210 g dm^{-3} clay, and 34 g dm^{-3} silt (physical attributes) and the following chemical characteristics: pH ($CaCl_2$)= 4.2; M.O.= 4 g dm^3; P-resina= 2 mg dm^3; Al^{-3+}= 6 mmolc dm^{-3}; H+Al $^{+3}$= 20 mmolc dm^{-3}; K= 0.26 mmolc dm^{-3}; Ca= 2 mmolc dm^{-3}; Mg=1 mmolc dm^{-3}; SB= 2 mmolc dm^{-3}; CTC= 22 mmolc dm^{-3}; V= 10%; S= 18 mg dm^{-3}; B= 0,29 mg dm^{-3}; Cu= 0.4 mg dm^{-3}; Fe= 3 mg dm^{-3}; Mn= 2.8 mg dm^{-3}; Zn= 0.2 mg dm^{-3}, which were determined using the methodologies proposed by Embrapa [17], Raij et. al. [18].

Soil correction (liming method) was made based on the soil analysis results to increase the base saturation index, Mg and Ca content. The base saturation (V) ideal for the bean culture should be 70%, and the soil acidity correction was carried out 70 days before planting, keeping the pots always moist and covered to promote a better reaction. The fertilisation of the planting and covering in the conventional treatment followed the recommendation proposed by Bulletin 200 for the state of São Paulo [19].

2.4 Irrigation System

The experiment had a drip irrigation system with a spacing of 0.2 m between the emitters and an average flow of 2 L h^{-1} connected to distributors with two outlets and fixed by an arrow rod in each vessel, with a pressure of 10mca operation. Thus, irrigation management was carried out via soil with three tensiometers per treatment, randomly installed in the replications at a depth of 0.15 m.

The soil monitoring water tension was performed daily with a digital tensimeter, and the tension values were converted into a volumetric unit based on the equation in the soil water retention curve proposed by Van Genuchten [20]. Management aimed to keep the soil close to the field capacity (6 kPa – 10 kPa). Throughout the cycle, the total volume applied was 23 litres.

2.5 Waste Characterisation

Sugarcane bagasse ash was collected from the factory Zilor – Energy and Food boiler in Lençóis Paulista (SP). The wastes collected for use in the experiment were subjected to analysis of the composition of the macro/micronutrients and silicon.

For chemical characterisation of the elements that constitute the residual ash obtained from the sugarcane biomass incomplete combustion of the boilers, macronutrient and micronutrient analysis was performed with the following chemical characteristics: N = 1.1, P=0.30, K= 13.75, Ca = 12.6, Mg = 7.0, S= 3.3 (g kg $^{-1}$), Fe = 12900, Cu = 40, Zn = 57.5, Mn= 535, B= 41.0, which were determined using the methodology proposed Malavolta [21] and In order to identify and quantify the elements that constitute the residual ash from the incomplete combustion of the biomass samples, an analyses in energy dispersion X-ray spectroscopy (EDS) was realised.

The Biosolid used was collected at the ETE-SABESP sewage treatment plant in Botucatu-SP is treated according to art.3 of the Conama 375/2006 to reduce pathogens, remaining at rest for drying installs for 45 days, with a temperature of 55 ºC until the material reaches 20% humidity. The following characteristics of the dry base sludge were determined: N = 2.8, P_2O_5 = 3.5, Ca = 1.5, Mg=0.4, S= 0.4, C. O= 26 (%); Na = 1132, B= 145, Cu= 185, Fe = 33793, Mn= 259, Zn = 701, (mg Kg^{-1} to the natural), C/N = 7/1 pH =5,8.

2.6 Monitoring Soil Solution

We used twenty-seven porous capsule extractors to obtain the soil solution, three for each treatment, installed in a depth of 0.15 m of the polyethene pots. The soil solution sampling was performed weekly, always after irrigation, for six weeks, always in the afternoon (3 pm)

The vacuum was applied to the extractor using a plastic syringe and valve. The solution samples were stored in plastic containers with identification. We used a pHmeter and conductivity meter to measure the pH and electric conductivity (mS cm ^{1}) solutions. At the end of the cycle, these macros and micronutrients of the soil solution samples were analysed, with direct readings in the solution for K, Ca, Mg, Cu, Fe, Mn, and Zn, colourimetry for P, B, and S. Nitrogen analysis was performed by distillation method according to Kjeldahl [22].

2.7 Parameters

The leaf's nutritional content was evaluated after 70 days of the plant germination. Thus, 20 g of leaves from each plant were randomly collected, and thirty-six plants were evaluated, two per treatment. The leaves were stored in paper bags and dried in a forced ventilation oven for 24 hours. After drying, the leaves were ground and analysed according to the methodology for determining the nutritional content [21].

After 70 days of the incubation of the soil incorporated with wastes (before planting), soil samples were collected (collection 1) and at the end of the experiment - 90 days (collection 2). All collections were performed at a depth of 20 cm to determine pH, OM (organic matter), H+Al^{+3}, BS (bases sum), V%, CEC (cation exchange capacity), macronutrients (N, P, K, Ca, Mg and S) and the micronutrients (B, Cu, Fe, Mn, and Zn) silicon according to the methodology proposed by Raij [23].

Soil electrical conductivity (EC) was monitored weekly with a moisture sensor (HH2 Moisture Meter). With one evaluation per week in all treatments (180 pots). Of the determinations of silicon content in the soil, two composite samples were collected for each treatment after the 70 DAP soil waste incubation (before planting) and at the end (90 DAP), according to the methodology of Korndörfer et al. [24].

2.8 Data Analysis

The data were initially submitted to normality verification and homoscedasticity of considering the test for normality of Shapiro-Wilk and submitted to variance analysis (ANOVA) and if there was a significant effect submitted multiple comparison tests, using Tukey for comparisons between means and when significant by ANOVA factorial interaction was compared with conventional treatment using Dunnett's test. The Principal Component Analysis (PCA) and Pearson's Correlation test were performed to analyse the variability in behaviour about the doses tested. All analyses were performed considering a 5% significance level.

Statistical analyses were performed using Agroestat©, Minitab 18©, and R software version 4.1.0 (R Core Team, 2021), and for better understanding of the results graph's elements were prepared using SigmaPlot software, version 14 (Systat Software Inc. 2010).

3. RESULTS AND DISCUSSION

It verified an interaction of the SBA and BS factors only for soil pH, phosphorus content, potential acidity, and base saturation in the first sample collection. The soil's organic matter and potassium contents were influenced only by the SBA doses at 70 DAP (days after planting). The highest pH values were measured for treatments 6 and 7 when combined, although they did not differ from the highest biosolid dose (Fig. 1a). The conventional treatment showed the lowest average but did not differ from treatments 3, 4, and 8. The 10 t of SBA application presented a statistically lower pH value than the 5 t dose in treatments where biosolids were not applied.

This way, the applied ash doses change the pH, considering its neutralising properties. Adding 10 t of SBA significantly reduced the pH compared to applying 5 t in the absence of biosolid. This shows that the applied ash dose can influence the soil pH and that the waste there affects the soil acidity, although the mechanism is unclear.

The soil organic matter content increased with the SBA application, mainly at the dose of 10 t ha^{-1} of the waste (Fig. 1b). Although the SBA characterisation does not indicate the presence of organic waste, it is possible to assume that this material may come from an incomplete burning in the sugarcane production system. Condensed carbon molecules added to the soil favoured the increase of the OM content.

However, considering BS characterisation indicated the carbon presence, it was expected that his application to the soil could increase the original carbon content, but this effect did not happen.

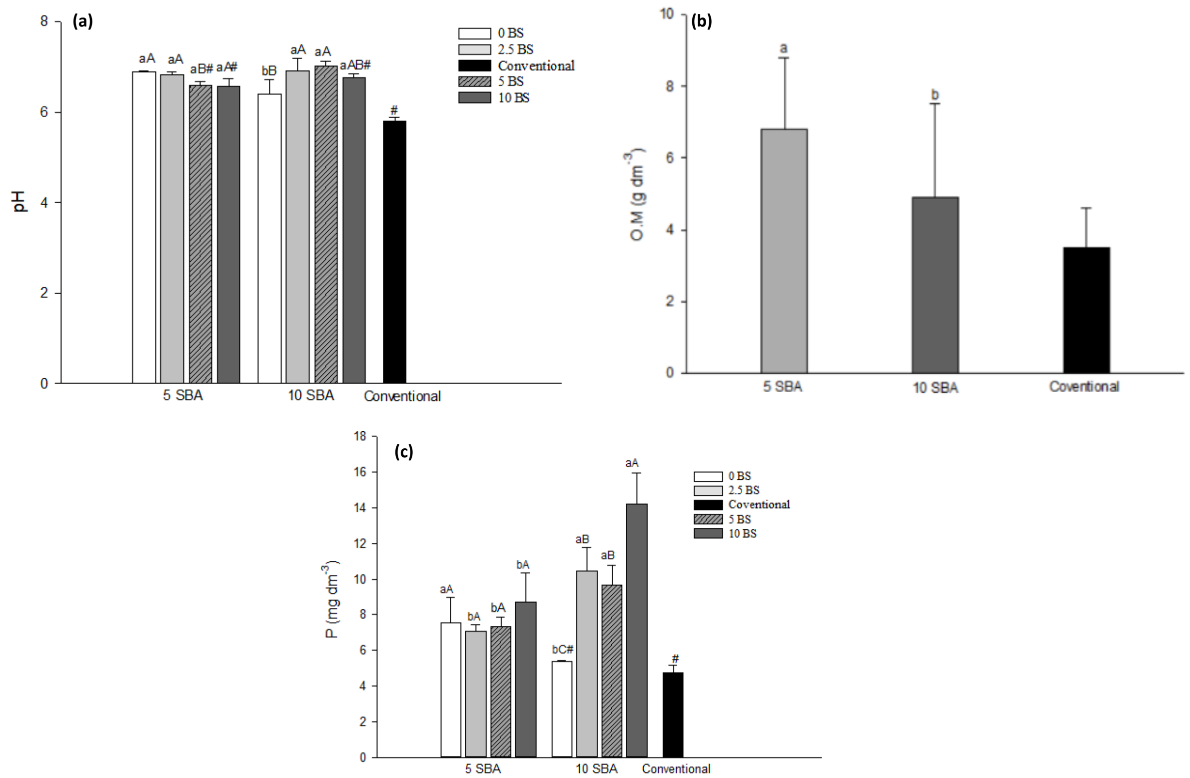

Fig. 1. (a) Soil pH; (b) organic matter content in the soil as a function of the different doses of ash from sugarcane bagasse (SBA) and biosolid (BS) at data collection 1; (c) Phosphorus (P) content in the soil as a function of the different doses of ash from sugarcane bagasse and biosolid at collection 1. The doses of SBA (5, 10) represent t ha^{-1} of the residue. Means followed by the same lowercase letter for sugarcane bagasse ash and uppercase for biosolid do not differ from each other by the Tukey test p< .05. Means followed with # do not differ from the control treatment by the Dunnett Test p< .05

**Collection 1: days after planting*

**Collection 2: days before sowing*

For P levels (Fig. 1c) were observed in treatments without the BS addition, the lowest contents were different between them (1 and 5), even though treatment 5 did not differ from the conventional one. Combining BS with the highest SBA dose ash (10 t ha 1) generally resulted in elevated P levels compared to the 5 SBA treatment (Fig. 1c). However, the BS doses (2.5, 5, and 10 t) combined with 5 t of SBA did not differ on the P content measured in the soil that did not receive a biosolid application, although it differs from the conventional one.

Marin and Rusãnescu [25] also found that applying biosolids contributes to an increase in mobile phosphorus content by 9.6-15.7 ppm compared to treatments that did not receive an application. This increase occurs due to the application of biosolids and the solubilisation of minerals in the soil containing phosphorus.

The combined waste application (70 days before sowing) possibly increased P content in the soil. This effect was near 610% at the highest dose (10t) and 168.5% in the absence of BS compared to mineral fertiliser.

Shan et al. [26] found a similar effect on the P availability when they applied increasing doses of BS, with an increase of 144% relative to conventional treatment. Boudjabi et al. [27] also studied the application of increasing biosolid amount reporting increases in P levels.
The conventional treatment had lower available P content in the soil (137%) than before treatments. This effect is probably related to liming and fertilisation (NPK) treatment. This demonstrates the possible viability of the waste in correcting and fertilising soil.

According to Novais et al. [28], organic or mineral sources may act as sources or drains of available P, depending on the soil conditions and pH. In the present trial, as observed in Fig. 3, the treatment T4 (5 t SBA + 10 t BS ha 1) and conventional lodge a positive correlation for N and P in the plant's nutrition. This effect indicates an antagonistic relationship caused by the P excess about the micronutrients B and Zn, which lodge a negative correlation and content below the recommended for the bean crop. This relation was also reported by Zeffa et al. [29] in a study about the genetic variability of different bean cultivars. The authors found a negative correlation in P, Zn, and Fe grains. The Zn deficiency is a limiting factor for production, especially in legumes, due to its nutritional value [30].

The availability of phosphorus can also be influenced by the availability of organic matter, which minimises its fixation, and the content of elements such as Ca, Al, and Fe that can precipitate it [31].

Grupta et al. [32] also identified a P sorption increase caused by the high levels effect of free Fe oxides. The authors also identified a reduction in P adsorption when 10 t ha^{-1} of ash was applied in rice and wheat fields. The high content of Fe and Al in the soil affects the availability of P, especially from mineral sources.

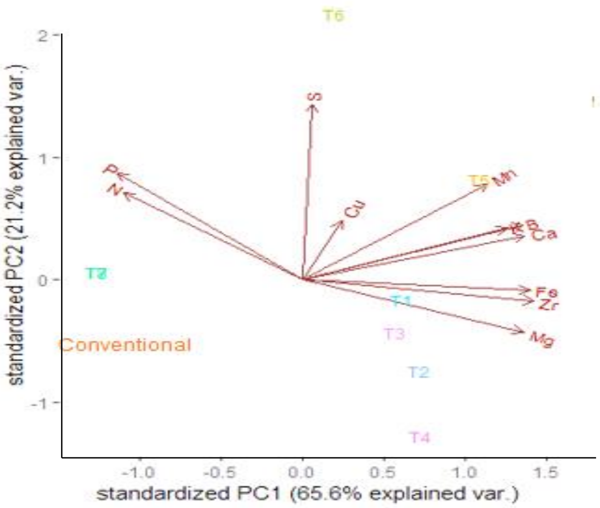

Fig. 2. Biplot displaying eigenvectors and scores for principal components 1 and principal components 2 for macro and micronutrients in the beans

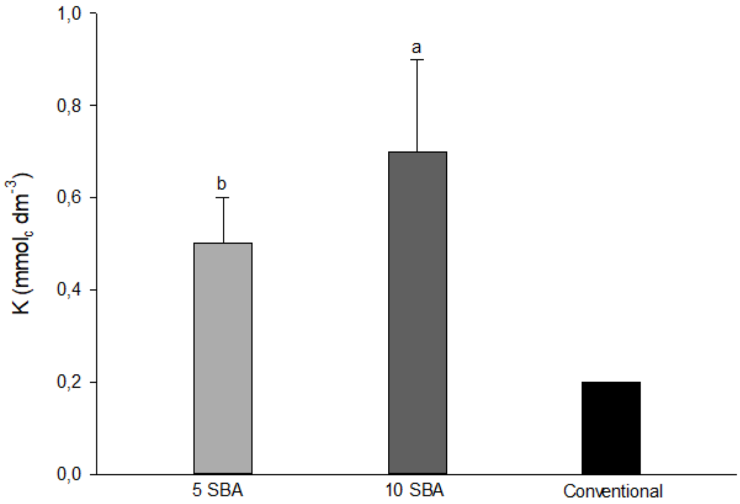

Fig. 3. The Potassium (K) content in the soil as a function of the different doses of ash from sugarcane bagasse and biosolid at collection 1. Means followed by the same letter do not differ with 5% significance by Tukey's test

About K contents, the 10 t SBA dose promoted the most significant increase in the content of this element, differing from the 5 t SBA dose and the conventional treatment, indicating that this waste (SBA) can replace commercial sources of K (Fig. 3). In rapeseed cultivation feijão guandu, the k contents increased more than twice from the highest dose to the control treatment [33].

The present assay also identified a correlation between the conventional treatment plants and the Fe contents in the solution. There was a positive correlation between Fe in the soil solution (Fig. 4) and an increase in the ion content at the end of the cycle (38.98%). It was also noted that in this treatment (conventional), there was a negative correlation for P, K, and N in the soil solution, which suggests that these nutrients managed to be better used by the plant bean.

It was observed isolate effect of the waste for Fe, with more influence in treatments with BS when compared to SBA (Fig. 5a-c), and a similar behaviour was observed about the Zn and Mn content. This effect denotes that the biosolid has a higher Fe, Zn and Mn content than the ash composition. There was an increase of 90% in the Fe content for the highest dose of BS and 96% for the highest amount of SBA, although the conventional one obtained a more significant increase in content in soil at the end of the crop cycle (146%). These values seem to indicate that the plants of the conventional treatment absorbed lower amounts of Fe, which can be seen in the negative correlation between the Fe content and the conventional treatment, while there was a positive relationship between the treatments 5, 6, 7 for this element in the plant (Fig. 2).

According to the present results, there was a positive correlation between the waste application and the availability of Fe levels for absorption by bean plants. In contrast to these results in the soil solution, the conventional treatment showed a positive correlation with Fe and had a negative correlation with the main micronutrients, both in the solution and in the nutrients absorbed by the plant (Figs. 2 and 4), which is possibly related to the values verified for soil electric conductivity in the vegetative stage (2.01 mS cm^{1}), solution conductivity (1.20), and pH of the solution (7.5) that may have in general affected the absorption of micronutrients by the plants (Table 1).

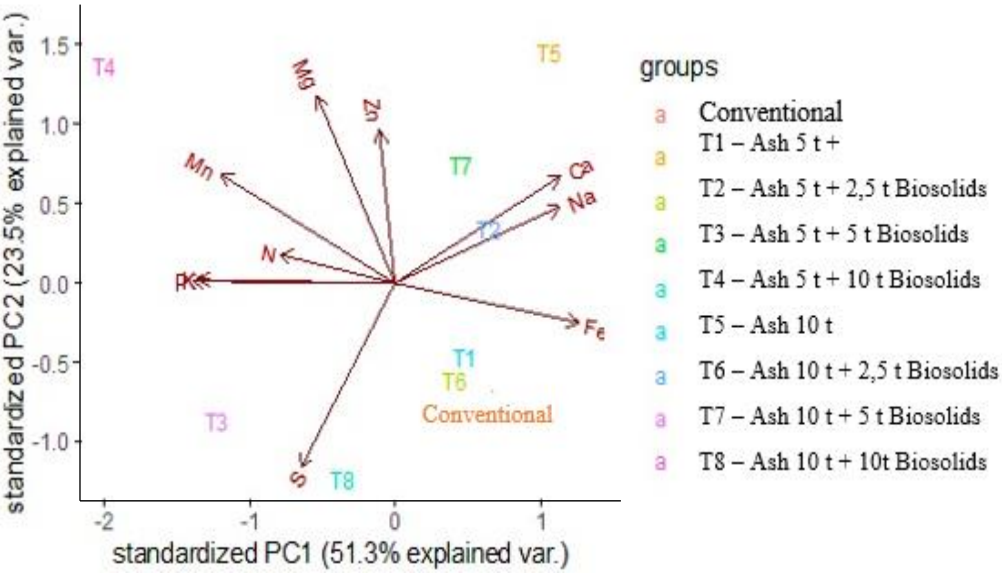

Fig. 4. Biplot displaying eigenvectors and scores for principal components 1 and principal components 2 of nutrients in the soil solution

The Fe availability decreases as the pH increases [21], and the condition observed in the soil solution in the conventional treatment showed a neutral to basic pH from 42 DAP onwards (Table 1). Possibly, the plants from the treatments with an association of the waste (mainly treatments 1 and 3) had a positive correlation with Fe in the plant leaves due to the greater availability promoted by both sources, but also by the pH range recorded in the soil solution (6.5 and 6.2) – (Table 1), that favoured the availability. According to Conama nº 375/2006, pH between 4, 0 and 6.0 favours the most significant Fe availability.

The authors Dechen & Nachtigal [34] report adequate levels of O.M. to provide a better use of Fe by plants due to its acidifying and reducing characteristics and ability to form chelates in adverse pH conditions. As already reported, both absorption and transport of Fe will also depend on P concentration, Ca content, and pH. For the plant bean plants in the present trial, conventional treatment one had the highest Ca content in the soil and a negative correlation for the plants' uptake at the end of the cycle. Fe is considered one of the more essential micronutrients for bean crops, and its availability is reduced mainly in calcareous soils [35].

Table 1. pH and conductivity electric of the solution in the function of tested the doses

	Days after planting													
Treatment	**35**			**42**	**49**		**56**		**63**		**70**		**mean**	
	pH	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**mS cm^1**	**pH**
T1	6,1	3,14	7,4	0,37	6,7	2,67	6,3	0,53	7,1	1,73	6,5	1,52	1,66	6,7
T2	6,1	1,26	7,4	0,42	7,3	1,09	7,7	1,14	7,5	1,16	7,5	1,10	1,03	7,3
T3	5,2	1,77	6,8	0,55	7,3	0,53	8,0	2,76	7,7	1,65	6,2	2,21	1,58	6,8
T4	5,0	0,96	6,7	0,55	7,2	0,90	7,7	0,95	8,5	1,02	6,9	2,74	1,19	6,2
T5	7,0	0,27	6,3	2,11	7,7	0,37	6,7	1,55	7,0	0,37	7,5	0,65	0,89	7,0
T6	7,3	1,58	8,2	1,88	7,1	1,73	7,0	1,73	7,8	1,78	7,4	1,76	1,74	7,5
T7	6,7	0,48	7,3	0,82	7,8	0,70	7,6	0,41	7,2	0,43	8,0	1,49	1,92	7,4
T8	6,5	0,62	7,0	1,30	7,8	1,01	7,4	0,37	8,7	1,19	6,8	0,46	0,82	7,4
Conventional	6,7	1,26	8,2	1,15	7,5	5,47	8,0	1,23	7,4	1,15	7,5	0,70	1,82	7,5

T_1 : 5t ash, T_2 : 5t ash+ 2,5 de biosolid, T_3 : 5t ash+ 5 de biosolid, T_4 : 5t ash+10 de biosolid, T_5 : 10t ash, T_6 : 10t ash+ 2,5t biosolid, T_7 : 10t ash+ 5t biosolid, T_8 : 10t ash+10t biosolid, T_9 : conventional

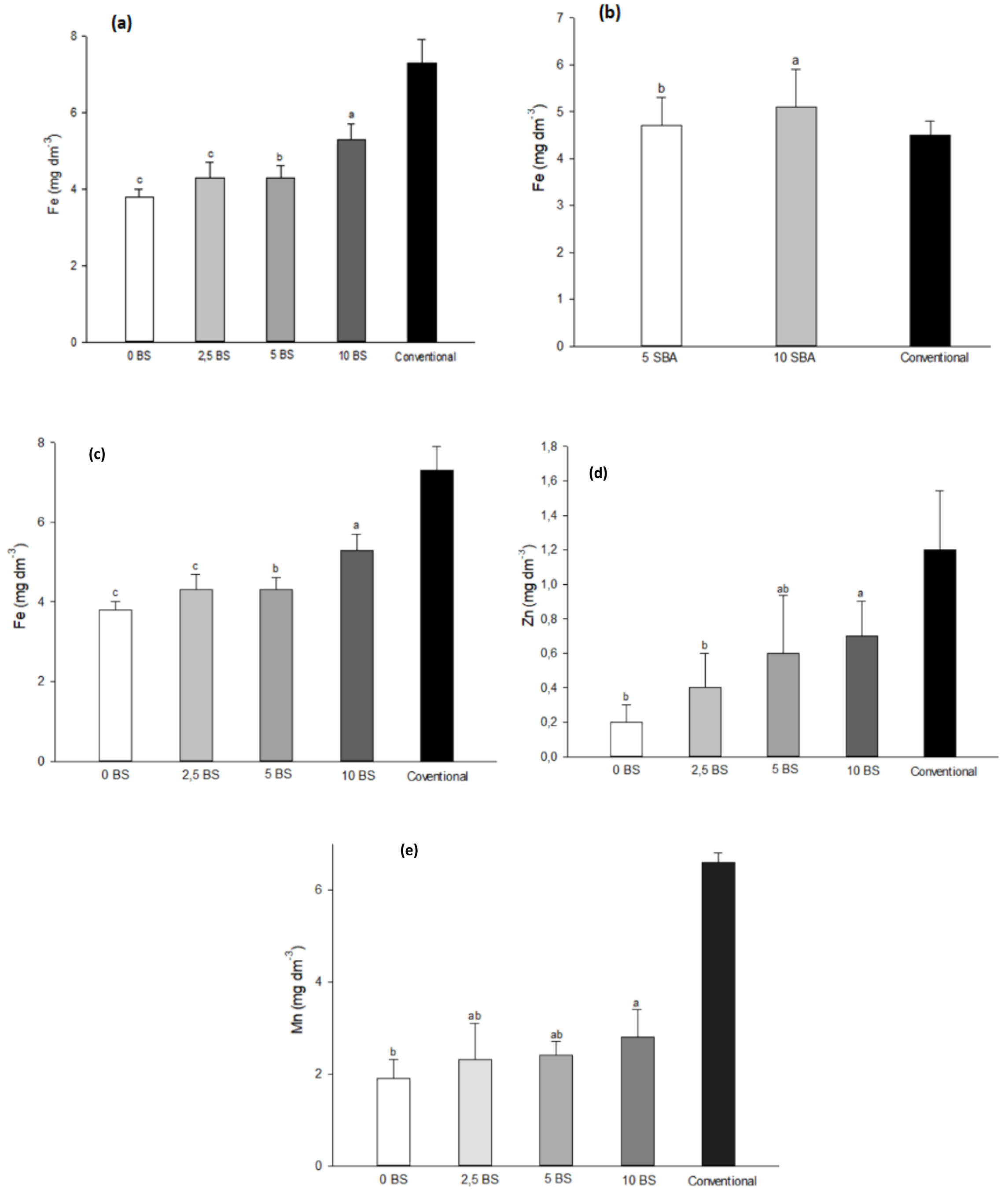

Fig. 5. The Fe content in the soil as a function of the different doses of ash from sugarcane bagasse and biosolid at (a) collection 1; (b) collection 1;(c) and collection 2; (d) Contents of Manganese – collection 2; (e) Zinc collection 2. Means followed by the same letter do not differ with 5% significance by Tukey's test

**Collection 1: days after planting*
**Collection 2: days before sowing*

All associations' base saturation values (V%) reached levels above the recommended for the beans crop (around 70%). As an exception, the conventional treatment reached a value of 6.43% less (Fig. 6a-b). The base saturation developed from low to high since the initial analysis because of liming and the application of ash doses associated with the biosolid. Although both wastes may have contributed to the increase in V%, SBA seems to have been predominant since the treatments with the addition of BS doses associated with ash did not statistically change the V% values. The ash represents a rapid nutrient source availability for plants, as the burning of organic material releases nutrients from organic structures, which reduces the need for mineralisation by soil microorganisms.

The potential acidity (H+Al) had a decreasing behaviour about biosolids doses in almost all associations, except in treatments with equal proportions of waste and the conventional one. A reduction of 64.6% was observed about the lowest mean found (7.08) and 43.15% for the conventional treatment compared to the before-treatment soil. Kitamura [36] found a similar behaviour to this decreasing relationship, with reductions in percentage for

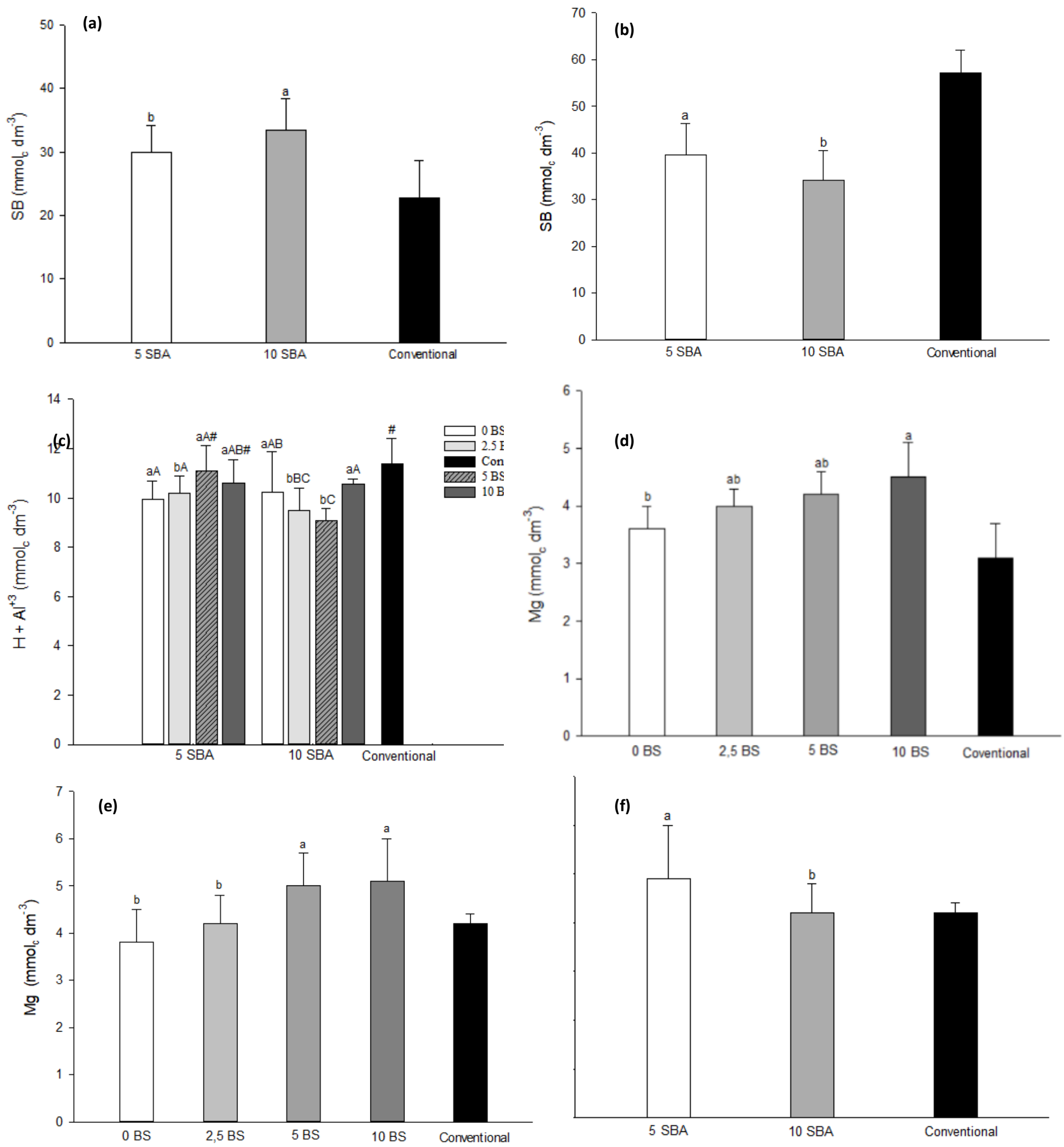

Fig. 6. The base saturation (V%) - collection 1 (a) and collection 2 (b); (c) Potential acidity (H+Al); Magnesium content (d) collection 1; (e) collection 2; (f) collection 2 in the soil as a function of the different doses of ash from sugarcane bagasse and biosolid. Means followed by the same letter do not differ with 5% significance by Tukey's test

potential acidity in the ranges 27, 61, 55, and 92% of biosolid (6.25, 100, 250, and 500 Mg ha^{-1}) and lower than the conventional one (Fig. 6c).

Nonetheless, the plants of the treatments with higher doses differed from these results, which may be associated with a more significant ammoniacal N release available by the BS. The hypothesis can be partially confirmed, considering that, during the soil solution monitoring, within the same dose (10 t) of ash, the pH varied between 6.6 and 8, with higher pH for the treatments with high ash (treatment 6 and 8).

About the ionic *status*, there was an increase in the content of K with an isolated effect for ash, reaching values 393.3% higher than the content found for the conventional treatment. This result is evidence of the waste capacity to supply the K content to the plants equitably to the mineral fertiliser. This characteristic is because K is the macronutrient in greater quantity in this waste, readily available to the plant. For the Mg content (Fig. 7d-f), the two wastes increased the element in the soil compared to the conventional treatment. The absence of magnesium application in the conventional treatment, with application only NPK, indicates that waste can be nutritionally more complete alternative sources than conventional mineral fertilisers.

The improvement of silicon availability can be seen as a positive factor of the application of ash in the aspect of the structure of the plants and possible resistance to adverse environmental factors.

Silicon is considered a non-essential element but plays an active role in the development of plants, promoting the growth of many species, particularly among grasses, providing an increase in biomass (height of the plant, root weight and surface area, leaf area) by up to 70-85% [37,38-42].

The SBA doses influenced the Ca levels in the two collections (Fig. 7 a and b). In the first collection, the highest content of this nutrient was at dose 10 SBA. However, in the second collection, the highest content recorded was at dose 5 SBA. (Fig. 7).

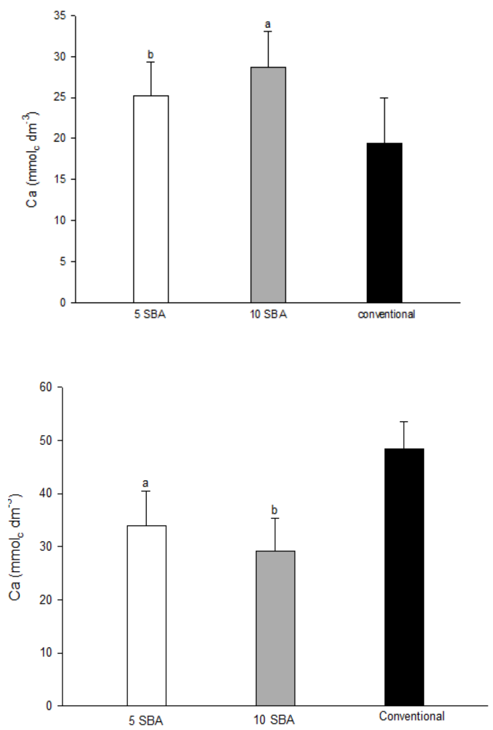

Fig. 7. The calcio (Ca) content in the soil as a function of the different doses of ash from sugarcane bagasse and biosolid at collections 1 and 2. Means followed by the same letter do not differ with 5% significance by Tukey's test

Chen et al. [38] found that Ca^{2+} levels increased significantly in organic fertiliser. According to Rubio et al. [33], using ash bagasse increases the content of Ca, with results for the higher dose – 39,5 Mg ha^{-1} [43-46].

4. CONCLUSION

The waste application influenced the K availability, notably for the highest ash doses. This effect was also recorded for N, P, Ca and Mg following the mineralisation process. Concerning micronutrients, the waste favoured the availability of Fe following the applied dose criterion.

The tested doses also interfered with the soil's chemical properties, signalling an effect on the V% and availability of micronutrients. Nutrient availability is influenced by soil pH ranges, observing that the different doses of ash influence the pH of the soil.

Preliminary results show strong evidence that soil behaviour can be influenced by combinations of doses of residues applied to the soil. The results can be used to develop new studies since information on the combination of both residues is not found in the literature.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the National Council for Scientific and Technological Development (CNPQ), the collaboration of the Agro forest Biomass and Bioenergy Laboratory (LABB), part of the Bioenergy Research Institute (IPBEN – UNESP) and the Botucatu Biosciences Institute.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/108961