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Effect of industrial and domestic ash from biomass combustion, and spent coffee grounds, on soil fertility and plant growth: Experiments at field conditions

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Abstract

A study was conducted at field conditions in order to evaluate the effect of application of ash from biomass combustion on some soil fertility characteristics and plant growth. Application of 7.5 Mg ha^{-1} industrial (fly) ash, domestic ash and a 50:50 mix of domestic ash and spent coffee grounds was made in different soil parcels. *Lolium perenne* seeds were sown and the grown biomass was harvested and quantified after 60 days. Soil samples from each parcel were also collected after that period and characterized. Both soil and grown biomass samples were analyzed for Ca, Mg, Na, K, P, Fe, Mn, Zn and Al contents. Soil pH was determined before and after amendment. All applications rose significantly soil pH. Domestic ash, whether combined with coffee grounds or not, proved to be efficient at supplying available macronutrients Ca, Mg, K, P to the soil and also reducing availability of Al (more than industrial ash). However, it inhibited plant growth, even more when combined with spent coffee grounds. As regards to elemental abundance in plant tissue, both domestic ash treatments reduced Ca and enhanced Al contents, unlike industrial ash, which proved less harmful for the load applied in the soil. Hence, it was possible to conclude that application load should be a limiting factor for this management option for the studied materials.

Keywords: biomass ash, spent coffee grounds, soil, fertilization, nutrients, plant growth

1. Introduction

Biomass is perhaps the most promising source of renewable energy regarding the use of alternatives to using fossil fuels, with all countries having a trend of increasing their share of biomass in the process of industrial combustion (Fuller et al. 2015). Biomass ash may be defined as the inorganic uncombustible part of fuel which remains after complete combustion of a biomass fuel (Khan et al. 2009; Melotti et al. 2013; Vassilev et al. 2010, 2013). Fly ash is the finest fraction of it that is collected in dedusting equipment downstream to the combustion chamber (Jala and Goyal 2006; Melotti et al. 2013; Pandey and Singh 2010; Tarelho et al. 2015), with bulk density depending on several factors but reported to be roughly in the range of 0.27-1.80 g cm^{-3} (Augusto et al. 2001; Demeyer et al. 2001; Jala and Goyal 2006; Lanzerstorfer 2015). Chemically, fly ash is usually characterized by high pH, in the range 8-13 (Augusto et al. 2008; Basu et al. 2009; Demeyer et al. 2001; Park et al. 2012; Tarelho et al. 2012, 2015). Its elemental composition is very rich in macronutrients essential to plants, such as Ca, Mg, K, P or S, besides a variety of other elements like Na, Fe, Mn, Zn, Al, Si, B, Mo, Ti, etc. (Girón et al. 2013; Herbert and Krishnan 2016; Lanzerstorfer 2015; Li et al. 2012; Nunes et al. 2016; Rajamma et al. 2015; Tarelho et al. 2015; Vassilev et al. 2013). These characteristics make biomass ashes attractive for soil amendment, subject which has been explored previously by other authors with positive and promising results (Augusto et al. 2008; Lopez et al. 2009; Matsi and Keramidas, 1999; Niu et al. 2016; Nkana et al. 2002; Park et al. 2012; Saarsalmi et al. 2012). Several other potential benefits from application of biomass ash in soils have been listed in the literature (e.g. Demeyer et al. 2001; Fuller et al. 2015; Niu et al. 2016), namely: alteration in soil texture (higher porosity, aeration and water holding capacity), improving enzymatic activity or immobilization of heavy metals. The application of biomass ashes on the soil has also been studied, although more poorly, in terms of their effect on plant growth stimulation/inhibition and nutrient uptake. In this field, however, there are some contradictory results. For example, Etiegni et al. (1991), Matsi and Keramidas (1999) and Nkana et al. (1998) observed a significant increase in plant yield and in its content in Ca, Mg and K after fly ash application. Saarsalmi et al. (2012) reported that wood ash given together with N increased microbial biomass when compared to values from unamended soils and from soils treated only with N. On the other hand, Augusto et al. (2008) suggested that tree growth improvement should only be expected for organic soils, since nitrogen is the first liming agent in most mineral soils, and ash is virtually N-free. Basu et al. (2009) further stated that the application of fly ash (both biomass and coal fly ash), particularly if unweathered, may reduce plant development by inhibiting the microbial respiration, enzymatic activity and soil N cycling processes. Also Brännvall et al. (2015) found in their work that soil fertilization with fly ash (from combustion of tree bark) mixed with biosolids (anaerobically digested) did not enhance biomass production neither nutrient uptake by plants (quite the contrary).

Spent coffee ground is a residue with fine particle size and high moisture content (80% to 85%), organic load and acidity, obtained during instant coffee preparation from raw coffee powder with hot water or steam (Mussatto et al. 2011). This material may represent a pollutant material when discharged to the environment, due to its high content in caffeine, tannins and polyphenols (Limousy et al. 2013). Since coffee has been consumed for over 1000 years and is nowadays one of the most widely consumed beverages around the world, a significant amount of this residue is produced daily. Since the development of small coffee machines that one can purchase to domestic use, each coffee home-consumer is now a producer of spent coffee grounds. This residue has been studied in recent years in order to find a sustainable environmental application to it. It has been proved to be suitable for a variety of practices, such as composting, or other agricultural purposes (Hachicha et al. 2012; Liu and Price 2011), non-structural fill applications, like road embankment extremities (Arulrajah et al. 2014), co-combustion fuel (Limousy et al. 2013), renewable resource in the tannin extraction process (Low et al. 2015), or production of CO_2 adsorbent materials (Plaza et al. 2012).

This work aimed to assess the effect of biomass ash (from industrial and domestic combustion) and spent coffee grounds on soil fertilization and plant growth. The field work was performed in a slightly acidic Portuguese soil, aiming at extending to this Southern European region the knowledge that has been developed especially for Northern Europe and tropical acidic soils. The field experiment aimed not only at finding a feasible way to recover industrial biomass ash, diverting it from landfills, but also at a residential level, testing beneficial effects of applying ash produced domestically in one's garden. The management of our own residues is the driven force for studying the application of domestic ash and spent coffee grounds into the soil.

2. Materials and methods

In this study experimental size soil plots were carried out at field conditions aiming to assess the effects of biomass ash application on soil properties and plant growth. Two types of ash from biomass combustion were tested: i) industrial fly ash (IA) collected at the electrostatic precipitator from a fluidized bed combustion system of a pulp and paper industrial facility, and ii) domestic ash (DA) collected at the grate of a conventional domestic woodstove operating with a mix of biomass fuels. The latter aimed at representing the regular operation of a typical residential biomass combustion equipment for heating purposes under day life practices in typical winter conditions. Another application consisted of a 50:50 mixture (weight, dry basis) of the domestic ash from the wood stove with spent coffee grounds (SCG) collected from a coffee-shop. The material applied on the soil resulted from a combined 2-day sample of SCG, and was used as received, without any pre-treatment, in order to better simulate what would be the behavior of any person who wanted to manage its own waste (the quantity that was mixed with DA was the necessary to produce a 50:50 dry basis mixture). The studied materials were applied on soil parcels in a load of 7.5 Mg ha^{-1} (dry basis). The materials were applied on the surface of the soil parcels, taking care so that the entire plot area would receive equal distribution of material. In the case of DA+SCG application, the materials were previously mixed and then the resulting mixture was applied in similar manner. The 7.5 Mg ha^{-1} load was chosen considering literature about application of biomass ash loads in soil (Augusto et al. 2008; Basu et al. 2009; Matsi and Keramidas 1999; Park et al. 2012; Perucci et al. 2008; Saarsalmi et al. 2012), and also considering a high enough ash load in order to notice some effects of the treatment. On the other hand, it should not be high at a level incompatible with domestic management of solid wastes such as DA or SCG. A control test (CT) was included in the experiment, consisting of a parcel of soil to which no material was added. The field experiment was conducted in a typical, slightly acidic, soil of the central coastal region of Portugal, in the district of Aveiro (40°45'30.65"N, 8°29'20.11"W). The studied soil is classified by the Portuguese soil map as a cambisol (APA, 2011). The tested field was divided into a grid of 12 parcels, each one of 0.25 m^2 (square parcels of 0.5 m side). Each parcel was separated from the next one by at least 0.2 m. The layout of the grid is shown in Figure 1, where it can be seen that each line of the grid had one parcel of each tested condition (that is, an ash treatment type) and that each condition was replicated 3 times.

The rationale behind the adopted spatial distribution of samples was made in order to minimize the role that environmental conditions (e.g., minor changes in orography or soil properties) could have in the behavior of the amended soil parcels, that is, an empirical experimental design was conceived to have the experimental plots with the same treatment at distinct locations in the experimental field. The size of sample plots was chosen considering soil field conditions, namely to guarantee minimum effects of variation in natural soil properties for the distinct samples, and conceived in order to have at least tree replicates for each type of test. Small plots allow a better level of control of the experiment, and this is important in the field in order to minimize the number of variables that can influence the results. This way, we have submitted the distinct tests and replicates to a field soil that can be considered uniform in properties, and thus decreasing the number of variables that can influence the experiment. In selecting the size of the test-field it was also considered the domestic type of application, considering the limited amount of domestic ash and spent coffee grounds that can be generated by family houses and the subsequent local application of those wastes.

Ryegrass (*Lolium perenne*), a feed crop commonly grown in Portugal, was sown in all soil parcels in order to evaluate the stimulation/inhibition effect of the different tested materials in plant growth. 5.55 g of seeds were sown in each soil parcel, according to a commercially advised rate of 20 to 25 $g_{seeds}\ m^{-2}$ and to other studies, e.g. Matsi and Keramidas (1999).

Sixty days after seeding, the aboveground biomass (cut at about 2-3 cm above the surface of the soils) was harvested from the different soil parcels, dried in an oven (at 105 ºC) for 24h and weighed. The germination index (GI) was calculated for each parcel according to Equation 1, where *m* designates mass.

$$GI = (m_{biomass\ grown}/m_{seeds\ sown}) / (m_{biomass\ grown\ in\ CT}/m_{seeds\ sown\ in\ CT}) \qquad (1)$$

The GI has been used in previous studies, since it has been proved to be a very sensitive index (Tiquia et al. 1996). When greater than 0.8 GI indicates the inexistence of phytotoxicity of the amendment material (Araújo and Monteiro 2005).

Sub-samples of the dry biomass were ashed at 550ºC according to CEN/TS 14775:2004. The produced ash was then digested according to CEN/TS 15290:2006, with the suitable ratio of the four recommended reagents: 2 mL of 30% (w/w) hydrogen peroxide (H_2O_2), 3 mL of 65% (w/w) nitric acid (HNO_3) and 0.75 mL of 40% (w/w) hydrofluoric acid (HF), plus 7.5 mL of 4% (w/w) boric acid (H_3BO_3), and 20 mL distilled water, all of them commercial analytical grade reagents. This procedure was also adopted for the determination of the chemical composition of the amendment materials applied to the different soil parcels. The digestion procedure was performed in a Berghof Speedwave ® Four microwave system, with TFM™ digestion vessels.

Soil samples (0-15 cm depth) were also collected from each parcel after the 60 days period. Those samples were air-dried to constant mass and sieved to 2 mm (ASTM Retsch Test Sieve). After this pre-treatment, soil samples were extracted by the Mehlich-3 (M3) extraction technique, which allows to quantify the exchangeable (and thus plant available) concentration of nutrients. The M3 extractant comprises 0.2 M CH_3COOH, 0.015 M NH_4F, 0.013 M HNO_3, 0.001 M ethylene diamine tetraacetic acid (EDTA), and 0.25 M NH_4NO_3. In this procedure, phosphorous is extracted by reaction with acetic acid and fluoride compounds, while exchangeable K, Na, Mg and Ca are extracted by the action of ammonium nitrate and nitric acid. The micronutrients (Mn and Fe, plus Zn) are extracted by NH_4 and EDTA.

The content of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), aluminum (Al) and zinc (Zn) in the digested biomass and soil amendment materials samples, and Mehlich 3 extracted soil samples were analyzed by atomic absorption/emission spectroscopy, with a PerkinElmer AAnalyst 200 – Atomic Absorption Spectrometer. Phosphorous content was determined by colorimetric determination, using a Camspec ® M501 Single Beam Scanning UV/Visible Spectrophotometer with infrared phototube. For this purpose, the methodology proposed in Greenberg et al. (1992) was adopted. In this procedure, ammonium molybdate and potassium antimonyl tartrate react in acid medium (provided by sulphuric acid) with orthophosphate to form a heteropoly acid – phosphomolybdic acid – that is reduced to intensely colored molybdenum blue by acid ascorbic, detectable by spectrophotometry at 880 nm.

All soil samples and applied materials (IA, DA and SCG) were analyzed for pH in a 1:5 (v/v) ratio of soil in water, accordingly to ISO 10390:2005. The measurement was performed in a

Denver Instrument® model 25 pH/ion meter. In order to characterize the soil and the suitability of the amendment materials to apply on it, a determination of the organic matter content was performed adapting the procedure described in CEN/TS 14775:2004. A vertical undisturbed sample of the original untreated soil was also taken in order to determine soil dry bulk density (according to ASTM D7263-09) and field capacity (by means of staged water addition until saturation is reached, quantifying the amount of water that the soil can retain).

A two-sample t-test procedure ($p < 0.05$) was applied to the experimental results to statistically differentiate the means at 95% confidence level.

3. Results and discussion

Table 1 compiles some relevant data on the physical characteristics of the soil used in the experiment at field conditions, prior to any material addition. The elemental composition of the original soil selected to experiments in the field is reflected in the analysis of the control soil (CT) and is shown in Figure 3, in order to allow comparison to the elemental composition of the amended soil parcels. The soil is originally an acidic, very rich in organic matter (13% wt., dry basis) soil. Previous studies in this field of research have shown that typical values of pH in Portuguese soils fall in the range of 4.2-7.2 in urban areas and 4.0-5.8 in rural areas, while the organic matter (as carbon) content varies in the ranges 0.6-11% wt. and 2.2-5.0% wt. in urban and rural areas, respectively (Rodrigues et al. 2010, 2013). Soil's dry bulk density is low (0.596 g cm^{-3}), when compared to literature values of 1.1-1.6 g cm^{-3} (Hillel 1980). Naturally, if the soil has low density, it will be more porous and, consequently, it will have higher water holding capacity, which is characteristic of cambisols. Table 2 summarizes the main physical-chemical characteristics of the materials applied in the soil. Their chemical composition is shown in Figure 2. As expected, both types of biomass ash are highly alkaline, with pH in the range of 11.8 to 12.4.

Differences in the organic matter content of the ashes, with higher values (15.7%wt.) in the case of domestic ashes, are related to the higher amount of unburnt carbon content in these ashes, due probably to lower combustion temperature or inadequate load of fuel/combustion air in the domestic woodstove, which promote a lower fuel conversion.

Spent coffee grounds are almost entirely not stabilized organic matter (about 98% wt.) and have pH lower than 6, which is in agreement with data provided in the literature (Arulrajah et al. 2014; Liu and Price 2011).

Among the analyzed elements, Ca and K are the most abundant elements in industrial and domestic ash's composition (especially in the latter), reflecting the original composition of the type of biomass burnt, in accordance with the literature (e.g. Vassilev et al. 2010). Both ash types also show considerable amounts of Na, Mg (especially DA), P, Fe and Al (especially IA), which is also in accordance with reported information in the literature for some types of biomass ash (Vassilev et al. 2013). Spent coffee grounds are particularly rich in K, but also in Mg and P, the macronutrients in which domestic ash is poorer.

The pH of the soil at the end of the field experiment is shown in Table 3. All applications significantly ($p<0.0001$) increased soil pH compared to the control test, to which no material was added. Amendment with domestic ash was the most efficient in raising soil pH, with a value of 7.88±0.06 two months after application. All values are considerably high and fall near (either below or above) the top limit of the range pointed out in the literature for maximum nutrient availability of 6 to 7.5 (UNIDO and IFDC 1996). It is worth noting that even when combined with slightly acidic SCG, domestic ash caused greater raise in soil pH than industrial ash. This suggests high neutralizing capacity of domestic ash, possibly due to its greater richness in Ca, comparatively to the other materials used.

As regards to biomass yield (see Table 4), no significant difference ($p=0.8117$) was observed between the mass of biomass grown in control parcels and parcels of soil treated with IA. This is not an unprecedented result, since Park et al. (2012) and Brännvall et al. (2015) both recorded similar results. This means that application of 7.5 Mg ha^{-1} industrial fly ash did not produce any contamination in soil that would inhibit plant growth (phytotoxicity). On the other hand, application of DA seems to have caused a significant ($p=0.0352$) inhibiting effect on biomass development, which could be related with excessive pH raise or most likely to excessive nutrient enrichment, which may have caused excessive increase in the soil salinity and lead to a counter-productive effect. When combining DA with SCG, the effect was even worse, with the yield of biomass being approximately half of the quantity harvested from the control parcel. Since the effect in soil pH was very similar among the three treatments, this inhibitory effect of the plant growth is more likely due to the composition of the SCG, not only in terms of the possibility of excessive content of some chemical elements, but also in terms of its 98% wt. composition in organic matter. In fact, the literature has reported that organic wastes may induce phytotoxicity in plants, pointing out possible explanations for this effect, such as the presence of heavy metals, ammonia, salts and low molecular weight organic acids (e.g. Zucconi et al. 1985). Hence, at this load of application (7.5 Mg ha^{-1}), only industrial ash proved to not induce negative effects on the growth of the studied plant. Soil amendment with DA combined with SCG revealed to be the most hazardous application, with a GI of 0.51±0.08. Figure 3 shows the elemental concentration of the M3 extracted macro and micronutrients in all soil parcels, comparing the treated soils with the control soil.

All treatments produced noticeable raise (and statistically significant, $p<0.05$) on the concentrations of available macronutrients Ca, Mg and K in the soil. This was probably due to the chemical composition of the materials applied, which are rich in those elements, and also to the raise in soil pH, which may have enhanced these nutrient's availability. Similar effects are well documented in the literature (e.g. Augusto et al. 2008; Nkana et al. 1998, 2002; Pandey and Singh 2010; Saarsalmi et al. 2012). Application of DA or DA+SCG proved to deliver a higher raise in the abundance and availability of those macronutrients in the soil when compared to the application of IA. This is most likely due to the greater amount of those chemical elements in the composition of DA, which become available in the soil with rising pH. Moreover, it should be noted that the raise in pH caused by these treatments was in fact greater than the one produced by IA application. Similarly to that registered for the pH, the application to the soil of DA or DA+SCG did not differ statistically from each other in what availability of Ca, Mg and K is concerned ($0.0681<p<0.2832$). Thus, despite SCG having more (total) Mg and much more (total) K than DA in its composition, the available fraction (M3 available) of those chemical elements in SCG proved to be relatively small. Regarding the P availability, there was no statistically significant effect of the application of industrial ash ($p=0.0779$). This may be due to the low solubility of P from ash, since it is usually bound to compounds of low solubility, like apatite (Augusto et al. 2008). However, contradictory results about P can be found in the literature. On the other hand, the application of DA or DA+SCG did rise significantly ($p=0.0725$)

the levels of M3 available P in the treated soil, when compared to CT, but, once again, with no significant difference between these two treatments.

Regarding the other analyzed elements, Fe, Mn and Zn are recognized as essential plant micronutrients; Na can be an important cause of excess salinity in some soils (saline-sodic and saline soils); and Al may enhance soil acidity to levels not compatible with the development of most plant species. In the case of IA application, it did not produce any significant difference comparatively to the concentrations of Al and Fe registered in the control plot, while DA application significantly reduced the available Al and Fe concentration in the soil, whether combined with SCG or not; the outcome of the two treatments was once again statistically identical. The raise in soil pH produced by DA (whether combined with SCG or not) is likely to be responsible for this reduction in micronutrients availability, namely Al, which has been previously reported in other literature studies (e.g. Brännvall et al. 2015; Nkana et al. 1998; Pandey and Singh 2010). Brännvall et al. (2015) states that Al solubility and availability is low enough for soil pH above 5, which has been surpassed by the adopted amendments. According to Nkana et al. (1998), also the raises in exchangeable base cations may be associated with decrease in Al availability and toxicity. All applications rose bioavailability of Na and Mn. It is worth noting that IA rose statistically more ($p=0.0464$) the Na level than DA, although the latter had a greater concentration of (total, not necessarily available) Na in its composition. The available Zn concentration remained statistically unaltered in result of the three soil additives application.

Figure 4 shows the elemental concentration of the macro and micronutrients, and also Na and Al, present in the biomass harvested after the 60 days field experiment.

In what macronutrients Mg, K and P are concerned, the t-test showed that the registered differences between biomass grown in treated soil and in the control soil parcels were not statistically significant. On the other hand, DA and DA+SCG applications reduced Ca concentrations in the plant tissue ($p=0.0031$) from around 25 to around 10 g Ca kg^{-1}, possibly due to excessive pH raise in the root of the plant, inhibiting the uptake of the available Ca. Contradictory results have been found in the literature regarding this. Several authors have registered significant increase Ca and K (Augusto et al. 2008; Demeyer et al. 2001; Nkana et al. 1998), while Brännvall et al. (2015) found decrease in this nutrients content in plant tissue, as well as for P, Fe and Mn. Park et al. (2012) only registered significant increase in the content of K. These results show the variability of plants' responses to the amendment of soil with biomass ash. This may be due to soil type, plant type, pH of the initial soil and pH achieved after amendment, the form of nutrients in the ash composition and ash load. In the case of P, availability above pH 7 may become limited due to the formation of insoluble calcium phosphate compounds, since it is strongly dictated by precipitation and surface adsorption reactions (Park et al. 2012). This can help explain the results obtained. The lack of increase in Ca and Mg content in plant tissue may also be due to the antagonist effect of Mg with Ca/K (Demeyer et al. 2001; Nkana et al. 1998), or perhaps with excess salinity, namely Na content (UNIDO and IFDC 1996).

As regards to micronutrients, the differences registered in Fe and Mn contents were always marginal, statistically non-significant. Similar results were obtained for the Na content. Total Al content in the plant was enhanced by addition of DA and DA+SCG (equal magnitude among treatments) from around 1.0 to around 2.3 g Al kg^{-1}.

Repeating the harvest in time would have been adequate to further test and confirm these results, and even to compare the response of ryegrass to ash amendment amid different weather seasons. However, and since perennial ryegrass tens to die in April-May and should be replanted every year, sequential harvesting procedures would be made for different seeding procedures, which would not allow straight comparison amid results obtained.

4. Conclusions

All three amendments significantly raised soil pH to levels very close to the recommended limit for optimum for plant growth, especially domestic ash. Perhaps in accordance with this, application of 7.5 Mg ha^{-1} domestic ash seemed to significantly inhibit plant growth, especially when combined with spent coffee grounds. That hazardous effect was not observed when using industrial ash as amendment.

All treatments produced noticeable raises on the concentrations of available macronutrients Ca, Mg and K in the soil, especially the application of DA (whether combined with SCG or not). The two applications involving DA were also capable of significantly rising M3 available P content in the soil.

DA and DA+SCG application on the soil showed some concerning effects on plant tissue, reducing Ca content and enhancing Al content. Lowering the ash load, weathering the domestic ash or substituting the powder application by a granular or pelletized-form application could improve DA performance. A higher load could, however, be suitable for IA application, in order to potentiate its benefits to the soil, while evaluating if it maintains a harmless behavior with regard to plant growth and nutrition. Spent coffee grounds could possibly be suitable for soil amending if previously stabilized.

Further investigation is still needed in this subject, namely, by repeating these experiments at field conditions (seeding, amendment and harvesting) in time and space, for example throughout a year, to perform tests and harvest campaigns during the different seasons. Other types of soil should also be tested.

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Table 1. Initial characteristics of the field soil where the experiments were developed

pH	5.03 ± 0.14
Organic matter content (% wt.,db[a])	13.9 ± 0.3
(Dry) Bulk density [g cm^{-3}]	0.596
Field capacity [kg_{water} $kg^{-1}_{dry\ soil}$]	0.636

[a]db - dry basis

Table 2. Initial characteristics of the applied amendment materials

	Industrial Ash	Domestic Ash	Spent Coffee Grounds
Moisture content (% wt., wb[a])	0.46 ± 0.20	4.52 ± 0.81	55.8 ± 0.12
Organic Matter Content (% wt., db[b])	7.09 ± 1.03	15.7 ± 2.33	98.1 ± 0.02
pH	12.4 ± 0.01	11.8 ± 0.03	5.76 ± 0.11

[a]wb – wet basis or as received basis

[b]db – dry basis

Table 3. Soil pH at 60 days after application of the different tested amendment materials (plus control soil)

	pH
Control Soil CT	5.86 ± 0.05
Soil IA	7.36 ± 0.10
Soil DA	7.88 ± 0.06
Soil DA+SCG	7.67 ± 0.03

Table 4. Biomass yield [g per parcel] and germination index for the different tested conditions

Soil parcel	Biomass yield	Germination Index (GI)
Control Soil CT	12.4 ± 1.03	-
Soil IA	12.6 ± 0.89	1.02 ± 0.07
Soil DA	10.2 ± 0.65	0.82 ± 0.05
Soil DA+SCG	6.27 ± 0.97	0.51 ± 0.08

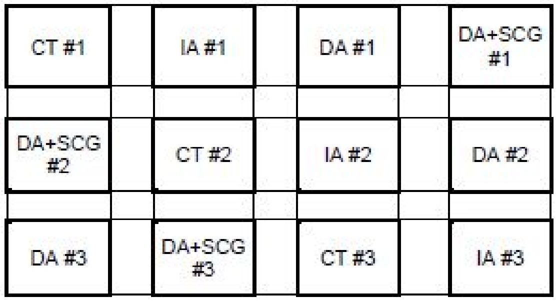

Fig 1 Field layout of the different soil parcels (CT=control soil, IA=soil treated with IA, DA= soil treated with DA, DA+SCG=soil treated with DA+SCG mixture)

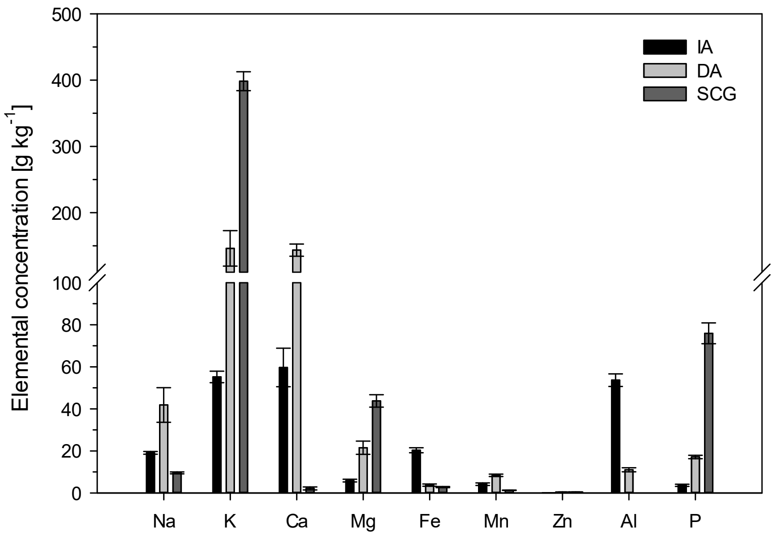

Fig 2 Concentration [g kg^{-1}] of the different chemical elements analyzed in the three amendment materials (IA= Industrial Ash; DA=Domestic Ash and SCG=Spent Coffee Grounds)

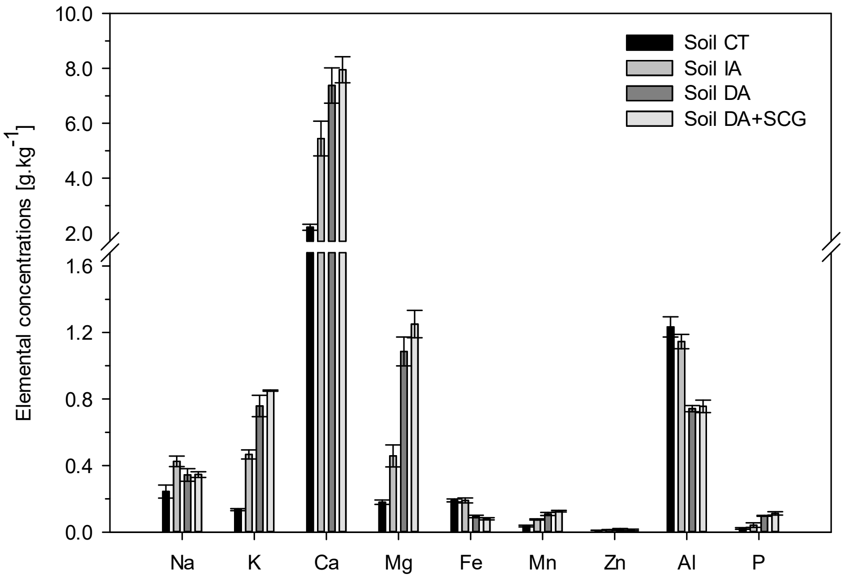

Fig 3 Concentration [g kg^{-1}] of plant available chemical elements in the soil 60 days after amendment

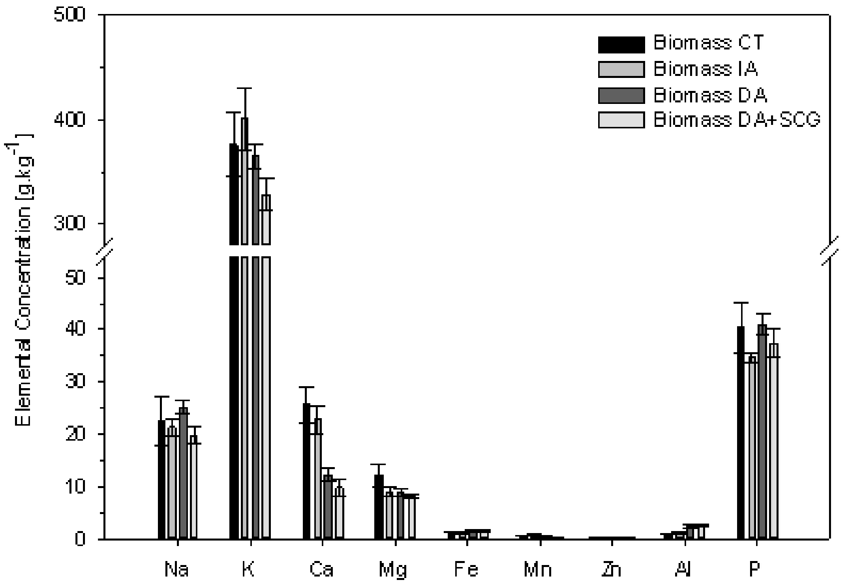

Fig 4 Concentration [g kg^{-1}] of total chemical elements in the biomass harvested from the different soil parcels