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ORIGINAL RESEARCH

Fermented soil amendments made from stabilized biosolids and fly ash improve maize (*Zea mays* L.) nutrition and growth

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Abstract

Purpose To evaluate the feasibility of using biosolids and fly ash, processed through the Bokashi fermentation process, as growth promoters of maize. These two components were included because they are generated in large amounts and represent an environmental problem all over the world. Additionally, these materials have high concentrations of nutrients, but they have not been widely used because they also contain traces of heavy metals.
Methods Components of regular Bokashi are as follows: soil, cow manure, chopped corn stalks, wheat bran, yeast, crushed charcoal, water and brown sugar. For this research, cow manure was replaced with biosolids, and charcoal was replaced with fly ash. The materials were mixed, inoculated with *Saccharomyces cerevisiae* and allowed to be fermented until the temperature stabilized. The maize plants were grown in four treatments: Bokashi with biosolids and fly ash, Bokashi with cow manure, chemical fertilizer and an unamended control.
Results The plants grown in the Bokashi with biosolids and fly ash (BBFA) treatment had the highest aerial biomass (49.71 g), total biomass (69.82 g), N concentration (242 % higher than the control) and P concentration (94% higher than the control). Cadmium and lead concentrations were below the detection limits both in the soil amendments and in the tissue of maize plants.
Conclusion Biosolids and fly ash processed by the Bokashi technique resulted in improved nutrition and growth of the maize plants. Through Bokashi fermentation, biosolids and fly ash can be safely used in agricultural or forestry applications.

Keywords Biosolids, Fly ash, Fermented soil amendments, Bokashi

Introduction

Very large amounts of chemical fertilizers have been employed to increase crop production around the world (Galloway and Cowling 2002). Since 1961, the use of nitrogen fertilizers has increased eightfold and phosphorus fertilizers threefold (Lu and Tian 2017). The overuse of agrochemicals has caused serious environmental problems related to altered biogeochemical cycles, the eutrophication of water bodies, a loss of biodiversity and the contamination of subsoil aquifers (Smith 2003; Turner et al. 2003; Díaz and Rosenberg 2008; Canfield et al. 2010; Howarth et al. 2011). Conventional agricultural practices that include the intensive use of agrochemicals contribute to the generation of greenhouse gases (Kahrl et al. 2010). The resultant changes in the Earth´s climate are affecting food production even more adversely than those reducing soil fertility (Brown and Funk 2008). These anthropogenic ecological changes have prompted some agronomists and agroecological scientists to adopt ecotechnologies that are employed by small-scale farmers (Wezel et al. 2014; Scotti et al. 2015). Most of these techniques employ organic waste materials that are readily available in any agricultural context. These can include animal manure, crop residues, industrial byproducts, food residues and even sewage sludge. All these materials can be used in any agricultural setting if processed properly

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(Singh et al. 2019). Most of the nutrients that are contained in these materials can be released to the soil environment and hence contribute to the fertility of such soils; this may entail processing by, for example, composting, vermicomposting or fermenting (Bokashi) before incorporation into the soil (Saldaña et al. 2014). When organic matter is fermented by the Bokashi technique, pH values are stabilized and brought to levels where most nutrients are readily available (Alattar et al. 2012). This fermentation process also generates high temperatures (> 80°C) that inhibit the propagation of pathogens (Singh et al. 2012b; Fatunla et al. 2017) that might be present in the biosolids. The overall activation of effective microorganisms that occurs during the fermentation process fosters the activation of soil microorganisms already present in the soil where the amendment is added. This creates the appropriate conditions for soil microbial activity, which is related to improved soil fertility (Singh et al. 2011).

Previous research has shown that stabilized biosolids and coal combustion fly ash can be used as soil amendments (Alves et al. 2006; Pandey and Singh 2010; Romanos et al. 2019). Although the use of these materials is controversial because they contain concentrations of heavy metals and a few organic compounds (Cahoon 2015). Therefore, we did not use these materials alone but as ingredients in a soil amendment that was fermented. We wanted to incorporate the nutritional value that these materials present and take advantage of the microbial activity that is enhanced during the fermentation process. Research has shown that bacterial activity aids in the proper decomposition of these materials and reduces their negative effect on other organisms (Fang et al. 2001). We considered national and international guidelines for the use of these materials as soil amendments (OMAFRA 1996; NOM-004-SEMARNAT-2002 2003; Yunusa et al. 2012). The application of these amendments can improve crop yield as well as soil health (Parkpian et al. 2002; Punshon et al. 2002). Research has shown the potential of fermenting biosolids while including biochar in the mixture to produce a soil amendment that improves maize growth (Andreev et al. 2016). In addition, by including a small percentage of fly ash (12%) in our soil amendment, we are looking for alternatives for its disposal and reutilization (Basu et al. 2009; Kaur and Goyal 2015). Our experiment was conducted under controlled conditions as a proof of concept, and we had control over the biosolids and fly ash at all times. Based on these premises, we wanted to explore the feasibility of employing the Bokashi fermentation technique to process biosolids and fly ash and turn them into a soil amendment that could improve soil fertility.

Here, we report the findings of a greenhouse experiment where fermented soil amendments (biosolids and fly ash) were applied to sterile and non-sterile soil treatments, and we record how the growth and nutrition of maize was affected by the application of these amendments.

Materials and methods

Soil amendment preparation

The standard recipe for preparing a Bokashi amendment comprises soil, cow manure, chopped corn stalks, wheat bran, yeast, crushed charcoal, water and brown sugar (Jaramillo-López et al. 2015). In order to prepare a fermented soil amendment with biosolids and fly ash (Bokashi of biosolids and fly ash: BBFA), cow manure was replaced by biosolids and a portion of charcoal by the fly ash (Table 1). Stabilized biosolids were obtained from the sewage treatment plant for the city of Morelia, Michoacán, Mexico, and the fly ash was obtained from the Presidente Plutarco Elías Calles coal-fired generating station, Petacalco, Guerrero, Mexico. Several studies suggest that only small amounts of fly ash should be added to the soil so that microbial activity is not inhibited (Wong and Lai 1996; Schutter and Furhmann 2001). Because of this, and on the basis of preliminary experiments (data not presented), only 12% of fly ash (W/W) was used in our soil amendments. All the materials were taken to the Research Institute for Ecosystems and Sustainability in Morelia, Mexico, to prepare the soil amendments. Biosolids were air-dried and crushed with wooden mallets and then sieved through a 2-mm mesh. The soil that was used to prepare the amendment came from the town of Santiago Undameo, Michoacán, Mexico and was a silt loam with a pH of 5.6, an organic matter content of 2.83%, and a P content of 0.002 g kg^{-1}. This soil was air-dried, crushed and mixed with quartz sand at a 1:1 ratio. One half of the soil was sterilized (Pro-Grow soil sterilizer, SS30, Brookfield, Wisconsin, USA) for 3 days, and each treatment was mixed with sterile and non-sterile soil.

Table 1 Components of the mixture used for Bokashi with biosolids and fly ash

Material	Amount (kg)
Biosolids	350
Soil	420
Fly ash	110
Chopped Corn Stalks	105
Crushed Charcoal	35
Wheat Bran	9
Raw Sugar	1.5
Saccharomyces cerevisiae	0.35

A *Saccharomyces cerevisiae* culture was prepared by dissolving raw sugar in warm water and then adding the *S. cerevisiae*. Once the other materials had been homogeneously mixed, the yeast culture was added, while ensuring that the mixture would be moist enough until it reached field capacity. The mixture presented in Table 1 was piled and covered with a tarpaulin to promote fermentation. The pile was turned twice a day for the first 10 days and then turned once a day for 8 further days. Once the temperature of the pile had fallen to 30°C, it was spread out and left to dry for 6 days. Once dry, the BBFA was bagged and ready for use. The Bokashi with cow manure (BCM) and the BBFA were fermented following the guidelines from Jaramillo-López et al. (2015).

The effect of the amendment was tested in a greenhouse experiment at the Research Institute for Ecosystems and Sustainability in Morelia, Mexico.

Experimental design

A multi level factorial design was used: factor 1 was soil sterilization (sterile and non-sterile soil), factor 2 was soil amendment (unamended control, Bokashi with cow manure, Bokashi with biosolids and fly ash, and chemical fertilization), and factor 3 was the plant growth phase (6 weeks after sowing, 10 weeks after sowing). Six replicates per treatment resulted in a total of 96 experimental units (in 2-kg pots). For the BBFA and BCM treatments, 15% amendment was mixed with 85% soil substrate (W/W). The preparation of the chemical fertilizer mixture followed the guidelines published by Aguilar et al. (2017).

Maize sowing and vegetative measurements

Immediately after the amendments had been prepared, pots were filled with the corresponding treatment and sown with 3 hybrid maize seeds (*Zea mays* L. PUMA, Asgrow) in 3 holes equidistant from the center of the pot. Pots were placed in the greenhouse in randomized blocks and rotated once a week to reduce the border effect. One week after seed emergence, the sprouts were thinned to 1 plant per pot. All plants were kept at 80% field capacity during the whole experiment. Six (for the first harvest) and 10 (for the second harvest) weeks after sowing, the vegetative tissue was dried at 80°C for 5 days before the determination of the aerial plant biomass and root biomass.

Electrical conductivity and pH

Electrical conductivity (EC) and pH were determined for the biosolids, fly ash, soil, the BBFA and BCM at the beginning and at the end of the experiment (LAQUA water quality analyzer pH/ EC meter (F-74), HORIBA Scientific, Japan).

Determination of selected elements in vegetative tissue and in the soil

After they were dried, the shoots from the maize plants in the various treatments were ground and sieved (40 µm). Nitrogen and phosphorus concentrations were quantified by a micro-Kjeldahl method (Murphy and Riley 1962) and analyzed with a Bran-Luebbe AA3 auto analyzer (Bran-Luebbe, Mequon, Wisconsin, USA).

After the second harvest, concentrations of micronutrients (Ca, Cu, K, Mg, Mn, Mo, and Zn) and concentrations of two heavy metals (Cd and Pb) were determined in maize shoots, unamended soil and the BBFA samples with an ICP-OES model Plasma 400 (Perkin-Elmer, Brookfield, Wisconsin, USA) at the Geomagnetism and Exploration Laboratory of the National Autonomous University of Mexico, Mexico City, Mexico. In order to digest the vegetative tissue, 0.2 g of tissue was placed in a 75-ml beaker and 1 ml of deionized water, 10 ml of nitric acid and 1 ml of hydrochloric acid were added. The beaker was placed in an oven, and the temperature was raised to 180°C for 20 minutes and kept at that level for 10 minutes. Each digested sample was transferred to a plastic container, and its volume was brought to 100 ml. In addition, each container was then stored at 4°C until analyzed. To digest each soil sample, 0.5 g of soil was placed in a 75-ml beaker to which 1 ml of deionized water was added. Subsequently, 5 ml of hydrofluoric acid, 10 ml of nitric acid and 1 ml of hydrochloric acid were added. Each sample was heated in a microwave oven (MARS Xpress, CEM, Matthews, NC, USA) for 20 minutes at 160°C, then kept at that temperature for 15 minutes; 5 ml of boric acid was then added to neutralize the hydrofluoric acid, and the temperature was raised within 10 minutes to 170°C and maintained at that temperature for 5 minutes. Each sample was filtered with Whatman filter paper (Grade 40), then transferred to a plastic container; the volume was brought to 100 ml before its storage at 4°C until analysis.

Statistical analyses

Relationships were determined among pH, EC, and concentrations of Cd, Pb and micronutrients, as well as the aerial biomass, root biomass, total biomass, and the total N and P, with factors such as soil sterilization, soil amendment and the time of harvest. Data were analyzed with a generalized linear model fitted with the lowest AIC exhaustive analysis and a Tukey´s post hoc test by a least square means package (Lenth 2016). Models included all possible interactions. Data were subjected to a (two-way) marginal ANOVA (R software, version 3.4.3).

Results and discussion

Effect of Bokashi fermentation on pH, EC and micronutrients

The objective of this study was to show that biosolids and fly ash can, after being processed through Bokashi fermentation, be used as an effective soil amendment and as a growth promoter of maize. Both biosolids and fly ash represent an environmental problem because they are produced in very large amounts and they are difficult to dispose of (Arulrajah et al. 2011; Dwivedi and Jain 2014). Several studies have shown that these materials can be used as soil amendments either alone (Schutter and Fuhrmann 2001; Cuevas and Walter 2004; Kishor et al. 2010; Sarkar et al. 2012; Carlile et al. 2013; González-Flores et al. 2017) or in combination (Jaramillo-López et al. 2011; Jaramillo-López and Powell 2013; Brännvall et al. 2015). Those studies, however, only included biosolids and fly ash that were not composted. By composting organic matter, the nutritional potential of these materials is unleashed. This is because microbial activity from the Bokashi fermentation process accelerates the mineralization of organic matter, and pH and EC values reach normal levels (Lima et al. 2015). This is in tandem with this study because before the Bokashi process, the pH of the fly ash was 9.2 and that of the biosolids was 6.0. After fermentation, the resulting pH of Bokashi with biosolids and fly ash was 7.7 (Table 2). In addition, electrical conductivity (EC) was higher (1.15 mS cm^{-1}) in biosolids than in the other ingredients. When the Bokashi process used this material, the EC of the resulting product was 0.40 mS cm^{-1}, which was close to the EC value of the product of the Bokashi with cow manure (0.35 mS cm^{-1}) (Table 2).

Table 2 pH and EC values of biosolids, fly ash, soil, and of the Bokashi products derived from these (BBFA) or from cow manure, charcoal and soil (BCM)

Sample	pH (1:2)	EC (mS cm^{-1})
Biosolids	6.0 (± 0.05)	1.15 (± 0.05)
Fly ash	9.2 (± 0.10)	0.22 (± 0.05)
Soil (1 soil :1 quartz sand)	6.0 (± 0.17)	0.10 (± 0.02)
BBFA + Soil	7.7 (± 0.05)	0.40 (± 0.19)
BCM + Soil	6.5 (± 0.03)	0.35 (± 0.24)

(Mean values ± SD; n=3)

It is possible that the Bokashi fermentation process stabilized the pH of the two raw materials. After the pot experiment, the pH for the BBFA treatment had fallen from 7.7 to 6.2 at the first harvest and to 6.3 at the second harvest (Table 3). This change in pH while the plant was growing in the pot would have increased the availability of nutrients (Boechat et al. 2013). In pots with the BCM amendment, the pH increased slightly from 6.5, and reached neutral values. For the chemical fertilizer treatment, the pH remained slightly acidic throughout the experiment, while the pH for the unamended control increased slightly during the experiment but remained somewhat acidic (Table 3). The pH value is an indicator for nutrient availability, but the values in the 6.2 to 6.6 range are ideal only if enough nutrients are present in the soil (McCauley et al. 2009). The data presented in Table 2 served as baseline data and were not included in the two-way ANOVA that was performed with data from the first and second harvests (Table 3).

Table 3 pH and EC values of samples from treatments at sowing, the first harvest and the second harvest (n=24)

	Day 0		6 weeks	10 weeks	6 weeks	10 weeks
Treatment	pH (1:2)	EC (mS cm^{-1})	pH (1:2)	pH (1:2)	EC (mS cm^{-1})	EC (mS cm^{-1})
BBFA$^{\delta}$ + Soil	7.7 (± 0.05)^{e}	0.40 (± 0.19)^{ef}	6.2 (± 0.03)^{b}	6.3 (± 0.01)^{bc}	0.52 (± 0.04)^{cd}	0.44 (± 0.02)^{c}
BCM$^{\gamma}$ + Soil	6.5 (± 0.03)^{de}	0.35 (± 0.24)^{f}	6.9 (± 0.02)^{e}	7.1 (± 0.02)^{e}	0.44 (± 0.04)^{c}	0.32 (± 0.02)^{b}
Fertilizer + Soil	6.0 (± 0.17)^{abc}	0.10 (± 0.02)^{b}	6.1 (± 0.03)^{b}	5.8 (± 0.04)^{a}	0.60 (± 0.06)^{d}	0.80 (± 0.07)^{e}
Soil	6.0 (± 0.17)^{abc}	0.10 (± 0.02)^{b}	6.6 (± 0.03)^{cd}	6.6 (± 0.01)^{cd}	0.14 (± 0.02)^{a}	0.13 (± 0.02)^{a}

$^{\delta}$Bokashi with biosolids and fly ash

$^{\gamma}$Bokashi with cow manure

(Mean values ± SD; n=24; Two-way ANOVA with Tukey´s post hoc test through least square means)

During the experiments, the EC values were highest in the treatments with chemical fertilizers and EC values remained stable throughout the experiment for the BBFA, BCM and unamended treatments (Table 3). High EC values might mean that there are high concentrations of salts in the substrate at any given time, but this is probably not related to the efficiency of the plant to absorb such nutrients. Maize plants grown in the chemical fertilizer treatments were shorter than those grown in the Bokashi with biosolids and fly ash. The higher EC values found in the chemical fertilizer treatments might indicate that most of these nutrients could not be absorbed by the plant; this might lead to the increased leaching of nutrients to the deeper layers of the soil (Rosolem et al. 2010).

Concentrations of micronutrients differed significantly (P<0.05) among soil treatments. According to data provided by the Morelia sewage treatment plant, there were only very small concentrations of Cd (< 0.001 mg kg^{-1}) and Pb (0.012 mg kg^{-1}) in the biosolids. After the Bokashi fermentation, no detectable amounts of Cd or Pb were found in the resulting amendment (Table 4).

Table 4 Concentrations of various elements in the unamended (control) soil and in the BBFA treatment, as well as in maize plants grown for 10 weeks under those treatments

	Substrate		Maize shoot	
Element	Soil (mg g^{-1})	BBFA (mg g^{-1})	Control (mg g^{-1})	BBFA treatment (mg g^{-1})
Ca*	5.35 (0.06)	3.36 (0.21)	2.99 (0.36)	1.96 (0.22)
Cd	<DL	<DL	< DL	< DL
Cu*	0.02 (0.00)	0.04 (0.00)	0.003 (0.00)	0.014 (0.00)
K	27.16 (0.14)	24.10 (0.51)	6.67 (0.12)	6.21 (0.05)
Mg*	10.06 (0.05)	9.45 (0.08)	1.20 (0.09)	0.78 (0.16)
Mn*	0.97 (0.01)	0.95 (0.03)	0.34 (0.00)	0.38 (0.02)
Mo	0.36 (0.02)	0.20 (0.01)	0.09 (0.01)	0.10 (0.009)
Pb	<DL	<DL	< DL	< DL
Zn*	2.26 (0.31)	0.82 (0.18)	0.006 (0.00)	0.048 (0.00)

*Values with significant differences between treatments (chi-squared test). DL: detection limits. (mean ± SD; n=12)

As expected, the Cd and Pb concentrations in maize plants were below the detection limits as seen in the amendments before the plants were grown in these treatments. As seen in Table 4, concentrations of the various elements that were determined do not differ between the soil and the BBFA. In general, the values presented in the soil are within the standard concentrations found in agricultural soils. Concentrations of heavy metals do not exceed the maximum allowed concentration. Because these concentrations were within recommended limits, the resulting fermented amendment posed no risk to plants, humans and the environment (NOM-004-SEMARNAT-2002 2003; Yunusa et al. 2012). An additional benefit of processing these materials through fermentation is that their carbon footprint might be reduced because of decreased greenhouse gas emissions. This effect was seen by other researchers when composting pig slurry and converting it into pelletized fertilizer (Pampuro et al. 2016, 2017a). In our experiment, we did not see any signs of toxicity in the maize plants grown in the

BBFA amendment treatment. Similar results were obtained in bioassays carried out with maize plants grown in soils with pig slurry compost (Pampuro et al. 2017b). This shows that these products can be used safely in agricultural applications.

Growth of maize

Maize plants grown in the BBFA treatment had the highest aerial biomass, and the maize grown in the control treatment had the lowest (Fig 1a, 1b). The addition of chemical fertilizer or BCM produced higher aerial plant biomass than did the control soil at each harvest time. Similarly, amended treatments had higher root biomass than did the control treatment (Fig 2a, 2b). In general, the root biomass in either harvest was higher in the treatments that had sterile soil than in those with non-sterile soil (Fig 2a, 2b).

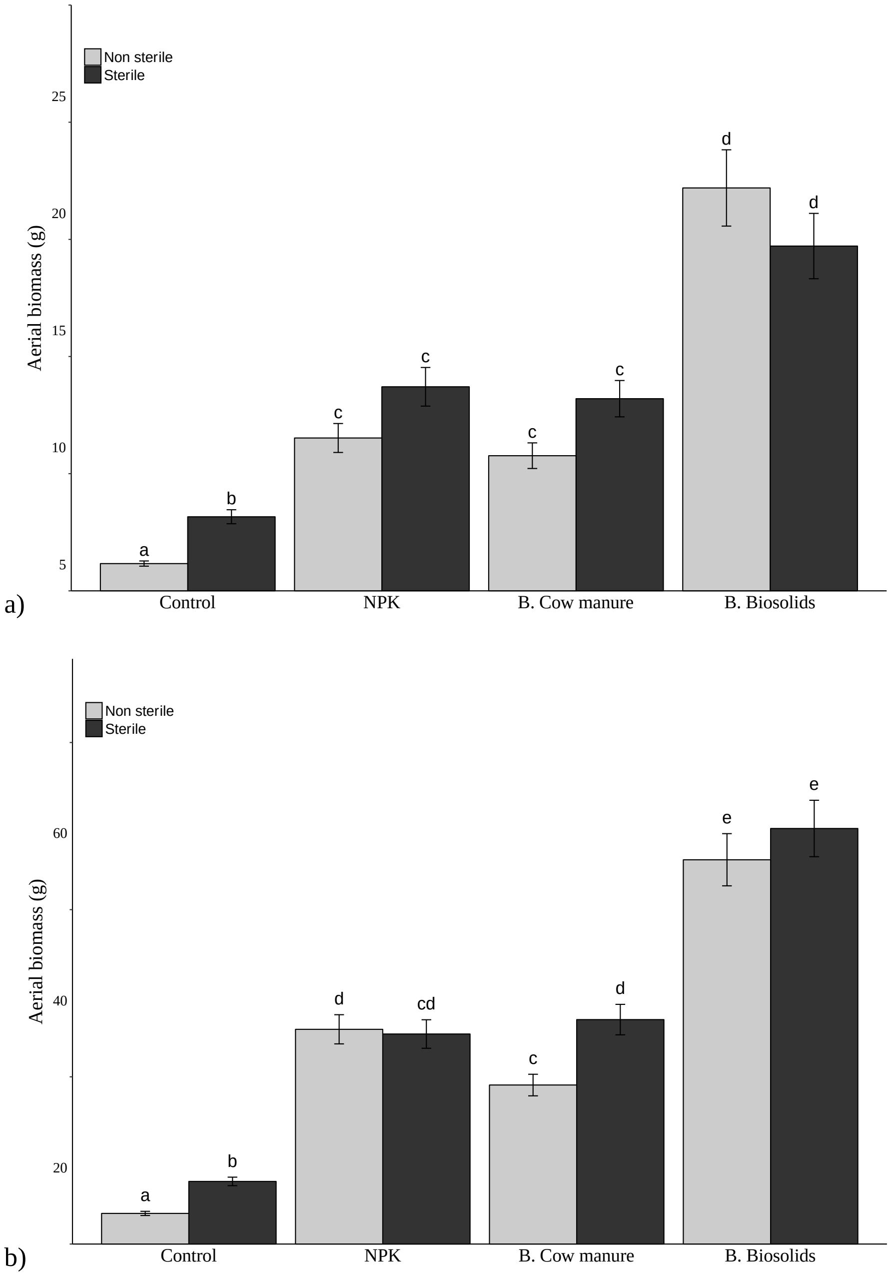


Fig. 1 Average aerial biomass of maize plants grown in various substrates including Bokashi with biosolids and fly ash (B. Biosolids), Bokashi with cow manure (B. Cow manure), chemical fertilizer (NPK) and unamended control. a) Data for plants 6 weeks after sowing; b) Data for plants 10 weeks after sowing. Different letters above each error bar show significant differences among treatments according to the chi-squared test ($p<0.05$)

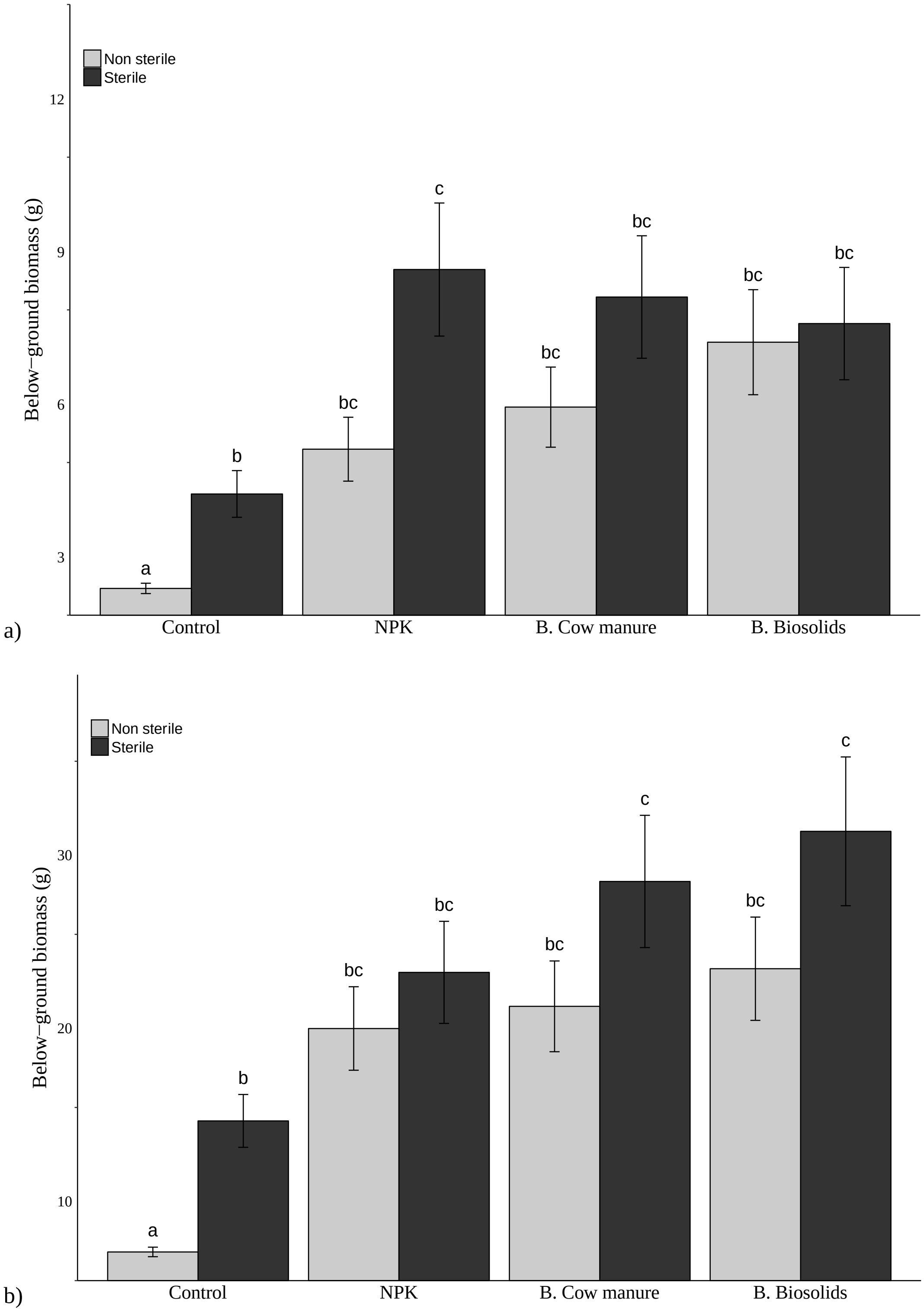


Fig. 2 Average root biomass of maize plants grown in various substrates including Bokashi with biosolids and fly ash (B. Biosolids), Bokashi with cow manure (B. Cow manure), chemical fertilizer (NPK) and unamended control. a) Data for plants 6 weeks after sowing; b) Data for plants 10 weeks after sowing. Different letters above each error bar show significant differences among treatments according to the chi-squared test ($p<0.05$)

The same trend was observed for total plant biomass. Maize plants grown in the BBFA treatment had a higher total biomass at each harvest time than with the other treatments (Fig 3a, 3b). There were no significant differences between the total plant biomass of maize plants grown in the treatments that had sterile or non-sterile soil.

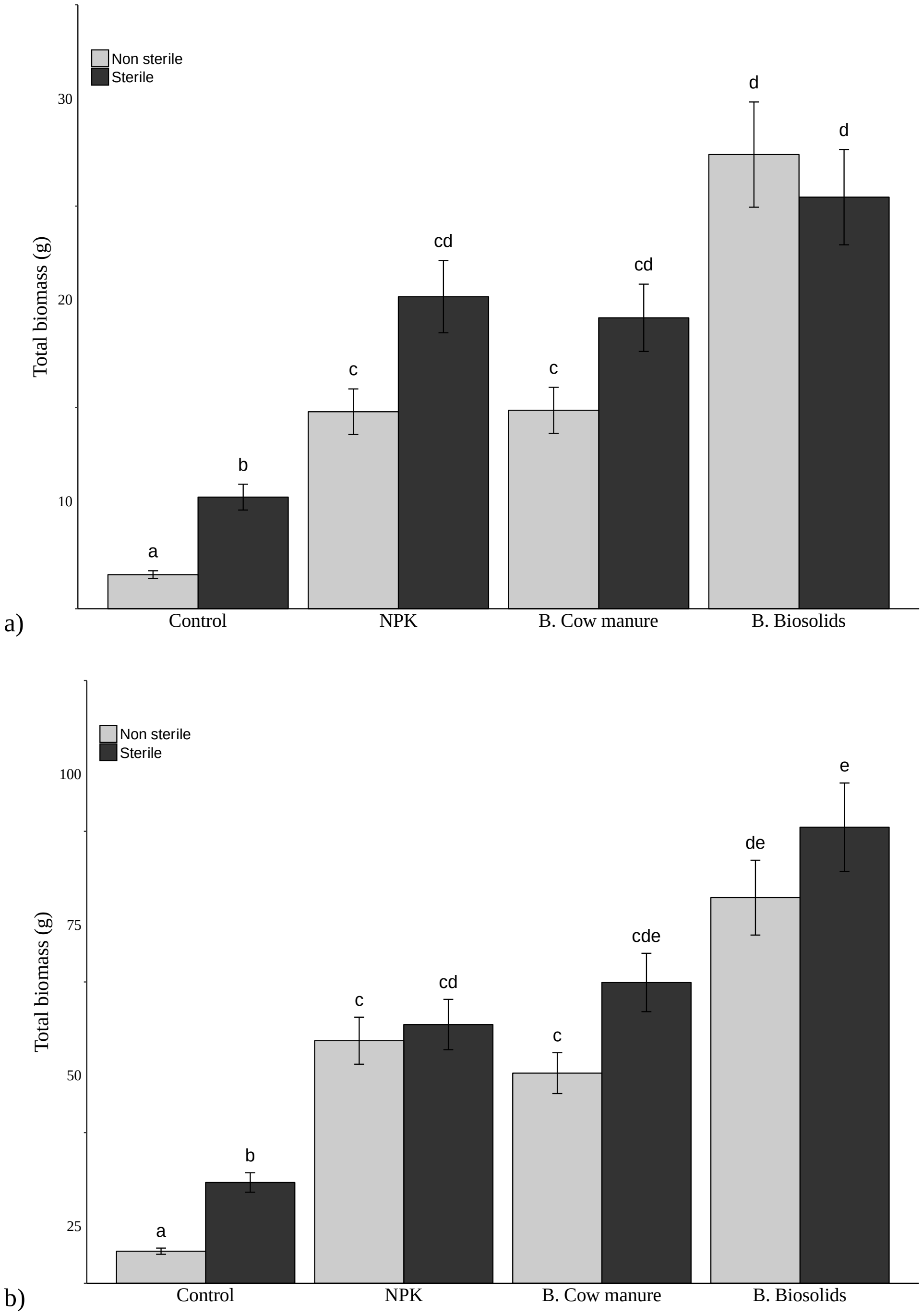


Fig. 3 Average total biomass of maize plants grown in various substrates including Bokashi with biosolids and fly ash (B. Biosolids), Bokashi with cow manure (B. Cow manure), chemical fertilizer (NPK) and unamended control. a) Data for plants 6 weeks after sowing; b) Data for plants 10 weeks after sowing. Different letters above each error bar show significant differences among treatments according to the chi-squared test ($p<0.05$)

The enhanced performance of maize in the Bokashi treated soil was predicated in increased microbial activity. Once the Bokashi product is incorporated in the soil, the microorganisms become active, and their metabolism enhances nutrient availability (Sasikala and Ramana 1998; Hädicke et al. 2011; Murillo-Amador et al. 2015). This effect was seen in the root biomass of maize plants grown in the treatments with sterile soil. This may be attributable to a lower competition for nutrients or to the elimination of root pathogens that occurred in the treatments with sterilized soil (Gianinazzi et al. 2010).

In the first harvest, the N concentration in maize plants was highest in the BBFA treatment (Fig 4a). In the second harvest, however, the N concentration in the plants was lower in the BBFA treatment than with the chemical fertilizer treatment, although the N was higher than with the BCM and control treatments (Fig 4b).

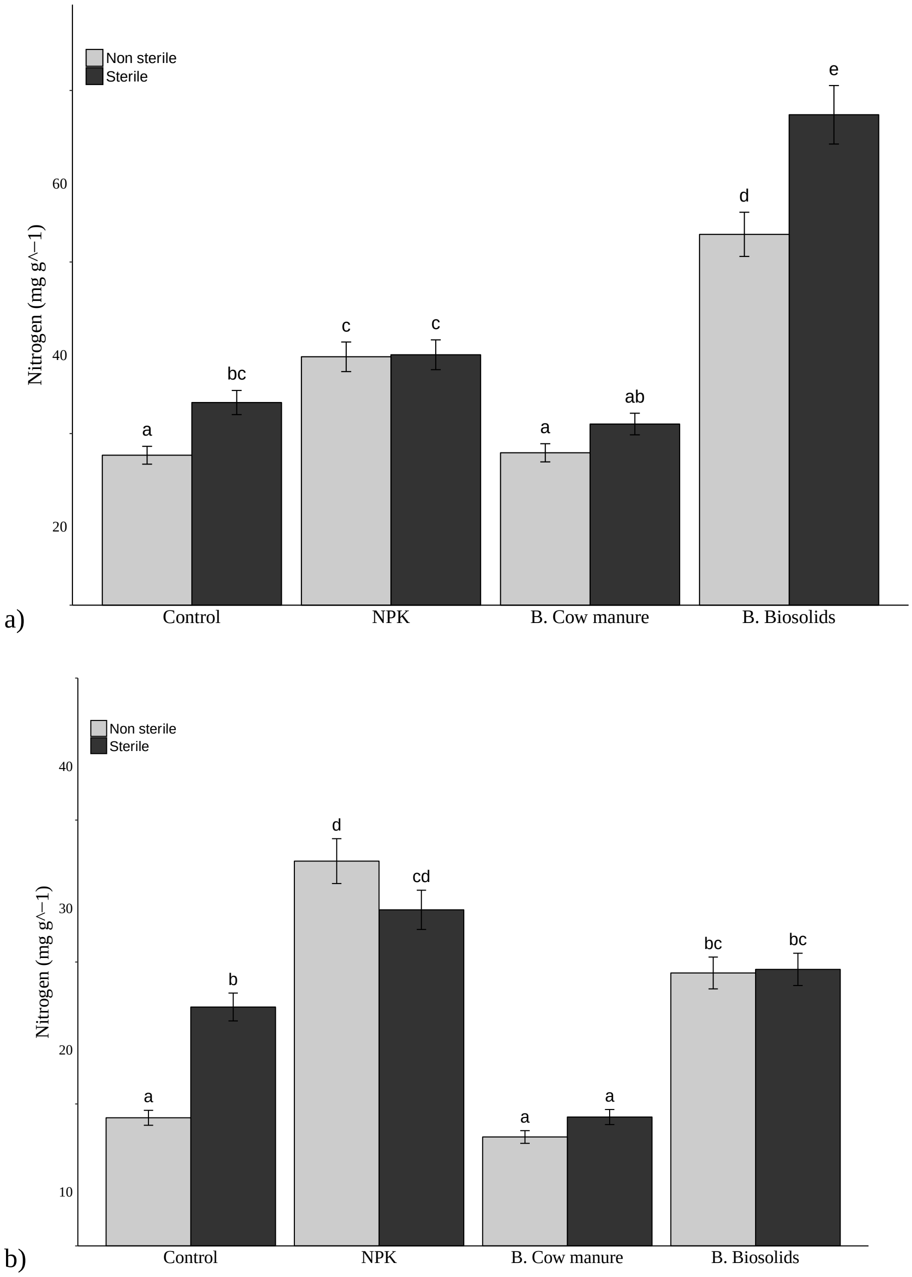
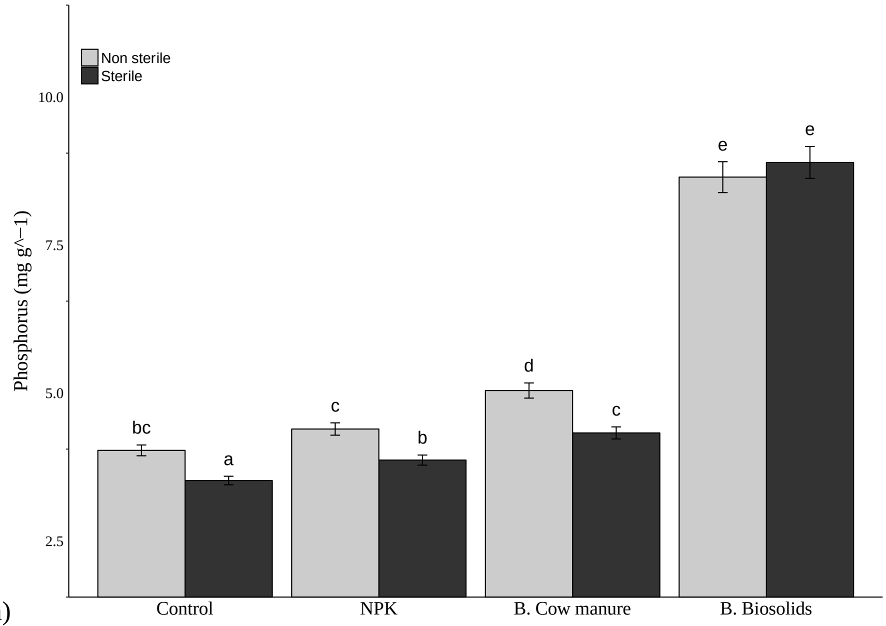
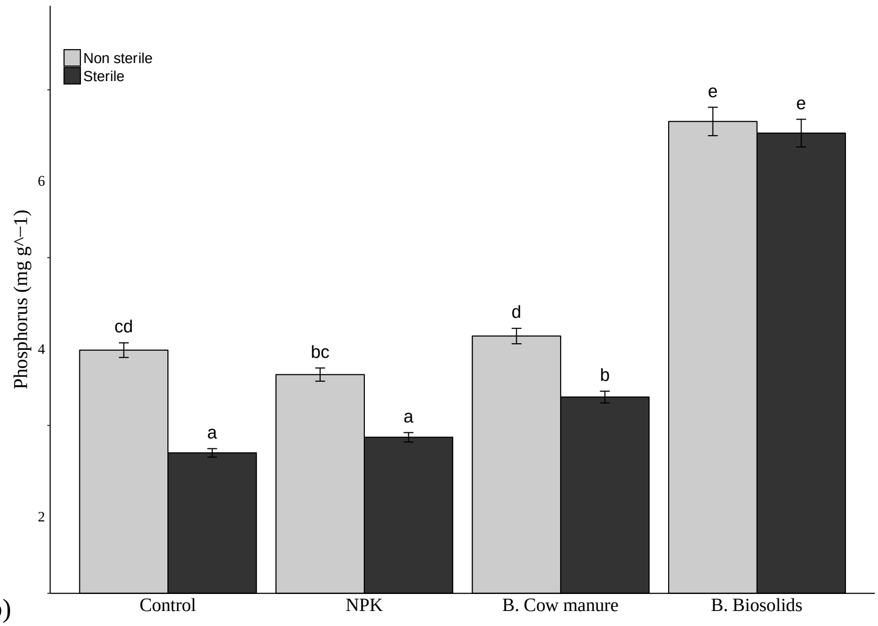


Fig. 4 Average N concentration in maize plants grown in various substrates including Bokashi with biosolids and fly ash (B. Biosolids), Bokashi with cow manure (B. Cow manure), chemical fertilizer (NPK) and unamended control using sterile and non-sterile soil. a) Data for plants 6 weeks after sowing; b) Data for plants 10 weeks after sowing. Different letters above each error bar show significant differences among treatments according to the chi-squared test ($p<0.05$)

All growth parameters that were measured in the maize plants were improved by the application of BBFA. In addition, higher concentrations of N and P were found in these same plants. Hence, the BBFA treatment provided the best growing medium for maize under greenhouse conditions. This was expected because of the increased levels of organic matter and nutrients contributed by the biosolids (Castaldi et al. 2006; Farasat and Namli 2016) and fly ash (Lai et al. 1999; Singh et al. 2012a). P concentrations were highest, at both harvest times, in maize plants grown in the BBFA amendment (Fig 5a, 5b). In treatments with BCM or chemical fertilizer, as well as in the control, P concentrations in the maize plants were higher in treatments incorporating non-sterile soil than in those based on sterile soil. It is possible that microorganisms present in the non-sterile soil helped the plants absorb P better than the plants grown in treatments with sterile soil, as seen by other researchers (Ortas 2011). This trend was not observed for the plants grown in the BBFA where no significant differences were found between treatments with sterile and non-sterile soil (Fig 5a, 5b). It is possible that P was more readily available in the BBFA treatment, and soil sterilization did not alter this condition. Adding organic matter in the form of biosolids increases P availability in the soil (Antille et al. 2014), which is probably what happened in our experiment.



a)



b)

Fig. 5 Average P concentration in maize plants grown in various substrates including Bokashi with biosolids and fly ash (B. Biosolids), Bokashi with cow manure (B. Cow manure), chemical fertilizer (NPK) and unamended control using sterile and non-sterile soil. a) Data for plants 6 weeks after sowing; b) Data for plants 10 weeks after sowing. Different letters above each error bar show significant differences among treatments according to the chi-squared test ($p<0.05$)

The growth of the maize plants in the medium with Bokashi with cow manure was similar to the growth in treatments with chemical fertilizers. Hence, the use of Bokashi with the commonly used ingredients (Yamada and Xu 2001) can be as efficient as the use of agrochemicals, while also increasing the organic matter content in the soil and conserving its fertility for a longer period of time (Parr and Hornick 1992; Formowitz et al. 2007; Černý et al. 2010). Plants grown in the fertilizer treatment had higher concentrations of N, but this did not result in higher plant biomass. In this regard, the chemical fertilizer treatment provided enough N for the plants, but the balance for the other nutrients was lacking (Güsewell et al. 2003). It is possible that the BBFA amendment provided the right nutrient balance, which resulted in overall higher plant biomass in maize plants grown in these treatments.

Although several experiments have used biosolids and fly ash under field conditions (Wong et al. 1996; Cuevas and Walter 2004; Kabirinejad and Hoodaji 2012; Jaramillo-López and Powell 2013; Brännvall et al. 2015), this is the first time, as far as we know, that a fermentation process with effective microorganisms was employed to produce an amendment with these waste materials.

Conclusion

We can conclude that through this fermentation process, biosolids and fly ash can be used in a safe way while improving the fertility of the soils and enhancing maize growth and nutrition. Both fly ash and biosolids have concentrations of heavy metals, so their use as ingredients in soil amendments must consider national and international guidelines. When using these materials, a baseline analysis is required for determining the limiting ratios of either material based on the concentration of heavy metals. Once this is determined, the ratio of amendment used should also consider the initial concentration of heavy metals in the soil prior to the amendment. This is the only way to guarantee that these materials do not pose any risk to humans and the environment. When using fly ash, protective gear (a respirator face mask) should be worn so that the operators do not inhale this material. By employing the Bokashi ecotechnology, every sewage treatment plant could process its biosolids and produce a soil amendment that could be used for agricultural or forestry applications. This could serve as a disposal alternative for these materials and even increase their value while turning them into a resource. In the present study, the heavy metals Cd and Pb could not be detected in the soil amendment.

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Compliance with ethical standards

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

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