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SABRINA MAGLOIRE

Chemical and physical properties of a dystrophic RED LATOSOL and yield of common bean (*Phaseolus vulgaris* var. IPR-Tuiuiú) after biochar and organic compost amendments

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Dissertation presented to the Agronomy Graduate Program of the Department of Agronomy, Center of Agricultural Science of the Paraná State University in Maringá, as a partial requirement for the degree of Master in Agronomy.

Field of study: Soils and Plant Nutrition

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I dedicate this dissertation to my mother, my father and my sister due to their permanent assistance during this work ,in spite of not being in Brqzil with me.

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BIOGRAPHY

Sabrina Magloire, daughter of Venitte Beauvais Magloire and Jean Magloire, was born on August 16, 1988 in the capital of Haïti, Port-au-Prince. She studied Agronomy at the Faculty of Agronomy and Veterinary Medicine of the State University of Haïti and started in 2015 the Master’s program in Agronomy at the Paraná State University in Maringá

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ABSTRACT

The maintenance of soil fertility and the food security are a global concern in agriculture, especially for acid soils. The black soils of the Amazonian rainforest, named ``Terras Pretas de Índios (TPI)´´, are nowadays considered the model of fertile soils. The researchers in Brazil came with a material whose benefits could persist in long term as TPI do:"biochar". The biochar has the ability to improve soil chemical and physical attributes and the crop yield. This study aims to evaluate the effects of biochar and organic compost in the improvement of the soil properties and bean production (*Phaseolus vulgaris* var. IPR-Tuiuiú) using a dystrophic RED LATOSOL from Fazenda Experimental de Iguatemi-Maringá. This research was conducted in a greenhouse of the Paraná State University in Maringá with 5 doses (25, 50, 100, 150, 200 t ha^{-1}) of biochar and organic compost and a control treatment with 5 replicates. Firstly, the soil chemical (pH, Al, H+Al, Mg, Ca, K, Na, SB, CEC, P, C, EC, Zn, Cu, Fe, Mn) and physical attributes (porosity and density) were analyzed. Then the soil chemical and physical attributes were submitted to Pearson's analysis with the total dry weight of grains ($p<0.05$). A multiple regression was performed with the soil attributes and germination rate, number of grains and total dry weight of grains. A cross-factorial experiment with one control treatment in a completely randomized design (5x2+1) was considered at 5% of probability. The only nutrient that increased in soil after biochar amendment was K. The biochar increased the pH_{H2O} and the carbon content in soil. Biochar decreased the concentration of Ca, H+Al, Cu, EC, CEC and the bulk density (BD), but had no effect on ΔpH, Al, P, Zn, Fe and Mn. Soil macro and microporosity were affected only by 200 t ha^{-1} of biochar. The organic compost increased pH_{H2O}, Ca, K, Na, P, C, SB, CEC, EC, Zn, Cu, Fe, Mn and macroporosity, decreased H+Al, microporosity, BD, had no effect on Al concentration and presented predominance of positive charge. The coconut shell biochar did not increase the bean yield but the organic compost did. The Ca^{2+} and the CEC showed negative correlation with the total dry weight of grains with biochar amendment but positive with organic compost. The organic compost attributed better chemical conditions to the soil than the biochar; but both affected similarly the physical attributes of the soil.

Keywords: Soil conditioners. Soil chemistry. pH. CEC

Atributos químicos e físicos de um LATOSSOLO VERMELHO distrófico e rendimento de feijão preto (*Phaseolus vulgaris* var. IPR-Tuiuiú) após adição de biochar

RESUMO

A manutenção da fertilidade do solo e a segurança alimentar são uma preocupação global na agricultura, especialmente para os solos ácidos. As Terras Pretas de Índios (TPI) da floresta amazônica se tornam hoje em dia o modelo de solos férteis. Os pesquisadores no Brasil vieram com um material cujos benefícios poderiam persistir em longo prazo como TPI: "biochar". O biochar pode melhorar os atributos químicos e físicos do solo e o rendimento de plantas. O objetivo deste estudo foi avaliar os efeitos do biochar e do composto orgânico na melhoria das propriedades do solo e da produção de feijão (*Phaseolus vulgaris* var. IPR-Tuiuiú) utilizando um LATOSSOLO VERMELHO distrófico da Fazenda Experimental de Iguatemi-Maringá. Esta pesquisa foi conduzida em estufa da Universidade Estadual de Maringá com 5 doses (25, 50, 100, 150, 200 t ha^{-1}) e 5 repetições de biochar e composto orgânico e uma testemunha. Os atributos químicos (pH, Al, H + Al, Mg, Ca, K, Na, SB, CTC, P, C, CE, Zn, Cu, Fe, Mn) e físicos (porosidade e densidade) foram analisados e submetidos à correlação de Pearson com o peso seco total dos grãos ($p<0.05$). Uma regressão múltipla foi realizada entre os atributos de solo e a taxa de germinação, o número de grãos e o peso seco total de grãos. Um experimento fatorial cruzado em um delineamento inteiramente casualizado com uma testemunha (5x2+1, α=0.05) foi considerado. O único nutriente que aumentasse com o biochar foi o K. O biochar aumentou o pH_{H2O} e o teor de carbono orgânico no solo. A macro e a microporosidade (MI) do solo foram afetadas apenas por 200 t ha^{-1} de biochar. O biochar diminuiu a concentração de Ca, H+Al, Cu, CE, CEC e a densidade aparente do solo, mas não teve efeito no ΔpH, Al, P, Zn, Fe e Mn. O composto orgânico aumentou pH_{H2O}, Ca, K, Na, P, C, SB, CTC, CE, Zn, Cu, Fe, Mn e MI; diminuiu H+Al, a MI e a densidade do solo, não teve efeito sobre Al e apresentou predomínio de carga positiva. O biochar não aumentou o rendimento de feijão ao contrário do composto. O Ca^{2+} e a CTC apresentaram correlação negativa com o peso seco total dos grãos com o biochar, mas positiva com o composto orgânico. A correlação de Pearson entre este variável e P não foi significante ($p<0.05$) com o biochar enquanto significante com o composto orgânico. O composto orgânico atribuiu melhores condições químicas ao solo do que o biochar; mas ambos afetaram na mesma forma os atributos físicos do solo.

Palavras-chave: Condicionadores de solo. Química do solo. pH. CTC

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LIST OF ABBREVIATIONS

BD	-	Bulk density
Bio	-	Biochar
CEC	-	Cation exchange capacity
DW1000	-	Dry weight of grains
EC	-	Electric conductivity
m	-	Percentage of aluminum saturation
MA	-	Macroporosity
MI	-	Microporosity
Org. C	-	Organic carbono
OC	-	Organic compost
pH	-	Potential hydrogen
PZC	-	Point of zero charge
SB	-	Sum of bases
TDWG	-	Total dry weight of grains
TP	-	Total porosity
V	-	Percentage of base saturation

SUMMARY

1 INTRODUCTION

Besides the soil degradation by human action, the chemical conditions inherited from the soil formation process make some soils naturally incapable of providing adequate chemical and physical conditions for the growth and development of plants without some previous amendments. Soil acidity is one of the limiting factors for the agricultural production (IQBAL, 2012). About 50% of the soils in the world are acidic and approximately 60% are found in tropical and subtropical countries (KOCHIAN et al., 2015). Their low pH, due to the presence of ions H^+ and principally Al^{3+} in the soil solution, make them really poor in alkali cations (MELO & WYPYCH, 2009).

The acidic soils are the main soils of Brazil and latosols are the most found. According to Canellas & Santos (2005), among the 750 million hectares of worldwide latosols, 300 million hectares are in Brazil. These soils represent about 30-40% of Brazilian soils, about 2, 691, 563 km^2 of the total surface of 8, 515, 767 km^2. Although they have some good physical attributes; they exhibit serious chemical conditions that decrease the agricultural production (KÄMPF et al., 2009). Different techniques of correction are used to not only increase the pH, but also control the Al content in soil solution (liming), provide nutrients (mineral fertilizer) and organic matter (composting, no-tillage) (YAMADA, 2005; ZANDONÁ et al., 2015).

These and other methods of crop production and soil productivity improvement, along with management policies, made Brazilian agriculture have reach an incredible success making this country the major world producer of several crop in recent years (MUELLER & MUELLER, 2014). Thus, Brazilian researchers, in order to maintain the good quality of acidic soils and also continuously increase agricultural production, decided not to stop looking for other techniques that would probably be more efficient. The “Black Indians soils” or “Dark earth” or ‘“Terras Pretas de Índios (TPI)” (in Portuguese)’ of the Amazonian rainforest has recently become the model of fertile soils. The TPI represent more than 10% of the Amazonian rainforest (MANGRICH et al., 2011) and exhibit great productivity differently from other nearby acidic and degraded soils (MAIA et al., 2011). The good chemical conditions of the TPI come from the strong accumulation of organic wastes processed by fire. In order to extend the amount of fertile soils by increasing the acidic soil productivity, researchers in Brazil came with a product which is rich in carbon and nutrients and whose benefits could persist in long term as TPI do: ”biochar” (MANGRICH et al., 2011). Biochar is a charcoal produced by pyrolysis of organic products, plants or animals (MOURA et al., 2010). The pyrolysis occurred in the absence or low presence of oxygen which promotes a lower rate of ash in contrary of the traditional charcoal. In this work, it was studied and compared the effects of two soil conditioners (a coconut shell biochar and organic compost) on the chemical and physical attributes of a dystrophic RED LATOSOL and on the yield of a black bean (*Phaseolus vulgaris* var. IPR Tuiuiú) produced in greenhouse, using also lime in the soil preparation.

1.1 Hypothesis

The soil incubation with biochar and organic compost has the ability to improve the chemical and physical attributes of the soil by providing better conditions for the development of black bean.

1.2 Objectives

To determine the chemical and physical attributes of the coconut shell biochar and the organic compost,

To evaluate the chemical and physical alteration in the dystrophic RED LATOSOL after the incorporation of crescent doses of biochar and organic compost, and

To evaluate the yield of black bean after the soil incubation with crescent doses of biochar and organic compost.

2 LITERATURE REVIEW

2.1 Tropical soils

2.1.1 Main characteristics of tropical soils

Tropical regions are found between the tropics of Cancer and Capricorn, between 23º27' parallel North and South of the globe (MATHIEU, 2009). The climate conditions for the formation of these soils include high temperature along the year with strong air humidity and a minimum of 3 to 4 months of rain and heat, without providing a large variation of the temperature. The high temperatures of these regions favor the microbe activities, the rapid decomposition of the soil organic matter (PETTER & MADARI, 2012) and the reduction or absence of soil humus. Such characteristics let them fragile and susceptible to degradation, considering the importance of soil humus in the water retention, the cation exchange capacity and the soil structure.

2.1.2 Formation and composition of tropical soils

In tropical soils, below the A and B horizons come a thick and very old colored part in which occur all the geochemical reactions (MATHIEU, 2009). These soils are formed by hydrolysis of primary minerals which favored the liberation of more soluble nutrients. The silicic acid and alkali cations are leached in the soil profile. The iron and the aluminum released have very low solubility and they accumulated in the form of iron and aluminum oxides (MAURIZOT et al., 2012). Particularly, the presence of Al^{3+} in soil solution makes these soils acid and then reduces their productivity (MAURIZOT et al., 2012).

2.2 Chemical and physical properties of Latosol

According to the Brazilian System of Soils Classification (EMBRAPA, 2006), tropical and subtropical soils are divided into 13 groups in which figured the Latosol; oxisol class according to American System of Soil Classification and Ferralsols in the FAO classification system, occupy about 40% of Brazil (CANELLAS & SANTOS, 2005). They are soils with very advanced evolution, rich in kaolinite, iron and aluminum oxides and hydroxides (EMBRAPA, 2006).

According to the Brazilian System of Soils Classification (EMBRAPA, 2006), tropical and subtropical soils are divided into 13 groups inside of which are the Latosol, also called Ferralsols in the FAO classification system. Latosols represent about 40% of Brazil soils (CANELLAS & SANTOS, 2005). They are soils with very advanced evolution, rich in kaolinite, iron and aluminum oxides and hydroxides (EMBRAPA, 2006)

Kaolinite is a 1:1 phylosilicate $Al_4Si_4O_{10}(OH)_8$ and is the main mineral of the clay fraction in humid tropical soils. The presence of silicic acid and the absence or low content of basic cations in the soil solution are the main factors for the formation of this clay. Kaolinite is associated with gibbsite [$Al(OH)_3$] which is the principal aluminum oxide in latosols. Differently from kaolinite, gibbsite needs low silicic acid content to be formed. (MELO & WYPYCH, 2009)

The specific surface area of the aluminum oxides in general is high and varies from 100 to 220 m^2 g^{-1} (KÄMPF et al., 2009). They present high pH at the PZC between 9.5 and 10. Their Cation Exchange Capacity (CEC) and their Anion Exchange Capacity (AEC) vary with the soil pH, the crystallinity, the specific surface area and the specific adsorption of organic compounds (KÄMPF et al., 2009).

The most common iron oxides and hydroxides are magnetite (Fe_3O_4), goethite (α-FeOOH) and hematite (α-Fe_2O_3). Iron oxides can be found in any fraction of soil by weathering of primary minerals, microbial activity or remobilization by protonation processes, complexation and reduction (COSTA & BIGHAM, 2009). In soils, iron oxides have more positive than negative charges; this property demonstrates its greatest anions adsorption capacity than cations. The iron oxides have a very high PZC between 7 to 9 and a high value of specific surface area (COSTA & BIGHAM, 2009).

These 3 main elements attribute to the latosols some properties that reflect their interaction. The iron and aluminum oxides have the ability to increase the positive charges of the soil (positive ΔpH values). Although iron and aluminum oxides favor the retention of nitrate (NO_3^-), which is a very important element for plants, and Si; they also adsorb phosphorus, making it unavailable in the soil, which explains the poverty of latosols in available P (KÄMPF et al., 2009).

However, these constituents attribute interesting physical characteristics. The large amount of gibbsite and iron oxides increases the soil porosity by the formation of fine aggregates and thus an improvement in the water infiltration.

2.3 Chemical and physical attributes of biochar

The term *biochar* is used when the charcoal is particularly produced to be soil conditioner improving soil attributes (QIAN et al., 2015; ZIMMERMANN et al., 2012). Adversely from combustion in the traditional coal production, pyrolysis (method for the production of biochar) does not increase the greenhouse effects (MOURA et al., 2010). In traditional coal production, only 35% of carbon remain in the material, the rest of it is sent to the air through smoke (CO_2, CO, CH_4). On the other hand, in the pyrolysis, about 80% of the carbon is fixed (MOURA et al., 2010). The biochar is then rich in carbon (HARIZ et al., 2015; WIDOWATI et al., 2014). The use of biochar is a strategy to reduce the amount of CO_2 produced by human activities (PETTER & MADARI, 2012).

The difference between charcoal in general and biochar is the goal. Biochar is produced for soil protection (NOVOTNY et al., 2015). According to Petter & Madari (2012), biochar is a product to reconcile the production of plants and the preservation of biodiversity, soil and water conservation and environmental protection. Some authors indicate a difference in the name of the biochar, depending if it comes from vegetal or animal products; they talked about vegetable charcoal (MOTA, 2013) or animal charcoal (RIBEIRO, 2011) or bonechar. But, in general, the most studied biochars are made from vegetable products.

Biochars are often used in acidic soils. Some studies used biochar in alkaline soil, but its efficiency is greater in the acidic soil than in soil with high pH (JEFFERY et al., 2011; BIEDERMAN & HARPOLE, 2013). Biochar improves nutrient retention capacity and exchangeable cation due to its great surface area, facilitates the availability of nutrients by plants and, thus, reduces the leaching of the important elements out of the soil (MAJOR et al., 2010). Rondon et al. (2007) and Zwieten et al. (2015) demonstrated the effects of biochar on P, K, Mg, Fe, Zn, Cu, Mn, Al, Pb content and CEC value, and observed as it acted in favoring normal levels of these ones (INAL et al., 2015 ; RONDON et al., 2007; ZWIETEN et al., 2015;. MAJOR et al., 2010).

Due to the diversity of materials that can be used in the production of biochar, the amount of nutrients varies. The nutrients in plant tissues like P, Na, K, Mg, Ca, Si, Fe, Mn e Zn remain in the biochar after pyrolysis (LAWRINENKO, 2014).

In general, it has been shown that the addition of biochar, in field or in pots, increases the pH and the CEC of acidic soils (RONDON et al., 2007, JIANG et al., 2012; PENG et al., 2011; KLOSS et al., 2014; ALLING et al., 2014). Biochar affects the soil micro and macro nutrients content (INAL et al., 2015; ALLING et al., 2014; ZWIETEN et al., 2010) and reduces the concentration of heavy metals (PARK et al., 2011).

Besides the chemical properties, this soil conditioner has interesting physical characteristics such as a large porosity (HUNT et al., 2010) which facilitates water filtration into the ground. Besides, it promotes the activity of the microorganisms (ZWIETEN et al., 2010; WARNOCK et al., 2007) by providing nutrients and creating appropriate conditions for its development. Thus, it facilitates soil aeration (PARK et al., 2011) once the organic matter is properly divided in the soil profile.

Biochar has also a low density and increases the soil porosity (HERATH et al., 2013). By improving the soil conditions and avoiding leaching of nutrients (JIEN & WANG, 2013; QIAN et al., 2015), the biochar can increase the agricultural yield involving a larger amount of biomass capable of capturing CO_2 (QIAN et al., 2015) and then contributes to the reduction of greenhouse gases.

2.4 Biochar and tropical soils interaction

The effects of biochar on soil depend on the biochar properties, the soil type, the plant species and the climate (THE CHAR TEAM, 2015). The quality of the wood, equipment and pyrolysis conditions define the biochar properties (MOURA et al., 2010). In several studies about this material, the considered soil categories are those having unsuitable characteristics for the growth and development of cultures, generally those that usually have very low pH.

Biochar applied in acidic soil (like latosols) has the ability to remove metal (Al^{3+}, Fe^{3+}, Pb^{2+}, Cd^{2+}, Cu^{2+}) in the soil solution by adsorption on its surface. Thus, the concentration of Al^{3+} and Fe^{3+} in the acid soil solution can be reduced and become unavailable, decreasing the risk of intoxication of the crops (PARK et al., 2011).

Biochar increased the soil pH and CEC (ZWIETEN et al., 2010) and then the yield of corn and bean in Latosol (MAJOR et al., 2010).The work carried out by Lychuk et al. (2015)

in an Amazonian latosol, the soil pH went from 3.9 to 4.19 and the CEC, from 9.76 to 11.5 $cmol_c\ kg^{-1}$ after biochar amendment. On the other hand, the amount of phosphorus, one of the important elements for plants, increased exponentially in soil with the biochar doses (XU et al., 2012). Furthermore, the concentration of K^+, Mg^{2+}, NO_3^- increased while the concentration of Al^{3+} and Mn^{2+} decreased in the soil solution with biochar amendment (ALLING et al., 2014).

The biochar effects on pH and CEC of an ultisol (PENG et al., 2011), a Cambisol and a planosol (KLOSS et al., 2014) are similar to its response in oxisol. However, it was shown that biochar has greater effect on acid soils than on neutral soil. From the four soils studied by Macdonald et al., (2014), namely, acid sandy soil, neutral vertisol, acid oxisol and alkaline calcisol, the biochar did not have effect on the pH of the neutral vertisol pH neither on the yield of the *Triticum aestivum*.

It was also demonstrated that the effects of biochar vary not only with the soil type but also with the biochar type, the doses, the particle size and the species studied.

Jay et al. (2015) worked with 2 biochar rates of *Castanea sativa* wood (20 and 50 t ha^{-1}) of particle size ranging from 1 and 6 mm incorporated in a sandy loam soil. This study did not obtain responses from these doses on the germination rate of barley, strawberry and potato, neither on the total plant dry matter at harvest.

On the other hand, Solaiman et al. (2012) used 5 biochars types made from Oil mallee, rice husks, new jarrah, old jarrah and wheat chaff in 10 soils (pH in water between 5 and 7.5) from Western Australia. They observed that all the biochars inhibited the seed germination at 100 t ha^{-1} but the results at lower rates varied a lot between biochar and soil types. Moreover, in the third part of this study, this variation happened among the 3 species studied at 10 and 100 t ha^{-1}. It was demonstrated that the seed germination varies with the biochar type ant the plant. While all the biochars addition decreased the seed germination of clover, the germination of bean strongly varied with biochar types and the wheat seed germination increased at 10 t ha^{-1} for some biochars. But all the biochars inhibited the seed germination of all the species at 100 t ha^{-1}.

Contrarly to the two studies, Voorde et al. (2014) studied the effect of 10t ha^{-1} of 2 biochars prepared at different temperature (400^oC and 600^oC) in a natural grassland after 4 months of incubation in a sandy soil (podzol soil). The biochars did not have effects on the total plant productivity but altered the plant community composition significantly.

Nevertheless in the study realized by Rondon et al. (2007) with biochar made from *Eucalyptus degluta*, the addition of 30, 60 e 90 g kg^{-1} of biochar for 4 weeks of incubation increased the biomass production and the yield of common bean in a clay-loam oxisol. The seeds were inoculated with effective *Rhizobium* strains and, five days after germination, 5 kg of N ha^{-1} were added.

Hardie et al. (2014) showed increase on the density and on the total porosity with biochar amendment after thirty months of incubation in a planosol.

Glab et al. (2016) demonstrated positive benefits of biochar amendment on the bulk density and total porosity of a loamy sandy soil after 3 months incubation. They proved that these 2 biochars had positive effects on the physical properties and that they varied with the biochar rates. The higher the rate is, the lower the bulk density and the higher the total porosity. However, this study mentioned that these changes not only depended on the rate but also on the size of biochar particles. They studied 3 ranges of particle size of biochar (0-0.5 mm; 0.5-1mm; 1-2 mm) and it was demonstrated that the total porosity was more affected by the particle size higher than 0.5mm.

Mankasingh et al. (2011) used laterite soil (rich in Fe and Al) and they obtained positive results in soil fertility after nine months incubation with cassia biochar. These authors recommended a biochar amendment rate more than 10 t ha^{-1} for high mineral content of tropical soils.

Zwieten et al. (2010) related both the importance of the utilization of fertilizer to biochar and the variability of the effects of biochar to soil types. The biochar along with fertilizer improve the bean biomass production in a higher level. In this study, the two biochars act differently on the soil properties. The effects of the biochar on the soil vary with the soil class and the presence or absence of fertilizer. Poultry litter biochar has more effect on Ferrosol than Calcarosol while papermill biochar has more effect on the Calcarosol than the Ferrosol.

2.5 Chemical and physical attributes of organic compost

Organic compost is a set of organic matter in an already advanced state of decomposition. It contains humic substances that are colloids with high reactivity, resistant to microorganism actions and interact with soil minerals. The amendment of organic compost is an agricultural technique that is considered a viable alternative to replace (fully or partially) mineral fertilizers since it has a wider range of nutrients than mineral fertilizers (RODRIGUES et al., 2011).

Organic compost is a material with probably higher content of nutrients than biochar because of it origins from a diversity of organic materials, especially vegetal residues, urine and solid excreta of animals (beef particularly). The excreta of bovine animals is generally made up of phosphore, calcium, and nitrogen (BLOOR et al., 2012).

The organic compost influences the chemical and physical properties of the soil in several ways. Organic compost amendment in the soil involves an increase in pH (RAMOS et al., 2009), in nutrients such as N, P, K, Ca, Mg (RODRIGUES et al., 2011) and traces elements for the development of the plants. In addition, it increases the amount of soil organic matter (RAMOS et al., 2009). With this stable humus amendment, there is an improvement on the soil structure and soil porosity which affects water regulation, decreases the potential effects of erosion on soil and involves better aeration (FUCHS, 2009). It also acts as a buffer in the soil (SILVA et al., 2004).

Attributing great soil conditions for the plants, the organic compost provides less stress for plants and then they are more resistant to diseases (FUCHS, 2009).

2.6 Chemical and physical interaction of organic compost with tropical soils

The soil organic matter can interact with the soil elements. It plays an important role in the cation exchange capacity and buffering capacity of the soil. In tropical soils rich in iron and aluminum oxides, the organic matter reacts with metals, clay minerals, soil oxides and other molecules from agricultural process.

2.6.1 Complexation of metals

The metals in the soil solution have a great affinity for organic compost. It can make them insoluble by complexation and then inaccessible for plants (SILVA et al., 2012). In tropical soils often with large amounts of iron and aluminum oxides (oxisol), the addition of organic compost decreases the concentration of metals (Al and Fe mainly and heavy metals) in the soil solution or increase the soil pH. Organic compost has different surface functional groups that react as ligands.

2.6.2 Interaction with oxides and clay minerals

The Fe and Al oxides and clay minerals of tropical soils have the ability to adsorb organic matter on their surfaces, protecting it from the decomposition by microorganisms (SILVA et al., 2012). This adsorption involves the formation of microaggregates and the reduction of positive charges. Thus, these minerals play an important role in the interaction between the organic matter and soil (PILLON et al., 2002). The phenolic (OH) and carboxyl (COOH) surface functional groups of the organic matter have a reactivity depending on the pH, making it a very reactive component (SILVA et al., 2004).

2.6.3 Liming in tropical soils

In tropical acidic soils, the correction of soil acidity is done by liming. In agriculture, the most widely used product is the limestone [Ca.Mg (CO_3)], which principally contents calcium and magnesium (SILVA et al., 2012). Added to the ground, it can react with the organic material.

Soil acidity correction with lime increases the pH, improves the chemical properties of the soil and the availability of nutrients. In contact with water, lime releases Ca^{2+}, HCO_3^- and OH^- as described in the reaction 1 (SOUSA et al., 2007).

$$CaCO_3+H_2O \leftrightarrow Ca^{2+}+ HCO_3^-+OH^- \quad (1)$$

The HCO_3^- ions may react with H^+ forming H_2O and CO_2 (2). These bicarbonates (HCO_3^-) and hydroxyl groups obtained from the dissolution of $CaCO_3$ neutralize the H^+ and Al^{3+} in the soil solution (4 and 5). Thus, the Al^{3+} ions precipitate to form an Aluminum mineral Al $(OH)_3$.

$$HCO_3^- +H^+ \rightarrow H_2CO_3 \quad (2)$$

$$H_2CO_3^- \rightarrow CO_{2\,(g)}+H_2O_{\,(l)} \quad (3)$$

$$OH^-+H^+ \leftrightarrow H_2O \quad (4)$$

$$Al^{3+}+3(OH^-) \rightarrow Al(OH)_3 \quad (5)$$

As the H^+ ions in the soil solution are progressively neutralized, the Ca^{2+} and Mg^{2+} cations will occupy the exchange sites on the minerals and organic matter surfaces and, thus, increase the base saturation of the soil exchange complex.

The limestone dissolution in water releases Ca^{2+} and Mg^{2+}, which will be adsorbed on the negative charge of organic matter, clay and oxides, increases the concentration of ions OH- which will act on the displacement of phosphorus, molybdenum and sulfur adsorbed on iron and aluminum oxides (SILVA et al., 2012).

In general, liming corrects the soil by adding alkaline cations like Ca, Mg, by increasing soil pH and involving precipitation of aluminum by formation of aluminum hydroxide (FANCELLI & NETO, 2007)

2.7 Bean crop

Bean crop (*Phaseolus vulgaris* L.) is a short cycle crop that has a strong demand in macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Cu, Cl, B, Zn, Mn, Mo, Fe). It requires pH 6.0 for maximum performance and also an abundant light (FANCELLI & NETO, 2007) and a non-compacted soil (bulk density<1.75 g cm^{-3}, REINERT et al., 2008). This culture does not tolerate exchangeable aluminum (CTSBF, 2012). The ideal water temperature in the soil for enzyme activity to provide the amount of nutrients is between 22 and 28ºC (FANCELLI & NETO, 2007).The bean crop requires electric conductivity below 2.4 dS m^{-1} and soil base saturation, between 50 to 65%.

The deficiency of nitrogen or phosphorus affects the development of *Phaseolus vulgaris,* reducing the height and number of leaves per plant and root production. However, the deficiency of potassium has even greater effects on vegetative bean parameters (LEAL & PRADO, 2008).

For most annual plants, the minimum value for the soil total porosity is 0.05 cm^3 cm^{-3}, the soil macroporosity must be higher than 0.01 cm^3cm^{-3} (BONETTI et al., 2015) and the no toxic percentage of aluminum is 15% (FAGERIA & KLUTHCOUSKI, 1980).

2.7.1 Crop production in Brazil

In the Paraná State (Brazil), beans have three (3) production times: July-November, December-January and February-April. Beans are widely consumed in the country. In 2011/2012, the total bean production in Brazil was 2 899 million tons (CONAB, 2012 cited by SEAB / DERAL, 2012) with 677 214 tons only in the State of Paraná (SEAB / DERAL, 2012), and this production was higher than in the other states.

Generally, the southern region of Brazil has the highest bean production portion. The total is more than one million tons and it represents about 30% of the country's production of beans (CTSBF, 2012).

2.7.2 Preparation for bean production and maintenance in Brazil

In order to increase the yield of bean crop in the State of Paraná, some recommendations are provided by CTSBF (2012) such as: 1- Limestone amendment: the amount of lime to apply to the soil is calculated after interpretation of the analysis of the range of acidity of the soil. 2- Seed inoculation with Rhizobium spp.; 200g of solution for 50 kg of seeds to increase the nodulation of bean. 3- Sowing density, about 240 000 plants ha^{-1}. 4- Macronutrients. The amount of nitrogen is divided: 15-20 kg ha^{-1} during the sowing, 20-60 kg ha^{-1} between the 15^{th} and the 25^{th} days after the emergence. On the other hand, the amount of phosphorus and potassium must be calculated taking into account the results of the soil analysis and the amount of these nutrients extracted with Mehlich 1 solution (0.05 mol m^{-3}HCl + 0.125 mol m^{-3} H_2SO_4).

2.7.3 Soil critical range of nutrients

Although the soil nutrients take part in the plant development processes, their absence, deficiency or excess in the soil can strongly affect their establishment. Table 1 showed the critical range for macronutrients and micronutrients in the soil for the bean crop.

Table 1 Critical range of soil macronutrients and micronutrients, for the bean crop

Macronutrients	Critical range		Micronutrients	Critical range ($mg\ kg^{-1}$)	
	Relative	Absolute		Lower	Upper
Phosphorus	-	15 to 40 mg dm^{-3}	Zinc	0.5	1.0
Potassium	3 to 5% CEC	0.15 to 0.3 cmolc dm^{-3}	Copper	0.4	0.8
Calcium	38 to 45% CEC	3.1 to 5.0 cmolc dm^{-3}	Manganese	3.0	5.0
Magnesium	9 to 15% CEC	0.5 to 0.8 cmolc dm^{-3}			

Source: Fancelli & Neto, 2007; CEC: Cation Exchange Capacity.

2.7.4 Description of "*Phaseolus vulgaris* var. IPR-Tuiuiú"

According to IAPAR (2010), the black bean variety IPR Tuiuiú is a short cycle crop with indeterminate growth type II (upright architecture). The mean time from the emergence to the harvest is 88 days. Physiologically matured, the pods are yellow with purple hue and are beige when ready to be harvested. The pods measure approximately 10 cm of length. The weight of 1000 seeds is about 227g and the potential production is 3942 kg ha^{-1}.

3 MATERIALS AND METHODS

3.1 Characteristics of the soil, biochar and organic compost

A 0-20cm depth soil material was collected from a dystrophic RED LATOSOL from forest [Fazenda Experimental de Iguatemi (FEI)] localized at 550 meters of altitude and latitude of 23º 25' South; 51º 57' West. The soil was sieved in a traditional field sieve, put in pot of 10 liter and dried at ambient temperature. To correct the soil acidity, a dolomitic lime with PRNT 77% was mixed to the soil at a unique dose equivalent to 3600 kg ha^{-1} and percentage of base saturation equal to 50%.

The biochar was produced with coconut shell, provided from the industry ALPHA CARBON, and activated with water vapor. It was ground and sieved at particles size less than 2 mm for the incubation of the soil. The organic compost (humidity rate: 16.87% w/w) was prepared from several organic residues in November 2014 by the Brazilian industry ORGANOPAR.

3.2 Definition of the experimental design

Doses of lime, biochar and organic compost were determined using: 1- the dystrophic RED LATOSOL characteristics, 2- literature data, 3- the results of a prior pH test carried out in laboratory conditions. A cross-factorial experiment with one additional treatment (5x2+1) in a completely randomized design was adopted with five (5) doses (25, 50, 100, 150, 200 t ha^{-1}), one control, five (5) replicates and two (2) soil conditioners (biochar and organic compost):

Five (5) kilograms of air dried soil were put in 55 plastic pots of 10 liters. The lime (22.5g) was added to all the pots (3600 kg ha^{-1}). On the first day, they received 1200 ml of water and 800 ml of water once a week just to keep the soil moist. The amount of added water was determined in laboratory. This incubation with lime took 30 days.

After that, the five (5) doses chosen for biochar and organic compost were added to 50 pots (25 pots for each conditioner): 25, 50, 100, 150 and 200 t ha^{-1} (or 52, 104, 208, 312, 416 g kg^{-1}) (Appendix B). The control treatment received only a unique lime dose. This incubation also took 30 days, so the total incubation period was 60 days.

3.3 Soil chemical analysis after incubation

After the incubation period, one sample of the mixture (soil and conditioner) of each 5 replicates was collected for chemical analysis. Each pot received, in the middle of the ground, a 10 cm^3 steel ring for analysis of physical attributes at the end of the bean production. The soil samples were dried at 45-50^oC during 5 days, until weight constancy and sieved at 2mm. The soil chemical analysis was carried out in the Characterization and Waste Recycling Laboratory (LCRR) and Soil Chemistry and Mineralogy Laboratory (LQMS) at the Paraná State University in Maringá using methods from Embrapa (2011) for these variables: pH (H_2O, KCl, $CaCl_2$), Al, H+Al, Mg, Ca, K, Na, sum of bases (SB), cation exchange capacity (CEC), P, organic carbon, Electric conductivity (EC), Zn, Cu, Fe, Mn. Other soil attributes such as ΔpH, pH_{PZC}, m% and V% were calculated from the results of pH, SB, CEC and the basics cations (Equations 7 to10).

$$\Delta pH = pH_{KCl} - pH_{H2O} \quad (7)$$

$$pH_{PZC} = (2*pH_{KCl}) - pH_{H2O} \quad (8)$$

$$m\% = \frac{Al}{Al+SB}*100 \quad (9)$$

$$V\% = \frac{SB}{CEC}*100 \quad (10)$$

3.3.1 Determination of pH in H_2O, KCl and $CaCl_2$ solutions

Ten (10) cm^3 of incubated soil were weighed (balance GEHAKA, BG1000) and put in a plastic cup of 200 ml. In this soil, it was added 25ml of deionized water, of potassium chloride (KCl) 1M or calcium chloride ($CaCl_2$) 0.01M for the pH determination in water, KCl or $CaCl_2$ respectively. They were then stirred for 10 minutes and put to rest for 30 min; the pH was read in a pH meter (HANNA instruments, HI2221 Calibration Check pH / ORP meter).

3.3.2 Determination of exchangeable Al, Ca, Mg

Five (5) cm^3 of soil were weighed with the same scale and they were added 50 ml of a 1 M KCl solution; they were stirred for 10 minutes with the same stirring table and put to rest for 1 day. The supernatant was divided into 2 parts for the analysis.

The first part was filtrated with a blue band filter (Unifil, C42, 12.5 mm) and 25 ml of it were pipetted and put in a plastic cup of 50 ml. Three to four drops of phenolphthalein 1% etilic alcool (1g of phenolphthalein in 100 ml of etilic alcool) were added in each cup and then titrated with NaOH 0.025 mol L^{-1} until it turned persistent pink. The volume solution NaOH used to titrate each up to persistent pink is the volume of exchangeable aluminum calculated by the formula:

$$\text{Al concentration (cmolc dm}^{-3}\text{) = Volume read on the titration tube} - 0.1 \qquad (11)$$

The second part, that is 5-10 ml of the same supernatant was pipetted and put into plastic tubes of 15 ml for the determination of exchangeable Ca^{2+} and Mg^{2+}. From these plastic tubes, it was pipetted 100 μl and 50 μl for the reading of the Ca^{2+} and Mg^{2+}, respectively, and then put into glass tubes. In the glass tubes for Ca^{2+} and Mg^{2+} determination, it was added 5 or 10 ml of lanthanum solution ($LaCl_3$), respectively, to mask the interference of other ions. Then, the absorbance for each tube was read with the atomic absorption equipment GBC-932AA. The concentration of calcium and magnesium was calculated:

$$\text{Ca (cmolc dm}^{-3}\text{) = (Reading*dilution*0.1)/20.04} \qquad (12)$$

$$\text{Mg (cmolc dm}^{-3}\text{) = (Reading*dilution*0.1)/12.2} \qquad (13)$$

3.3.3 Determination of potential acidity (H+Al)

For the determination of H+Al, 5cm^3 of soil were weight and 50 ml of calcium acetate 1M adjusted at pH7 [using glacial acetic acid (CH_3COOH), mark Nuclear] was added. After that, they were stirred for 10 minutes and put to rest for 30 minutes. The supernatant was filtrated with a blue band filter (Unifil, C42, 12.5 mm) and 25 ml of it received some drops of the same phenolphthalein 1% etilic alcool. The titration was carried out with a solution of NaOH 0.025 mol L^{-1} until it turned persistent pink. The potential acidity was calculated by:

$$\text{H+Al (cmolc kg}^{-1}\text{) = Volume of used NaOH 0.025 mol L}^{-1}\text{*0.5} \qquad (14)$$

3.3.4 Determination of the concentrations of P, K, Na, Fe, Cu, Zn, Mn

Five (5) cm^3 of the samples were weighed and received 50ml of Mehlich 1 (0.05 mol m^{-3}HCl + 0.125 mol m^{-3} H_2SO_4). Then, they were stirred in the same stirring table for 10 minutes, put to rest for 1 day. The supernatant was pipetted and put into plastic tubes of 50ml.

For the reading of P, 2.5-5ml of this supernatant received 5 or 2.5 ml of deionized water, respectively, in the proportion of 1:0.5 in volume or the inverse dependent on the treatment. This solution received 2.5 ml of acid-solution of ammonium molybdate [$(NH_4)6Mo_7O_{24}$] and a pinch of vitamin C. The higher the amount of phosphorus in the sample, the more purple it turned. The reading of P content in the sample was done with the spectrophotometer (MicroNal, B542). Equation 15 was considered for the determination of P concentration.

$$P\ (g\ kg^{-1}) = Reading*Fp*10 \tag{15}$$

Fp is an angular coefficient

Afterwards, the reading of K and Na was done with a photometer of emission of flame (MicroNal, B462). For the micronutrients Fe, Cu, Zn, Mn, the absorbance was read with the atomic absorption GBC-932AA spectrophotometer.

3.3.5 Determination of soil electric conductivity (EC)

A volume of 20 cm^3 of soil received 40ml of deionized water and was stirred for 10 minutes, put to rest for 30 minutes and then filtrated with a white band filter (Unifi, C40, 0.125mm). Twenty five ml of the solution were used for the reading of the electric conductivity with a conductivimeter (Digimed, DM-3).

3.3.6 Determination of carbon content in soil, biochar and organic compost

Diversely from the other analyses, only one cm^3 of soil (particles size <0,5mm) was considered for the determination of carbon. The samples were added to an Erlenmeyer, 10ml of a 1N potassium dichromate ($K_2Cr_2O_7$) and 20 ml of concentrate H_2SO_4 were added in this order. The mixture was put to rest for 24 hours. On the next day, phosphoric acid (H_3PO_4) 85.0%, ± 100ml of water tap and 15 drops of diphenylalanine were added in each erlen meyer. The titration was done with a 1M iron sulfate Fe_2SO_4 solution.

For the determination of organic carbon in biochar and the organic compost, the method by calcination (CARMO & SILVA, 2012) was used with 1.5 g of each material in a muffle furnace FORNITEC, 15x15x30. The material was place in crucibles, dried at 105^{o}C in oven (ODONTOBRÁS, MOD-EL-1.3) for a day, weighed in a scale (GEHAKA, AG200), calcined in the muffle at 550^{o}C for 3 hours and weighed once more. The percentage of organic carbon was calculated from the percentage of organic matter for each material.

$$\text{Organic matter (\%)} = \frac{W - (T - C)}{W} * 100 \qquad (16)$$

Organic carbon(%)= Organic matter (%) / 1.724

W = Weight of the sample (g) after heating at 105^{o}C

C = Tare of the crucible (g)

T = Total weight of ashes + crucible (g)

3.4 Evaluation of the physical attributes

At the end of the plant experiment, the steel rings put in each pot after the incubation and before the germination test were collected and prepared for the total porosity, macroporosity, microporosity and bulk density. They were collected so that the surface of the soil in each opening remained flat; one of the openings was closed with voile and an elastic band. The main equipment used for the determination of the porosity was a table tension and one oven (TECNAL, TE-394/2). The method of determination was from EMBRAPA (2011):

a. The steel rings were saturated for 24 hours with tap water and then weighed to determine the saturation weight.
b. They were saturated for 24 hours once more and put in the table at a tension of 60 centimeters until the water in the tube stopped dropping, or the equilibrium was obtained. The steel rings were then weighed again.
c. They were put in the oven at 110ºC for 24 hours and weighed.

By the measurements done and describe above, it was possible to calculate the total porosity (Equation 17), macroporosity (Equation 18), the microporosity (Equation 19) and the density (Equation 20).

$$\text{Total porosity} = \frac{\text{(Weight at saturation-dried weight)}}{\text{volume of the ring}} \qquad (17)$$

(18)

$$\text{Macroporosity} = \frac{\text{Weight at saturation-weight at 60cm after tension table}}{\text{volume of the ring}}$$

Microporosity= Total porosity- Macroporosity (19)

$$\text{Density} = \frac{\text{Dried weight-Tare}}{\text{Volume of the ring}} \quad (20)$$

3.5 Bean yield evaluation

3.5.1 Sowing and germination test of the bean crop

After collecting the soil samples for chemical analysis, in each pot the sowing of the black bean seeds (*Phaseolus vulgaris*, var. IPR-Tuiuiú) was carried out in humid soil (500 ml of water): 12 seeds were sown in each pot, using a circle model made of hard plastic presenting 12 holes with 2cm deep. The pots were irrigated every day with the same amount of water in all the pots. The counting time started 5 days after the sowing when the first seedling emerged and ended on the 14^{th} day, after thesowing. The germination rate was calculated for each pot, according to the equation 21.

$$\text{Germination rate} = \frac{\text{Number of germinated seeds in a pot}}{\text{Total sowing seeds in the same pot}} * 100 \quad (21)$$

3.5.2 Maintenance and bean grains production

From the seedlings in each pot, two seedlings were left for the evaluation of black bean yield. The volume of water was calculated in function of the amount of soil for the first irrigation: five (5) kilograms of soil received 1000ml (20%). But, for the next irrigation periods, the volume of water and the frequency of irrigation varied (from 200 ml to 600ml), depending on the temperature of the day and the soil moisture.

On 25^{th} days after the sowing, some symptoms of deficiency in nutrients appeared and there was a light attack of leaf miners (*Agromyza* sp) (Appendices F). On the 30^{th} days, pulverization was carried out with pesticide “Actara+Pirate” 0.5ml L^{-1}. The next day, the plants received 50 ml of a NPK solution. Each pot received 0.33g of N, 1g of P_2O_5 and 0.5g of K_2O. The sources for the fertilizer were: KH_2PO_4, KNO_3 and $CO(NH_2)_2$ (NOVAIS et al., 1991). Table 2 showed the amount used for each source.

Table 2 Amount used of each source of nutrients and nutrients content (NPK) of each one

Sources	Amount used for each source (g)	Nutrients content (g)		
		N	P_2O_5	K_2O
KH_2PO_4	230	-	120	32
KNO_3	102	14.12	-	58
$CO(NH_2)_2$	57	57	-	-

Source: Realized by the author

The variables considered for the evaluation of the black bean yield were: the germination rate, the number of grains, the total dry weight of grains and the dry weight of 1000 grains.

At the end of the production cycle, that is, 93 days after sowing or 88 days after the emergence of the seedlings, the pods containing grains were collected, counted, dried (65^{o}C for 3 days, TORRES et al., 2013) and weighed. The grains were then collected, counted and weighed for each pot; the value obtained was the total dry weight of grains. The dry weight of 1000 grains (DW1000) was calculated:

$$DW1000 = \frac{\text{Total dry weight of grains} * 1000}{\text{Number total of grains}} \quad (22)$$

3.6 Statistical analysis of the data

The soil data, the dry weight of 1000 grains and the total dry weight of grains were submitted to F-test, regression analysis and Dunnett test in Sisvar 5.6 and manually at 5% of probability considering a basic mathematic model 5x2+1, factorial experiment with one the control treatment. The dry weight of 1000 grains and the total dry weight of grains were submitted to the correlation analysis (Pearson's Correlation, α=0.05) with soil variables on SAS 9.0. Multiple regression analysis by stepwise on SAS 9.0 (α=0.05) was accomplished for the germination rate, the number of grains and the total dry weight of grains together with the soil chemical and physical attributes.

4 RESULTS

4.1 Chemical attributes of the dystrophic RED LATOSOL, biochar and organic compost

The dystrophic RED LATOSOL showed lower pH_{H2O} value (pH 4.2) than the biochar and the organic compost. Both biochar and organic compost are basic but the biochar presented higher pH_{H2O} than the compost, that is, about 4 units of pH. The value of pH_{H2O} for the coconut shell biochar in table 3 was similar to the results of Hariz et al. (2015) and Widowati et al. (2014), which were 9.3 and 9.4 respectively.

The biochar and the organic compost presented higher value of pH_{KCl} than the latosol. The biochar and the organic compost have higher pH_{PZC} than the latosol (Table 3). The ΔpH of both is lower than the latosol. The surface particles of the biochar and the organic compost may present more positive than negative charges at the pH values common in soils (5.5-6.5).

Table 3 PH values of the 0-20 cm depth dystrophic RED LATOSOL, the biochar and the organic compost

Materials	pH				
	H_2O	KCl	$CaCl_2$	PZC	ΔpH
Latosol	4.2±0.1	3.9±0.0	3.9±0.0	3.5±0.0	-0.3±0.1
Biochar	9.5±0.0	9.4±0.1	9.0±0.1	9.3±0.1	-0.1±0.1
Organic compost	7.2±0.0	7.1±0.0	7.1±0.0	7.1±0.0	-0.1±0.0

Average of two replicates ±standard deviation. pH_{H2O}: pH in deionized water; pH_{KCl}: pH in potassium chloride 1M; pH_{CaCl2}: pH in calcium chloride 0.01M; ΔpH and pH_{PZC} were calculated: $\Delta pH = pH_{KCl} - pH_{H2O}$, $pH_{PZC} = (2*pH_{KCl}) - pH_{H2O}$. Ideal $pH_{\mathbf{H2O}}$ value for bean crop: 6.0

The Ca^{2+}, Mg^{2+} and Na^{+} contents of the organic compost were higher than the biochar and the latosol (Table 5). The latosol was really poor in K^{+}, compared with the biochar and the organic compost. The biochar only had high content of K^{+} and exchangeable P among the macronutrients and bases cations. The P content of the latosol was very low in comparison with the 2 conditioners. The organic compost was made up of a large variety of organic residues whose elements remained in its composition and became available by mineralization associated to the microorganisms actions (RODRIGUES et al., 2011).

The highest value of H^{+}+Al^{3+} was with the latosol; the biochar did not present Al^{3+} neither H^{+}+Al^{3+}content (Table 5).

Table 4 Exchangeable bases, exchangeable acidity, potential acidity and available phosphorus of the dystrophic RED LATOSOL, the biochar and the organic compost

Materials	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	$H^{+}+Al^{3+}$	Available P
	cmolc dm^{-3}						mg dm^{-3}
Latosol	1.33±0.46	0.10±0.05	0.08±0.01	0.07±0.02	2.60±0.35	9.70±0.27	1.28±0.21
Biochar	0.08±0.04	0.03±0.00	8.06±0.07	0.57±0.16	0.00±0.00	0.00±0.00	838.07±1.08
Organic compost	5.86±1.00	4.18±0.97	6.29±0.16	7.17±0.18	1.35±0.07	1.73±0.35	820.12±0.00

Average of two replicates ± standard deviation. $H^{+}+Al^{3+}$:Calcium acetate 1M; Ca, Mg, Al: KCl 1M; K, Na, P: Mehlich 1. Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; Al: Aluminum; P: Phosphorus. Ideal values: Ca (3.1 to 5.0 cmolc dm^{-3}), Mg (0.5 to 0.8 cmolc dm^{-3}), K (0.15 to 0.3 cmolc dm^{-3}), P (15 to 40 mg dm^{-3})

Table 5 Aluminum and bases saturation, sum of bases, cation exchange capacity, micronutrients content, total carbon and electric conductivity of the dystrophic RED LATOSOL, the biochar and the organic compost

Materials	m	V	SB	CEC	Zn	Cu	Fe	Mn	Org. C	EC
	%		cmolc dm^{-3}		mg kg^{-1}				%	dS m^{-1}
Latosol	64±11	13±4	1.51±0.51	11.28±0.75	0.55±0.09	0.04±0.00	15.38±0.89	2.36±0.24	2±1.11	0.25±0.03
Biochar	0±0	100±0	8.74±0.27	8.74±0.27	2.54±0.44	0.07±0.01	6.98±0.57	3.90±0.72	40±2.71	1.67±0.02
Organic compost	8±1	65±5	16.32±2.36	25.23±1.83	40.04±0.31	0.04±0.00	9.33±1.02	63.58±1.87	9±0.19	9.14±0.03

Average of two replicates ± standard deviation. m, V, SB, CEC were calculated; SB= $Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}$; CEC = $Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + (H^{+}+Al^{3+})$; Zn, Cu, Fe, Mn: Mehlich 1; Org. C: Titration with Fe_2SO_4 and method with muffle furnace; EC, extract 1:2 at 25°C. SB: Sum of bases; CEC: Cation Exchange Capacity; m: Percentage of Aluminum saturation; V: Percentage of base saturation; Zn: Zinc; Cu: Copper; Fe: Iron; Mn: Manganese; Org. C: Organic Carbon; EC: Electric Conductivity. Ideal values: no toxic m% (15%), V% (50 to 65%), Zn (0.5 to 1.0 mg kg^{-1}), Cu (0.4 to 0.8 mg kg^{-1}), Mn (3.0 to 5.0 mg kg^{-1}), EC (<2.4 dS m^{-1})

The aluminum saturation of the latosol was very high in comparison with the biochar and the organic compost (Table 6). But the bases saturation (V%) value of the latosol showed its poverty in bases in regard to the biochar and the organic compost. The organic compost presented high sum of bases and cation exchange capacity values than the two other materials.

In regard to micronutrients, the organic compost presented much higher Zn and Mn content than the biochar and the latosol. But the latosol contains higher Fe content (Table 6).

The electric conductivity value was higher for the organic compost (Table 6) because of the presence of high amount of mineral in its composition.

The carbon content in biochar was very high (40%) considering the value for the organic compost (9%) (Table 6). Hariz et al. (2015) and Widowati et al. (2014) found different values of organic carbon: 42% and 60% respectively for coconut shell biochar.

4.2 Physical attributes of the dystrophic RED LATOSOL, biochar and organic compost

The biochar and the organic compost presented similar physical attributes (Table 6). The organic compost presented higher values of total porosity and macroporosity when compared to the biochar. These four (4) physical attributes were different for the biochar and organic compost when compared with the latosol (Table 6) that had smaller total porosity and macroporosity and greater microporosity and bulk density. As a consequence, both biochar and organic compost can be used as amendments to improve the physical properties of the latosol such as macroporosity, total porosity and bulk density.

Table 6 Physical attributes of the dystrophic RED LATOSOL, biochar and organic compost

Materials	Total porosity	Macroporosity	Microporosity	Bulk Density
		$cm^3\ cm^{-3}$		$g\ cm^{-3}$
Latosol	0.55±0.02	0.08±0.00	0.46±0.03	1.25±0.03
Biochar	0.58±0.01	0.21±0.04	0.37±0.04	0.57±0.02
Organic compost	0.68±0.01	0.25±0.05	0.43±0.04	0.70±0.04

Average of two replicates ± standard deviation. Ideal values for most plants: Total porosity (>0.05 $cm^3\ cm^{-3}$), macroporosity (>0.01 $cm^3\ cm^{-3}$), bulk density (<1.75 $g\ cm^{-3}$)

4.3 Chemical attributes of the soil after 60 days of incubation

The pH_{H2O} increased linearly with the doses of biochar and organic compost (Figure 1). However, the effect of the organic compost on this attribute was lesser than the biochar

(Table 7). The better liming effect with the biochar can be explained by the firing production process that produces oxides of metal that release OH^- in the presence of water.

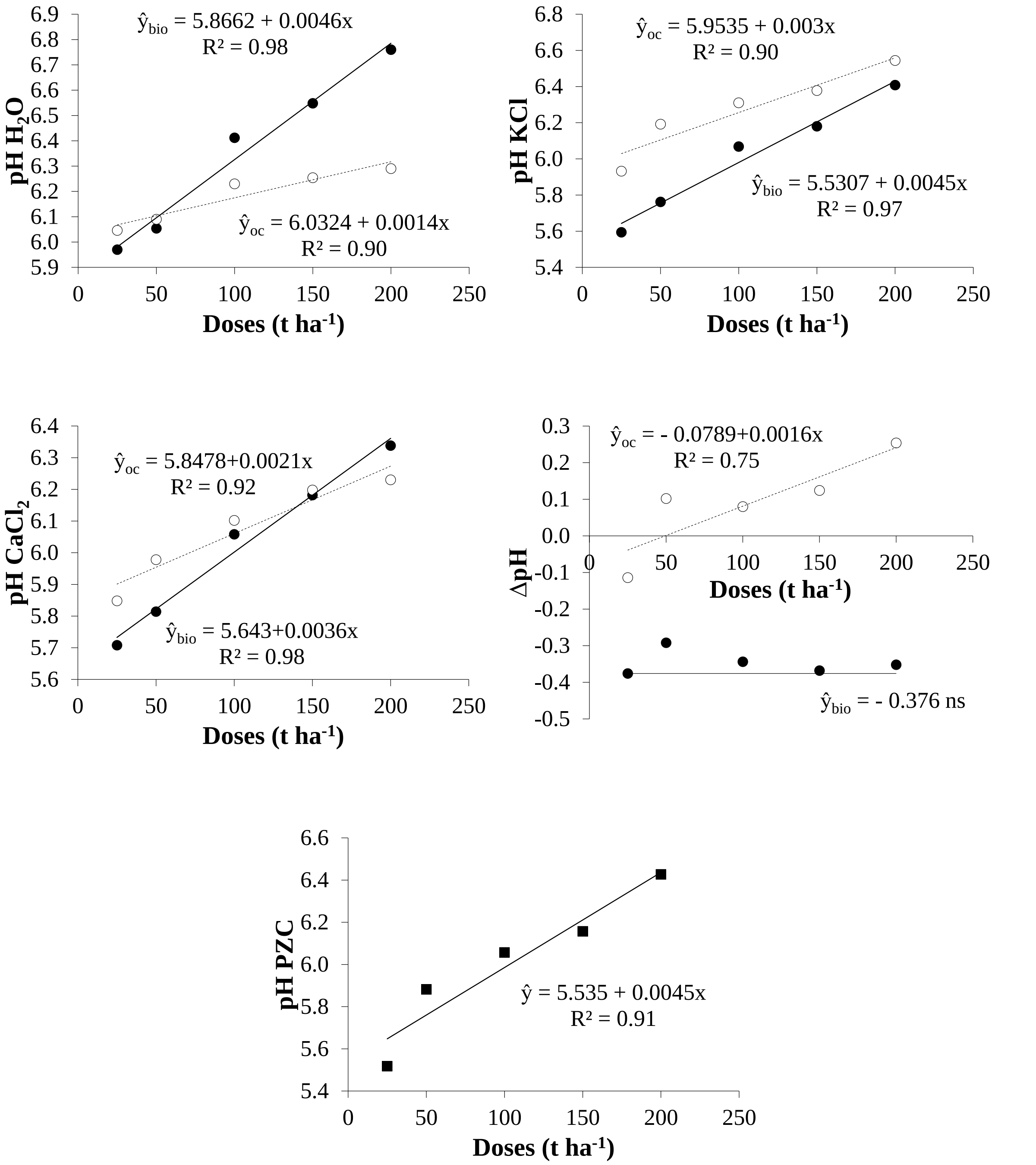
Table 7 Different pH values of the dystrophic RED LATOSOL after amendment of different doses of lime, biochar and organic compost amendment

Doses ($t\ ha^{-1}$)	pH_{H2O}	pH_{KCl}	pH_{CaCl2}	ΔpH	pH_{PZC}
			Control		
0	6.3±0.1	5.9±0.1	6.0±0.1	-0.4±0.1	5.5±0.2
			Biochar		
25	6.0±0.0	5.6±0.1	5.7±0.0	-0.4±0.1	5.2±0.1
50	6.1±0.0	5.8±0.1	5.8±0.1	-0.3±0.1	5.5±0.2
100	6.4±0.0	6.1±0.1	6.1±0.0	-0.3±0.1	5.7±0.1
150	6.6±0.1	6.2±0.1	6.2±0.1	-0.4±0.1	5.8±0.1
200	6.8±0.0	6.4±0.0	6.3±0.0	-0.4±0.1	6.1±0.1
			Organic compost		
25	6.0±0.1	5.9±0.1	5.8±0.1	-0.1±0.2	5.8±0.2
50	6.1±0.1	6.2±0.1	6.0±0.0	0.1±0.1	6.3±0.1
100	6.2±0.0	6.3±0.0	6.1±0.1	0.1±0.0	6.4±0.1
150	6.3±0.0	6.4±0.0	6.2±0.0	0.1±0.0	6.5±0.1
200	6.3±0.1	6.5±0.0	6.2±0.0	0.3±0.1	6.8±0.1

Average of five replicates ± standard deviation. pH_{H2O}: pH in deionized water; pH_{KCl}: pH in potassium chloride 1M; pH_{CaCl2}: pH in calcium chloride 0.01M; ΔpH and pH_{PZC} were calculated: $\Delta pH = pH_{KCl} - pH_{H2O}$, $pH_{PZC} = (2 * pH_{KCl}) - pH_{H2O}$. Ideal pH_{H2O} value for bean crop: 6.0

The ΔpH with biochar presented no significant different ($p>0.05$) with the doses (Figure 1). The incubation with organic compost affected the ΔpH in different ways; it showed a predominance of positive charge, so it increased the anion exchange capacity (AEC) of the soil (Table 7).

The pH at the point of zero charge (pH_{PZC}) increased with the doses of both biochar and organic compost. Increase of the pH_{PZC} involved an increase of the anion exchange capacity of the soil (Figure 1).



bio or ●: biochar; oc or ○: organic compost; ■: both conditioners

Figure 1 Tendency of the pH_{H2O}, pH_{KCl}, pH_{CaCl2}, ΔpH and pH_{PZC} of the soils with crescent doses of biochar and organic compost.

Table 8 Distribution of exchangeable cations, exchangeable acidity, potential acidity, phosphorus and total carbon content of the dystrophic RED LATOSOL after incubation of different doses of biochar and organic compost

Doses ($t\ ha^{-1}$)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	$H^{+}+Al^{3+}$	Available P	Org. C
	cmolc dm^{-3}						mg dm^{-3}	g dm^{-3}
				Control				
0	3.0±1.0	0.97±0.59	0.1±0.0	0.05±0.01	0.14±0.09	3.7±0.4	1.0±0.2	21.0±1.7
				Biochar				
25	3.1±0.3	0.81±0.04	0.3±0.0	0.07±0.00	0.08±0.08	3.7±0.4	2.4±0.2	22.5±1.3
50	2.5±0.2	0.73±0.10	0.4±0.0	0.08±0.01	0.06±0.05	3.8±0.5	4.5±0.4	22.0±1.3
100	1.9±0.1	0.72±0.16	0.8±0.0	0.05±0.02	0.06±0.05	1.8±0.4	8.7±0.7	25.8±1.4
150	1.9±0.3	0.74±0.05	0.8±0.1	0.05±0.04	0.06±0.05	1.0±0.3	7.0±1.5	24.0±0.8
200	1.6±0.2	0.60±0.06	1.1±0.1	0.12±0.02	0.10±0.00	0.1±0.1	7.7±1.3	26.5±1.0
				Organic compost				
25	3.8±0.2	0.83±0.06	0.2±0.0	0.18±0.02	0.08±0.04	3.8±0.6	8.7±1.6	21.8±1.9
50	4.8±0.4	0.88±0.11	0.4±0.0	0.31±0.03	0.12±0.04	3.1±0.3	57.4±18.6	22.5±1.3
100	5.9±0.3	0.92±0.07	0.6±0.0	0.55±0.04	0.10±0.07	2.5±0.3	218.5±35.4	22.2±1.3
150	6.9±0.4	0.96±0.10	0.9±0.1	0.82±0.05	0.12±0.04	2.5±0.3	272.1±30.7	23.5±1.2
200	7.8±0.4	0.96±0.05	1.1±0.0	1.01±0.06	0.16±0.05	2.5±0.3	324.0±20.9	24.0±1.4

Average of five replicates ± standard deviation. $H^{+}+Al^{3+}$:Calcium acetate 1M; Ca, Mg, Al: KCl 1M; K, Na, P: Mehlich 1; Org. C: Titration with $FeSO_4$. Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; Al: Aluminum; P: Phosphorus; Org. C: Organic Carbon. Ideal values for bean crop: Ca (3.1 to 5.0 cmolc dm^{-3}), Mg (0.5 to 0.8 cmolc dm^{-3}), K (0.15 to 0.3 cmolc dm^{-3}), P (15 to 40 mg dm^{-3}).

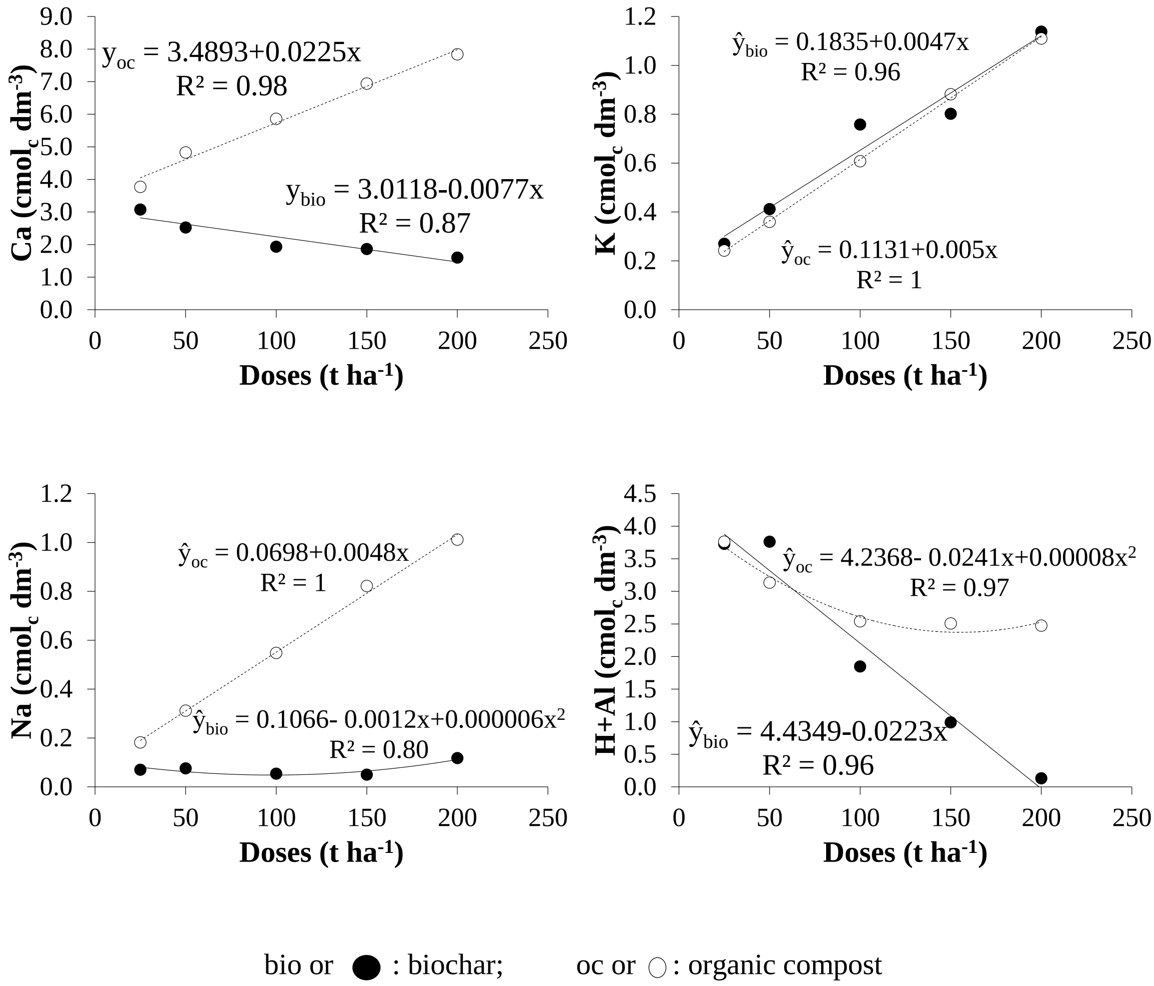


Figure 2 Tendency of calcium, potassium, sodium and H+Al concentration in the soil with crescent doses of biochar and organic compost.

The concentration of calcium in the incubated soil with biochar (Table 8) decreased linearly ($p < 0,05$) with the doses. Nevertheless, it increased linearly with the doses of organic compost. Hence, an opposite behavior was observed for biochar and organic compost taking into account the calcium content (Table 8). Given the low content of Ca^{2+} of the biochar, it diluted the Ca^{2+} concentration in soil with crescent doses in terms of weight. The organic compost, contrarily, released this cation in soil by mineralization.

For the concentration of magnesium, a significant difference ($p < 0.05$) was observed for the biochar and the organic compost treatments. The organic compost treatments presented mean value of 0.91 cmolc dm^{-3} and the biochar 0.72 cmolc dm^{-3} (Table 8). The pure biochar was poor in nutrients, especially calcium; the biochar had a dilution effect in the concentration of the bases cations, including calcium in the soil.

Otherwise, the K^+ concentration increased linearly both for the doses of biochar and the organic compost (Figure 2). The concentration of potassium in the pure biochar and pure organic compost and the high solubility of this nutrient in the soil solution can explain this increase of K^+ with biochar and compost amendment.

The biochar treatments showed a quadratic tendency with the doses. A higher dose of sodium in the pure biochar than the control treatment started increasing significantly the soil Na^+ concentration at dose 200 t ha^{-1} (Figure 2). Na^+ content of the soils with the organic compost increased linearly with the doses. Due to its high Na^+ content and the high solubility of Na^+ in water, the organic compost released easily this nutrient into the soil solution by the mineralization process.

For the Al^{3+} values in soil, there was no significant difference among the doses but it was observed significant difference ($p<0.05$) for the conditioners (Table 8). The higher mean value of Al^{3+} was observed for the treatments with the organic compost with 0.12 cmolc cm^{-3} while the biochar presented a mean value of 0.07 cmolc dm^{-3} for this soil attribute. Given that the organic compost is rich in Al, the soil incubated with organic compost presented higher value of Al^{3+} but the difference could not be observed with the crescent doses because, the organic compost also regulated the Al^{3+} in the soil solution by precipitation and the formation of $Al(OH)_3$ (SILVA et al., 2012). In regard to biochar, Park et al. (2011) mentioned that this material can favor the immobilization of metal by specific or non-specific adsorption.

The H^++Al^{3+} concentration in soil incubated with biochar decreased linearly with the doses but followed a quadratic tendency with the organic compost (Figure 2). This decrease involved a reduction in the hydrogen content of the soil solution with the doses, which explain the increase of the pH_{H2O} with biochar and organic compost.

Exchangeable P with biochar application was not affected by crescent doses (Figure 3) and remained insufficient for bean crop related to the recommended values of Fancelli & Neto (2007). The P content increased with organic compost (Figure 3). Considering the amount of P in the pure biochar, the biochar is resistant to release P in soil because of its small mineralization and the high pH among its particles. The coconut shell biochar seems to have difficulty to release P. Park et al. (2011) mentioned an increase of the availability of P and K with biochar addition in soil. The type of material that was used to produce the biochar seems to greatly affect the opposite response from the study of Park et al. (2011) whose biochar was made up of chicken manure, which is a less resistant material. The organic compost, on the other hand, increased linearly the P concentration in soil not only because of its high content but also because of its mineralization by microorganism activities.

The amount of organic carbon in the soil increased linearly with biochar and organic compost doses (Figure 3) but the effect of the biochar was much higher than the organic compost because of the higher content of C in the pure biochar. The biochar is an advisable source of carbon for the soil because it is made up of carbon resistant to mineralization (RONDON et al., 2007).

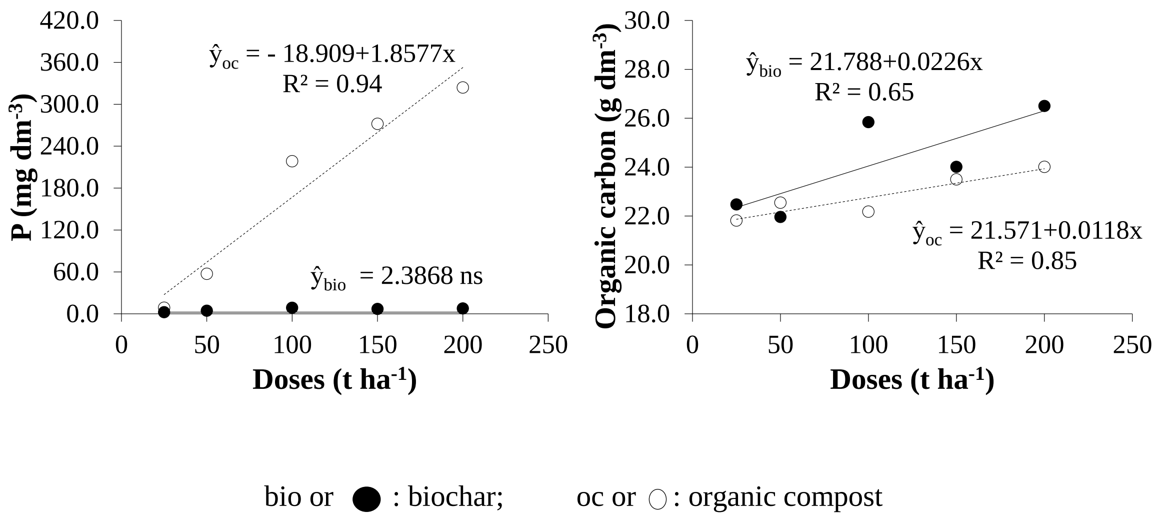


Figure 3 Phosphorus concentration and organic carbon content in the soil with crescent doses of biochar and organic compost

Taking into account the distribution of bases, acidity, phosphorus (Table 8), it is possible to observe that the biochar and the organic compost affected the soil differently. A similar behavior was observed for the potassium and organic carbon (Table 8).

The sum of bases values decreased linearly with the doses of biochar but it increased with the doses of organic compost (Table 9). The cation exchange capacity (CEC) values followed the tendency of the variation of the Ca^{2+} in the soil (Figure 2 and Figure 4). The decrease in calcium content with biochar amendment seriously affected the cation exchange capacity of the soil because calcium generally represents more than 50% of the CEC (VITTI et al., 2006). The bases saturation (V%) of the soil increased with both conditioners.

Biochar amendment decreased linearly the electric conductivity of the soil (Figure 4) but the organic compost increased this soil chemical attribute. The biochar presented smaller salts content when compared to the organic compost.

Even though the biochar and the organic compost were statistically different concerning the CEC, and the EC, they presented similar behavior for the V% (Table 9).

Table 9 Chemical attributes of the dystrophic RED LATOSOL after incubation and before sowing

Doses	SB	CEC	V	M	EC
($t\ ha^{-1}$)	$cmolc\ dm^{-3}$		%	%	$dS\ m^{-1}$
			Control		
0	4.1±1.5	7.5±1.6	52.6±12.1	4.4±4.2	0.6±0.1
			Biochar		
25	4.2±0.3	7.9±0.6	52.7±2.9	1.9±1.9	0.5±0.0
50	3.7±0.1	7.4±0.5	49.5±3.5	1.6±1.5	0.4±0.0
100	3.4±0.3	5.3±0.4	65.1±6.1	1.7±1.5	0.3±0.0
150	3.4±0.3	4.4±0.5	77.8±4.6	1.7±1.6	0.2±0.1
200	3.3±0.2	3.5±0.3	96.4±3.6	2.9±0.2	0.3±0.0
			Organic compost		
25	4.8±0.2	7.5±1.6	56.5±3.6	1.6±0.9	1.1±0.1
50	6.1±0.4	9.2±0.6	65.9±1.8	1.9±0.7	1.4±0.2
100	7.4±0.3	9.9±0.5	74.4±1.5	1.3±0.9	1.8±0.1
150	8.8±0.5	11.3±0.7	77.8±1.1	1.4±0.6	2.3±0.2
200	9.9±0.4	12.4±0.5	80.0±1.8	1.6±0.5	2.6±0.2

Average of five replicates ± standard deviation. SB: Sum of bases; CEC: Cation exchange capacity; V: Percentage of base saturation; m: Percentage of aluminum saturation; EC: Electric conductivity. SB= $Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}$, CEC = $Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + (H^{+} + Al^{3+})$; EC, extract 1:2, at 25°C. Ideal values: no toxic m% (15%), V% (50 to 65%), EC (<2.4 $dS\ m^{-1}$).

In table 10, it is possible to observe the micronutrients Zn, Cu, Fe and Mn contents of both biochar and organic compost. The biochar did not affect the Zn concentration of the soil with crescent doses, but the organic compost increased linearly the Zn content in soil with the doses (Figure 5). In regard to copper, this micronutrient content decreased linearly in soil with the biochar but it increased significantly with the organic compost (Table 10). The biochar has the ability to favor the immobilization of copper and other heavy metals (PARK et al., 2011). But, in this study, the biochar only had effects on Cu with crescent doses. It did not significantly ($p<0.05$) affect iron and manganese in soil (Table 10).

Generally speaking, the coconut shell biochar released nutrients (macronutrients) in function of a gradient, from higher concentration to lower concentration. However, this could not be considered for the micronutrients because the biochar did not increase the Zn concentration in soil, whose nutrient was in higher concentration in it than the control treatment. No statistically differences ($p>0.05$) were observed for Fe and Mn content neither (Figure 5).

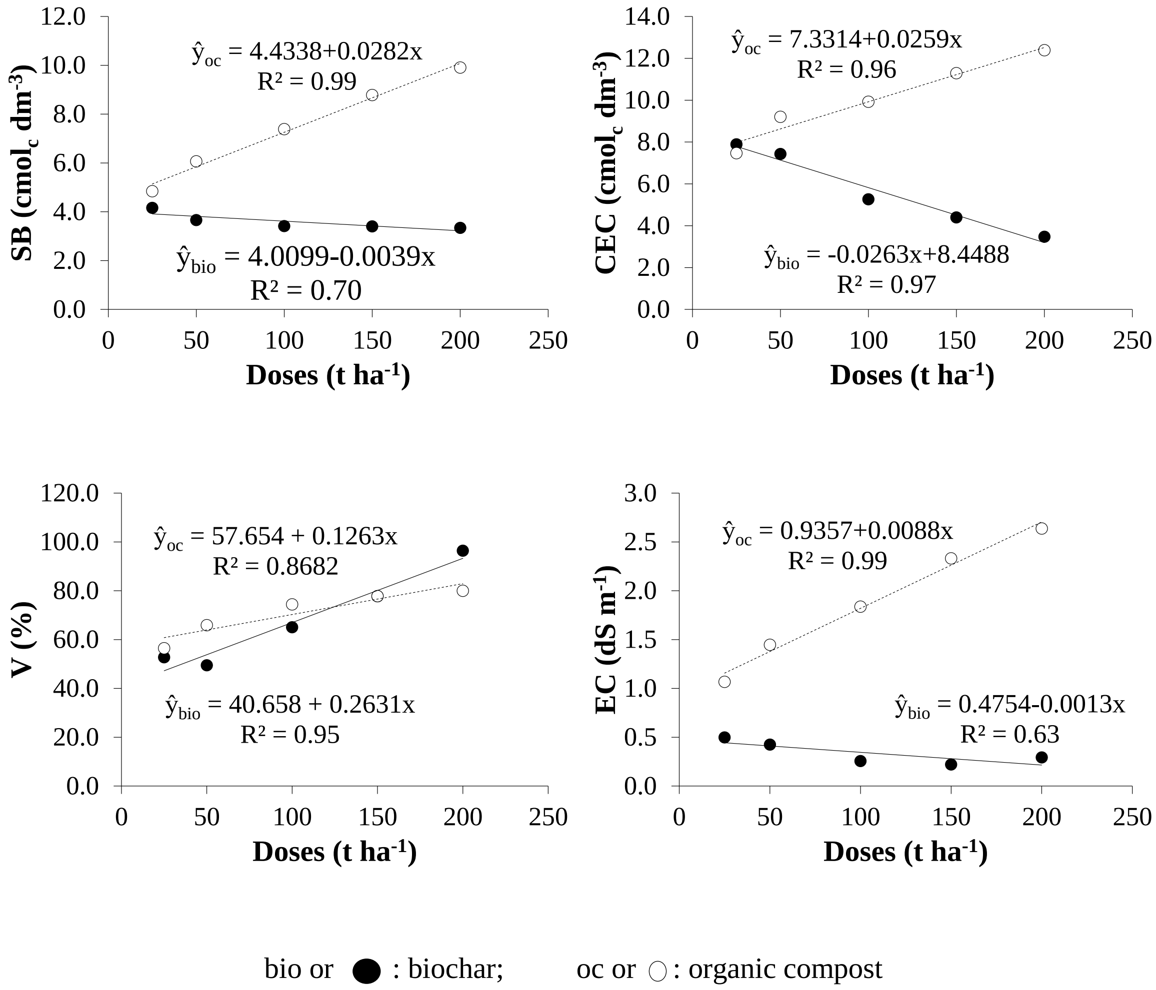


Figure 4 Sum of bases, cation exchange capacity, percentage of base saturation and electric conductivity of the soil with crescent doses of biochar and organic compost

Very few significant differences ($p<0.05$) were observed for Cu content in an opposite trend, that is to say, while Cu content decreased with the doses of biochar, Cu with organic compost had increased with the same doses. At pH value above of 6.0 of the soil incubated with biochar, the concentration of Zn, Cu, Fe and Mn were constant because of their low availability at these values of pH (FANCELLI & NETO, 2007). The reduction of Cu in soil with crescent doses of biochar was due to the affinity of the biochar for this micronutrient.

The mineralization of the organic compost, otherwise, resulted in significant ($p<0.05$) increase of all micronutrients studied. An increasing concentration was more pronounced in this order: Zn > Mn > Cu ~ Fe. Therefore the biochar is not a good source of micronutrients because it was not as intensively attacked by the microorganisms as the organic compost.

Table 10 Micronutrients content of the dystrophic RED LATOSOL after amendment and incubation for 60 days of different doses of biochar and organic compost

Doses ($t\ ha^{-1}$)	Zn	Cu	Fe	Mn
	$mg\ kg^{-1}$			
		Control		
0	0.9±0.1	0.031±0.000	11.8±2.1	5.0±0.4
		Biochar		
25	1.0±0.1	0.032±0.002	11.7±0.9	5.2±0.7
50	1.1±0.1	0.029±0.001	12.3±0.6	5.5±0.6
100	1.1±0.1	0.024±0.002	12.5±0.6	5.1±0.3
150	1.2±0.1	0.026±0.001	11.7±0.4	4.8±0.3
200	1.3±0.1	0.026±0.001	11.0±0.5	5.1±0.2
		Organic compost		
25	2.3±0.1	0.044±0.003	11.9±1.4	6.1±0.6
50	3.5±0.5	0.044±0.004	11.1±0.5	6.7±0.5
100	4.9±0.3	0.045±0.004	14.5±2.1	10.5±1.2
150	6.8±1.6	0.050±0.005	17.8±0.9	13.7±1.8
200	10.1±0.4	0.054±0.002	19.3±0.2	17.6±1.4

Average of five replicates ± standard deviation. Zn, Cu, Fe, Mn: Mehlich 1; Zn: Zinc; Cu: Copper; Fe: Iron; Mn: Manganese. Ideal values for bean crop: Zn (0.5 to 1.0 $mg\ kg^{-1}$), Cu (0.4 to 0.8 $mg\ kg^{-1}$), Mn (3.0 to 5.0 $mg\ kg^{-1}$)

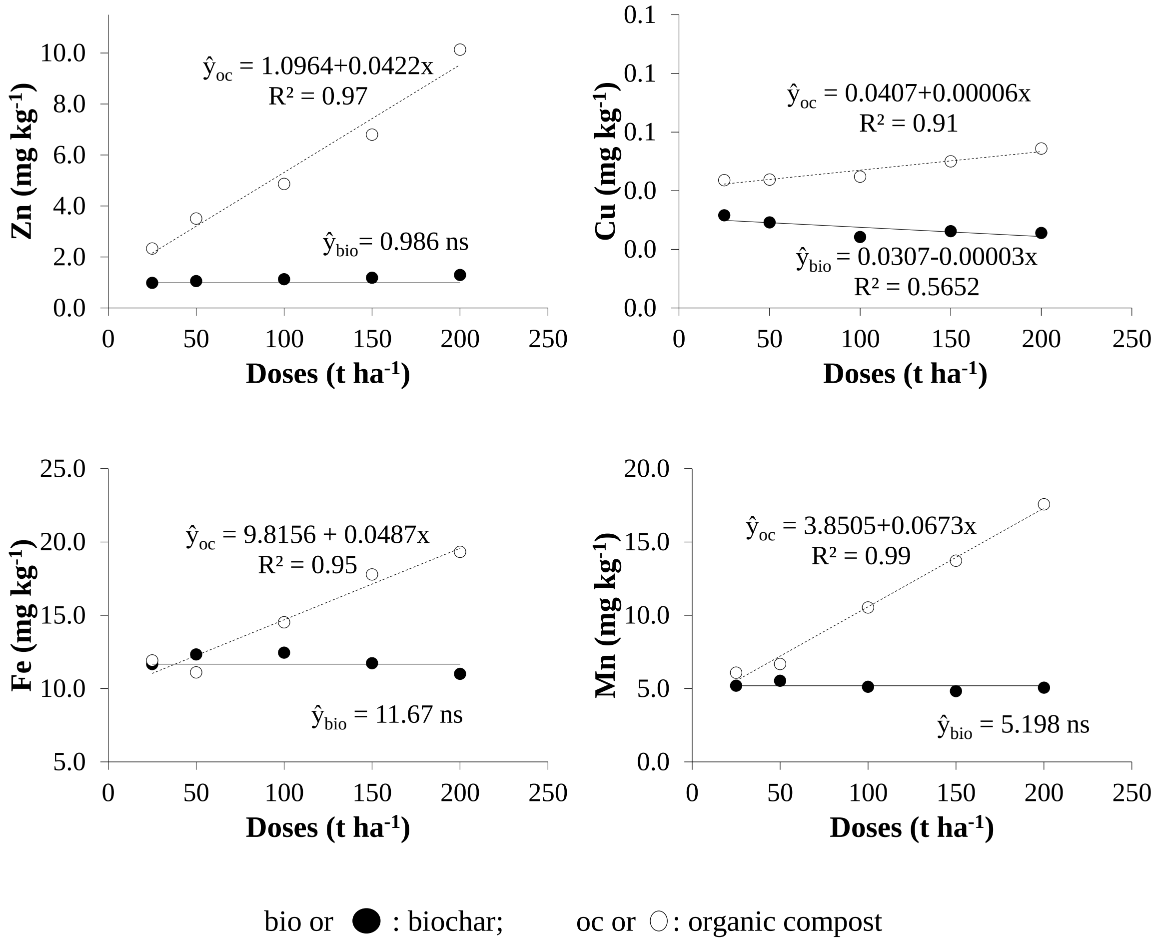


Figure 5 Micronutrients content of the soil with crescent doses of biochar and organic compost

4.4 Physical attributes of the soil after 60 days of incubation

Since pure biochar and organic compost had similar physical properties (Table 3) and they were very different from the dystrophic RED LATOSOL, both amendments were able to improve the soil attributes in a very similar way (Table 11).

Increasing doses of biochar and organic compost resulted in statistically significant ($p<0.05$) increase in the total porosity and macroporosity; an opposite trend was observed for the microporosity and bulk density (Figure 6).

Even if the organic compost was more porous than the biochar, it had similar behavior on the soil total porosity. The biochar increased the total porosity of the soil by means of a direct contribution from the pores within the biochar (HARDIE et al., 2014). The total porosity was increased with biochar amendment for Glab et al. (2016).

Table 11 Soil physical attributes of the dystrophic RED LATOSOL after amendment and incubation of different doses of biochar and organic compost

Doses (t ha^{-1})	Total porosity	Macroporosity	Microporosity	Bulk density
		cm^3 cm^{-3}		g cm^{-3}
		Control		
0	0.55±0.01	0.07±0.03	0.47±0.02	1.19±0.01
		Biochar		
25	0.55±0.02	0.06±0.01	0.50±0.02	1.19±0.03
50	0.55±0.01	0.06±0.02	0.49±0.02	1.17±0.01
100	0.56±0.01	0.08±0.04	0.48±0.03	1.13±0.03
150	0.57±0.01	0.10±0.01	0.48±0.02	1.10±0.02
200	0.58±0.01	0.17±0.02	0.41±0.01	1.05±0.01
		Organic compost		
25	0.55±0.01	0.12±0.04	0.43±0.03	1.15±0.02
50	0.55±0.01	0.15±0.02	0.40±0.02	1.12±0.01
100	0.58±0.03	0.19±0.03	0.39±0.02	1.09±0.03
150	0.57±0.08	0.20±0.03	0.36±0.06	1.11±0.09
200	0.59±0.01	0.21±0.01	0.38±0.01	1.08±0.01

Average of five replicates ± standard deviation. Ideal values for most plants: Total porosity (> 0.05 cm^3 cm^{-3}), macroporosity (>0.01 cm^3 cm^{-3}), bulk density (<1.75 g cm^{-3}).

The biochar and the organic compost amendment increased linearly the soil macroposrosity. The obtained values for both were higher than the minimum macroporosity for bean crop which was 0.01 cm^3 cm^{-3}. The microporosity and the bulk density decreased linearly for both biochar and organic compost (Figure 6).

The effect of biochar on the reduction of the soil bulk density started to be significantly ($p<0.05$) different from the control treatment from doses 150 t ha^{-1} to 200 t ha^{-1}. The soil bulk density facilitated the air and water circulation through the soil. Adding a low density material in the soil was able directly to decrease the bulk density. The alteration of the sizes of the soil aggregates can also be another reason of the decrease of the bulk density (GLAB et al., 2016).

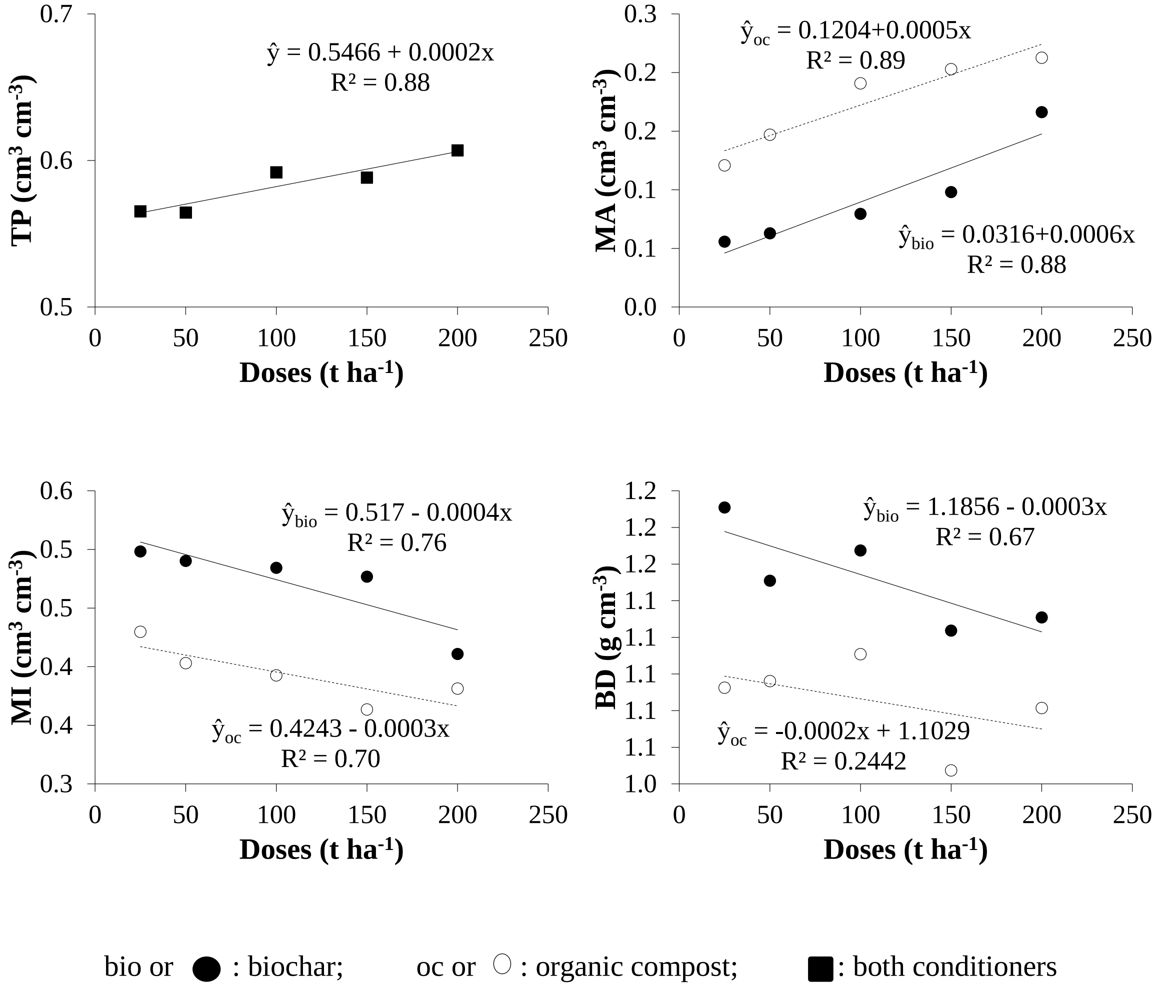


Figure 6 Tendency of the total porosity, macroporosity, microporosity and bulk density in the soil with crescent doses of biochar and organic compost

4.5 Agronomic performance of bean crop

The homoscedasticity was verified with the Levene-test on Sisvar 5.6. The analysis of variance was done at 5% of probability according to the model of factorial with one additional treatment: 5x2+1. The dry weight of 1000 grains and the total dry weight of grains were analyzed (Table 12).The significant differences were analyzed through regression, Tukey and Dunnett test at 5% of probability (Appendix I).

4.5.1 Dry weight of 1000 grains of the bean crop

There was a significant difference in the interaction between doses and conditioners ($p<0.05$) (Table 13) and a linear regression was obtained for the organic compost treatments (Figure 7). However, there was no significant difference ($p>0.05$) between biochar and organic compost into each dose (Figure 7). The minuscule letters in figure 7 showed the no significant difference among biochar and organic compost.

Table 12 Dry weight of 1000 grains (DW1000) and total dry weight of grains (TDWG) after incubation with biochar and organic compost

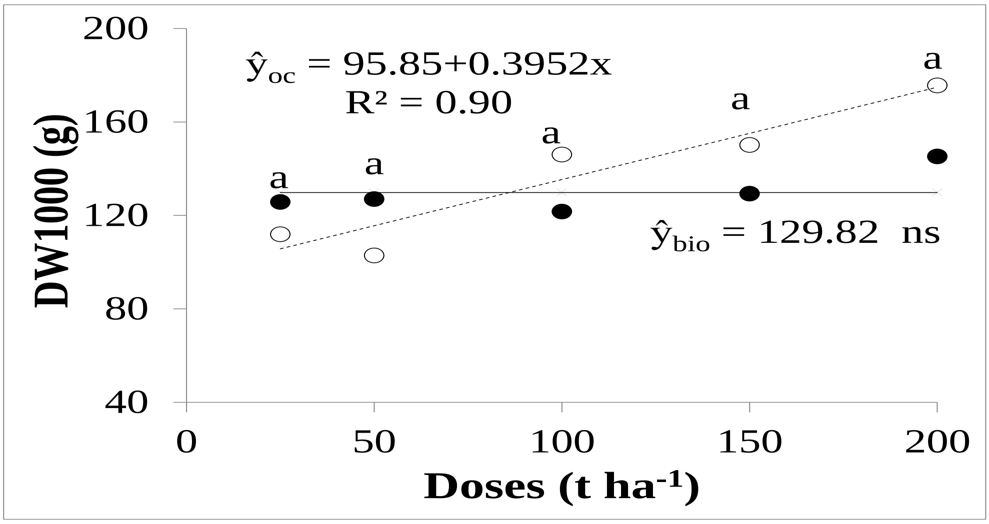
Doses (t ha^{-1})	DW1000 g	TDWG g
	Control	
0	135.19±16.83	6.80±1.28
	Biochar	
25	146.69±10.09	6.67±1.17
50	144.08±27.50	7.50±2.47
100	143.41±31.79	7.64±0.93
150	149.93±15.50	8.70±2.43
200	166.54±34.96	9.68±3.33
	Organic compost	
25	140.00±14.09	8.12 ±1.65
50	118.72± 8.72	10.73±2.14
100	160.51±18.00	20.92±1.94
150	161.42±14.58	22.47±3.53
200	187.26±17.59	27.61±4.74

Average of five replicates ± standard deviation.

Table 13 Analysis of variance for the dry weight of 1000 grains of the bean crop

Source	DF	Sum of square	Mean square	F calculated	F tabulated
(Treatments)	(10)	20690.69	2069.07	3.69	2.05*
Doses	4	13254.03	3313.51	5.89	2.58*
Conditioners	1	708.15	708.15	1.26	ns
Doses*Conditioners	4	6109.42	1527.36	2.72	2.58*
Factorial vs Control	1	619.09	619.09	1.10	ns
Residue	44	24747.27	562.44		
Total	54	45437.96			

*indicates a significant statistical difference with p<0. 05; ^{ns} indicates no significant difference with p<0. 05



bio or ● : biochar; oc or ○ : organic compost

Figure 7 Dry weight of 1000 grains (DW1000) for the doses of biochar and organic compost.

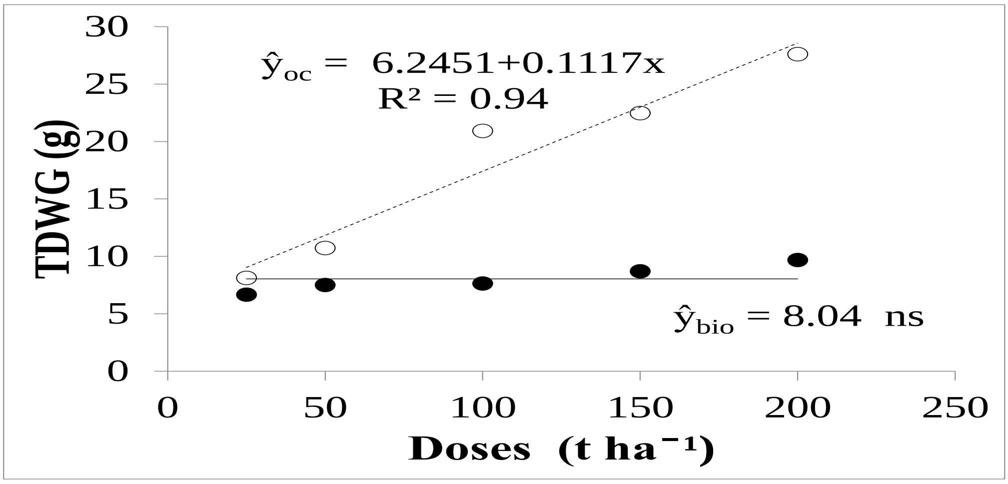
4.5.2 Total dry weight of grains

There was a significant interaction ($p<0.05$) among doses and conditioners and also between the factorial and the control treatments ($p<0.05$) (Table 14). There was significant difference between the doses for organic compost treatments but there was not for the biochar treatments in the regression analysis (Figure 8). Concerning the Tukey test for the analysis of conditioners into each dose, the biochar treatments significantly differed ($p<0.05$) from the organic compost treatments only for the doses 100, 150 and 200t ha^{-1} ($p<0.05$) (Figure 9). The Factorial vs Control treatment was analyzed by the Dunnett test at 5% of probability; there was no significant difference ($p>0.05$) between the control and the biochar treatments.

Table 14 Analysis of variance for the total dry weight of grains

Source	DF	Sum of square	Mean square	F calculated	F tabulated
(Treatments)	(10)	2791.61	279.16	42.11	2.05*
Doses	4	867.18	216.80	32.70	2.58*
Conditioners	1	1232.96	1232.96	185.97	4.06*
Dose*Conditioners	4	516.26	129.07	19.47	2.58*
Factorial vs Control	1	175.21	175.21	26.43	4.06*
Residue	44	291.71	6.63		
Total	54	3083.32			

*indicates a significant statistical difference with p<0. 05



bio or ● : biochar; oc or ○ : organic compost

Figure 8 Total dry weight of grains (TDWG) with the doses of biochar and organic compost.

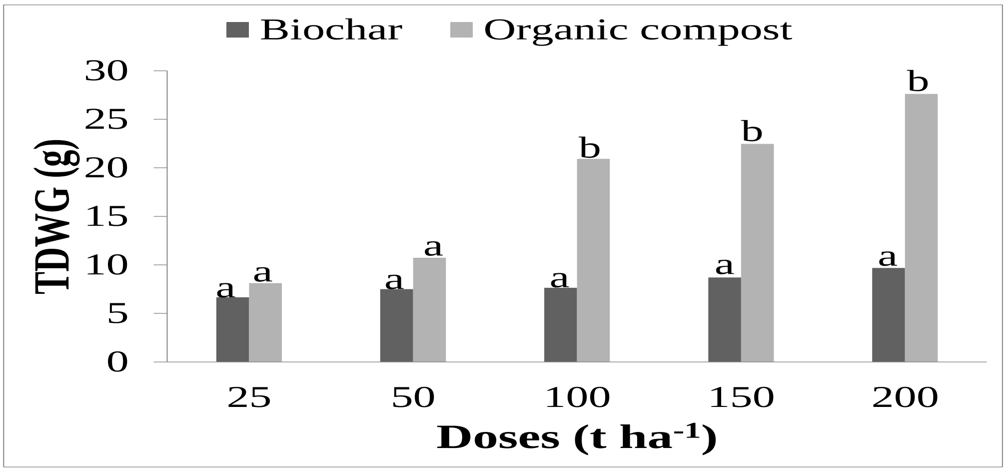


Figure 9 Total dry weight of grains for biochar and organic compost treatments into each dose.

There were no significant difference ($p<0.05$) between the control treatment and the biochar doses for the dry weight of 1000 grains and the total dry weight of grains. The biochar treatments presented values of dry weight of grains higher (at the doses 50, 100, 150 and 200t ha^{-1}) than the standard value of IAPAR for the variety Tuiuiú which is 3942kg ha^{-1} or 8.21g $5kg^{-1}$. The N deficiency during the seeds filling stage and maturity caused difficulty in completing the production cycle. The total dry weight of grains should offer higher values; nevertheless, knowing the importance of N in the plant physiology, especially in the photosynthesis and the protein synthesis (MALAVOLTA, 1997), the deficiency of this nutrient is harmful for most plants. Hariz et al. (2015) and Widowati et al. (2014) mentioned low content of total N of the coconut shell biochar: 0.38% and 0.95%. The high C content of the coconut shell biochar involved high ratio C/N which caused plants N deficiency due to the N immobilization in the soil and then involved negative effect on the soil N availability (ATKINSON et al., 2010; VOORDE et al., 2014; BIEDERMAN & HARPOLE, 2013). Biochar did not provide nitrogen benefits to the bean crop (JAY et al., 2015)

Considering the amount of nutrients of the pure biochar, it is clear that it is very hard to release nutrients in the soil solution. The coconut shell biochar is very resistant to the mineralization process associated to the biological activity.

The pH required by bean crop for a maximum performance is 6.0 (FANCELLI & NETO, 2007). The values of soil pH_{H2O} with the biochar are higher than the recommended value. Only K, Zn and Mn were at higher concentration in the soil than the required values for bean crop, with biochar amendment. Ca and P concentration values were below the recommended minimum critical range (FANCELLI & NETO, 2007). The EC, the Mg and the Cu are the only chemical attributes whose concentration in the soil remained in the range established for bean crop (FANCELLI & NETO, 2007). Nevertheless, for the organic compost, all the nutrients and the electric conductivity remained above the maximum critical range recommended for bean crop. The organic compost provided more nutrients for bean crop than biochar but the high concentration of the nutrients with organic compost can increase the electric conductivity of the soil and affect sensible crops such as the bean crop (FANCELLI & NETO, 2007).

4.6 Soil-plant relationship

4.6.1 Correlation analysis between bean variables and soil attributes

4.6.1.1 Pearson's correlation coefficients between total dry weight of grains and chemical attributes

The correlation analysis was carried out for the dry weight of grains (biochar and organic compost treatments) with the nutrients that participate in the CEC, the phosphorus, the soil micronutrients and the soil physical attributes.

In Table 15, the significant linear correlation for biochar treatments between the total dry weight of grains and the Ca, H+Al and the CEC was negative ($p<0.05$); the higher the Ca, the potential acidity or the CEC was, the less the total dry weight of grains was. Bean crop did not tolerate soil acidity which affected negatively the total dry weight of grains (FANCELLI & NETO, 2007). The negative correlation for the total dry weight of grains with the CEC was due to the decrease of the Ca concentration in soil with the crescent doses of biochar.

However, the total dry weight of grains had significant positive correlation with K ($p<0.05$) with biochar. The Zn concentration in soil had significant positive linear correlation with the total dry weight of grains ($p<0.05$) above all other micronutrients even if the Zn concentration in soil was not significantly ($p>0.05$) different among the doses of biochar. Zinc is an important micronutrient and it participates in the production of auxin, an important growth hormone. Besides, Zn is necessary for the formation of chlorophyll and carbohydrates (VITTI et al., 2006).

These linear correlations were different for the organic compost treatments (Table 15). With the increase of the Ca concentration in the soil, the total dry weight of grains presented a positive correlation. There was a positive linear correlation with K content as it was with the biochar treatments. The correlation with Na, P content and the CEC was also positive with the organic compost; the higher the Na, the P concentration or the CEC were, the higher the total dry weight of grains was. The linear correlation with H+Al was significantly negative ($p>0.05$). The total dry weight of grains had significant positive correlation with all the studied micronutrients ($p<0.05$) with the organic compost.

4.6.1.2 Pearson’s correlation coefficients between total dry weight of grains and soil physical attributes

There was a significant positive linear correlation ($r>0$; $p>0.05$) between the total dry weight of grains and the macroporosity for the biochar and organic compost treatments. Macropores are important for the cycling and storing nutrients, for the root respiration and exploration and for the air and water exchange in soil (USDA-NRCS, 2008). The microporosity and the bulk density presented significant ($r<0$; $p<0.05$) negative correlation with the dry weight of grains for the biochar treatments and compost treatments (Table 15). While the biochar treatments did not present any correlation with the total porosity, the organic compost treatments did (Table 15). There was a positive correlation between the total dry weight of grains and the macroporosity but the microporosity and the density presented a significant negative correlation with this same plant variable ($p<0.05$) for both conditioners.

The lower the soil density, the higher the air and water movement in the soil, the higher the root respiration is and then the higher the total dry weight of grains can be (USDA-NRCS, 2014).

Table 15 Pearson's correlation coefficients between the dry weight of grains and the exchangeable cations, phosphorus content or the physical attributes of the soil for biochar and compost treatments

Nutrients of the CEC and P	Biochar		Organic compost	
	R	p-valor	r	p-valor
Ca	-0.49	0.0065*	0.88	<.0001*
Mg	-	-	-	-
K	0.43	0.0164*	0.93	<.0001*
Na	-	-	0.92	<.0001*
H+Al	-0.50	0.0046*	-0.74	<.0001*
CEC	-0.54	0.0022*	0.80	<.0001*
P	-	-	0.94	<.0001*
Micronutrients	R	p-valor	r	p-valor
Zn	0.37	0.0439*	0.90	<.0001*
Cu	-	-	0.75	<.0001*
Fe	-	-	0.86	<.0001*
Mn	-	-	0.92	<.0001*
Physical attributes	R	p-valor	r	p-valor
Total porosity	-	-	0.48	0.0066*
Macroporosity	0.49	0.0061*	0.78	<.0001*
Microporosity	-0.45	0.0119*	-0.61	0.0003*
Bulk density	-0.47	0.0081*	-0.60	0.0004*

*indicates a significant statistical difference with p<0. 05; - indicates no significant difference with p<0. 05.

4.6.2 Multiple linear regression of the relationship soil-plant

The soil is the support of the plants and also the source of nutrients for its development. Table 16 shows the relation between the bean crop and the soil through equations of pedotransfer. The multiple linear regressions through stepwise analysis presented some relationship between plant variables and the soil attributes (Table 16). Considering the equations for biochar treatments (Table 16), the germination rate of bean crop depended on the pH_{PCZ}, and the total dry weight of grains depended on the soil CEC. In Table 16, the germination rate with organic compost depended on the electric conductivity (EC), the total porosity and the soil bulk density; the phosphorus and the total porosity showed a relation with the total dry weight of grains.

Table 16 Pedotransfer functions among agronomic variables and the chemical and physical attributes of soil (control and biochar treatments data; control and organic compost treatments data)

Variables	Biochar	R^2
Germination rate	Germination rate = 130.53-5.72*pH_{PZC}	0.14
Number of grains	NG=80.44-3.22*CEC	0.29
TDWG	TDWG= 11.64-0.64*CEC	0.29
	Organic compost	
Germination rate	Germination rate = 415.21-14.07*EC-187.03*TP-172.40*BD	0.81
Number of grains	NG= 71.91+0.29*P	0.82
TDWG	TDWG= -11.18+0.06*P+33.69*TP	0.91

TDWG: Total dry weight of grains; pH_{PZC}: pH at the Point of zero Charge; BD: bulk density; NG: Number of grains; CEC: Cation Exchange Capacity, EC: Electric conductivity; TP: Total Porosity; P: Phosphorus.

Besides, there was not a significant linear correlation between the total porosity and the total dry weight of grains for biochar treatments but there was a positive correlation for the organic compost treatments. Hence, the higher the total porosity for the organic compost, the higher the total dry weight of grains was. The total porosity was not linearly the attribute that more affected the total dry weight of grains (TDWG) for biochar treatments the most as it was shown by the linear equation of regression where the CEC was (TDWG= 11.64-0.64*CEC).

The low Ca concentration in the soil with the biochar and the function of Ca in the nutrient balance might stimulate the absorption of other ions (MALAVOLTA, 1997) like K. The higher the K concentration in soil, the higher the total dry weight of grains was.

On the other hand, the stepwise equation showed that the CEC of the incubated soil with biochar was the variable that linearly affected the total dry weight of grains ($p<0.05$). There was also a negative Pearson's correlation coefficient between the CEC and the total dry weight of grains for the biochar treatments (r=0.54, 0.0022). Although, the total dry weight was not significantly different among the doses, the values of the total dry weight of grains tended to increase with the doses. This negative correlation supposed a decrease in the CEC with the doses because of the low Ca of the coconut shell biochar that decreased the soil CEC. The increase of the doses of biochar may involve a dilution of the soil CEC. In other words, the greater the doses of coconut shell biochar, the lower the soil CEC was and thus affecting the bean production.

5 CONCLUSIONS

The biochar contained principally K, P as macronutrients and high organic carbon. The biochar with its high content of C and its resistance to mineralization can favor accumulation of carbon in soil with time as and when there is successive amendment of this soil conditioner. Both biochar and organic compost had similar effect on the soil physical attributes. However, they chemically affected the soil in different ways. The biochar acted like a controller of the nutrients in soil releasing nutrients by gradient of concentration among soil-biochar particles surface, on the other hand, the organic compost released freely nutrients in soil which could affect plant germination by increasing soil electric conductivity.

There was no significant difference ($p>0.05$) between the coconut shell biochar and the organic compost for the dry weight of 1000 grains at any dose. The only difference was that with organic compost, there was a higher number of grains which involved a significant ($p<0.05$) higher total dry weight of grains for organic compost at doses 100, 150 and 200 t ha^{-1} in comparison with the coconut shell biochar treatments.

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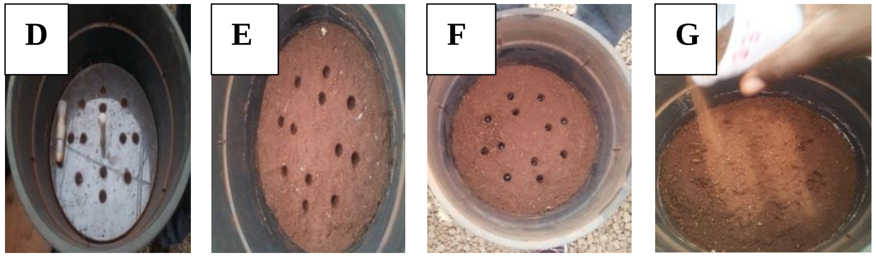
APPENDIX

Appendix A: Soil preparation and sowing

A-Pure biochar; B-Steel ring in pot; C-Soil mixtured with biochar



D, E-Material that helped for the sowing and the hole done for sowing; F, G: Sowing and filling the holes

Appendix B: The treatments

1: Control ; 2-6 Biochar treatments ; 7-11 Organic compost treatments (15 days from sowing)

All the plants together in the greenhouse (April 19th, 2016: 2 months from sowing)

Appendix C: Height of the plant according to dose (biochar-organic compost)

Control; 25 t ha^{-1} Biochar; 25 t ha^{-1} Organic compost

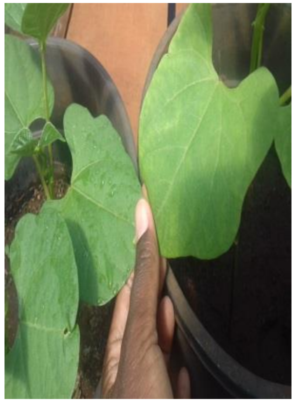
Control; 50 t ha^{-1} Biochar; 50 t ha^{-1} Organic compost

Control; 200 t ha^{-1} Biochar; 200 t ha^{-1} Organic compost

Control; 150 t ha^{-1} Biochar; 150 t ha^{-1} Organic compost

Control; 100 t ha^{-1} Biochar; 100 t ha^{-1} Organic compost

Appendix D: Color of the leaves (biochar and organic compost)



Plant leaves in organic compost in the left, plant leaves in biochar in the right

Bean crop in biochar in the left and in organic compost in the right (200 t ha^{-1})

Bean crop with the first dose of compost (left) and the last dose of organic compost (right)

Appendix E: N-deficiency with biochar

May 5th, 2016. Three different doses of biochar (25 t ha^{-1} , 50 t ha^{-1} , 150 t ha^{-1})

Appendix G

Germination rate (GR), number of pods (NP), number of grains (NG), Dry weight of 1000 grains and total dry weight of grains data

Doses (t ha⁻¹)	GR	NP	NG	DW1000	TDWG
	%	-	-	g	g
			Control		
0	100±0	16±3	56± 6	135.19±16.83	6.80±1.28
			Biochar		
25	100±0	15±1	53± 7	146.69±10.09	6.67±1.17
50	98 ±4	17±4	60±14	144.08±27.50	7.50±2.47
100	98 ±4	17±3	66±14	143.41±31.79	7.64±0.93
150	97 ±8	18±2	66±11	149.93±15.50	8.70±2.43
200	97 ±8	19±4	66± 9	166.54±34.96	9.68±3.33
			Organic compost		
25	98± 4	22±3	73 ±16	140.00±14.09	8.12 ±1.65
50	97± 8	33±6	105±25	118.72± 8.72	10.73±2.14
100	92± 6	40±7	144± 9	160.51±18.00	20.92±1.94
150	87±15	44±4	149±10	161.42±14.58	22.47±3.53
200	80± 5	41±6	157±17	187.26±17.59	27.61±4.74

Dry weight of 1000 grains

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Treatments	(10)	20690.69	2069.07	3.68	2.05*
Doses	4	13254.03	3313.51	5.89	2.58*
Conditioner	1	708.15	708.15	1.26	4.06ns
Doses*Conditioner	4	6109.42	1527.36	2.72	2.58*
Fatorial vs Control	1	619.09	619.09	1.10	4.06ns
Residue	44	24747.27	562.44		
Total	54	45437.96			

- Doses into each conditioner

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Doses/Biochar	4	1647.50	411.87	0.69	2.58 ns
Doses/Compost	4	17715.95	4428.99	7.46	2.58*
Error	40	23745.71	593.64		

Model: Linear; y=95.85+0.395x; R^2=0.90

- Conditioner into each dose

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Conditioner/25	1	477.94	477.94	0.81	4.06 ns
Conditioner/50	1	1458.58	1458.58	2.46	4.06 ns
Conditioner/100	1	1485.44	1485.44	2.50	4.06 ns
Conditioner/150	1	1086.68	1086.68	1.83	4.06 ns
Conditioner/200	1	2308.93	2308.93	3.89	4.06 ns
Error	40	23745.71	593.64		

	Conditionner	Mean values	Significance
Dose 25	Biochar	125.80	a
	Compost	111.97	a
Dose 50	Biochar	127.00	a
	Compost	102.85	a
Dose 100	Biochar	121.68	a
	Compost	146.06	a
Dose 150	Biochar	129.33	a
	Compost	150.18	a
Dose 200	Biochar	145.28	a
	Compost	175.66	a

Total dry weight of grains

Source	DF	Sum of square	Mean square	F calculated	F tabulated
(Treatments)	(10)	2791.61	279.16	42.11	2.05*
Doses	4	867.18	216.80	32.70	2.58*
Conditioners	1	1232.96	1232.96	185.97	4.06*
Dose*Conditioners	4	516.26	129.07	19.47	2.58*
Factorial vs Control	1	175.21	175.21	26.43	4.06*
Residue	44	291.71	6.63		
Total	54	3083.32			

- Doses into each conditioner

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Doses/Biochar	4	27.42	6.86	0.96	2.61ns
Doses/Compost	4	1356.03	339.01	47.55	2.61*
Error	40	285.15	7.13		

Model: Linear; Equation: $y=6.25+0.112x$; $R^2=0.94$

- Conditioner into each dose

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Conditioner/25	1	5.29	5.29	0.74	4.08ns
Conditioner/50	1	26.15	26.15	3.67	4.08ns
Conditioner/100	1	440.90	440.90	61.84	4.08*
Conditioner/150	1	473.89	473.89	66.46	4.08*
Conditioner/200	1	803.00	803.00	112.62	4.08*
Error	40	285.25			

	Conditionner	Mean values	Significance
Dose 25	Biochar	6.67	a
	Compost	8.12	a
Dose 50	Biochar	7.50	a
	Compost	10.73	a
Dose 100	Biochar	7.64	a
	Compost	20.92	b
Dose 150	Biochar	8.70	a
	Compost	22.47	b
Dose 200	Biochar	9.68	a
	Compost	27.61	b

- Factorial vs Conditionner (It was done only with biochar treatments)

$C_1=m_T-m_{25}=6.80-6.67=0.13$ ns
$C_2=m_T-m_{50}=6.80-7.50=-0.70$ ns
$C_3=m_T-m_{100}=6.80-7.64=-0.84$ ns
$C_4=m_T-m_{150}=6.80-8.70=-1.9$ ns
$C_5=m_T-m_{200}=6.80-9.68=-2.88$ ns

$DMS = td\sqrt{V(C)}$
$t_d(5\%, 10, 40)=2.85$
$DMS=2.85\sqrt{2.\frac{6.63}{5}}= 4.64$

Number of grains

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Treatments	(10)	82983.75	8298.38	44.57	2.05*
Doses	4	17113.28	4278.32	22.98	2.58*
Conditioner	1	50371.38	50371.38	270.55	4.06*
Doses*Conditioner	4	8803.52	2200.88	11.82	2.58*
Fatorial vs Control	1	6695.57	6695.57	35.96	4.06*
Residue	44	8192	186.18		
Total	54	91175.75			

- Doses into each conditioner

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Doses/Biochar	4	700.16	175.04	0.87	2.58 ns
Doses/Compost	4	25216.64	6304.16	31.31	2.58*
Error	40	8052.80	201.32		

Model: Linear: $y=78.25+0.452x$; $R^2=0.83$

- Conditioner into each dose

Sources	DF	Sum of square	Mean square	Fcal	Ftab
Conditioner/25	1	1040.40	1040.40	5.17	4.06 *
Conditioner/50	1	5107.60	5107.60	25.37	4.06 *
Conditioner/100	1	15366.40	15366.40	76.33	4.06 *
Conditioner/150	1	17139.60	17139.60	85.14	4.06 *
Conditioner/200	1	20520.90	20520.90	101.93	4.06 *
Error	40	8052.80	201.32		

	Conditionner	Mean values	Significance
Dose 25	Biochar	52.80	a
	Compost	73.20	b
Dose 50	Biochar	60.00	a
	Compost	105.20	b
Dose 100	Biochar	65.60	a
	Compost	144.00	b
Dose 150	Biochar	66.40	a
	Compost	149.20	b
Dose 200	Biochar	66.40	a
	Compost	157.00	b

- Factorial vs Conditionner (It was done only with biochar treatments)

$C_1=m_T-m_{25}=56.00-52.80= 3.2$ ns
$C_2=m_T-m_{50}=56.00-60.00= 4.00$ ns
$C_3=m_T-m_{100}=56.00-65.60= -9.60$ ns
$C_4=m_T-m_{150}=56.00-66.40= -10.4$ ns
$C_5=m_T-m_{200}=56.00-66.40= -10.4$ ns

$DMS = td\sqrt{V(C)}$
$t_d(5\%, 10, 40)=2.85$
$DMS=2.85\sqrt{2.\frac{186.18}{5}}= 24.59$

Appendix H: Pearson's correlation coefficient ($p<0.05$)

- **Control-Biochar treatments**

	germ	NG	TDWG	pHH_2O	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
germ	1							
NG	-0.38985	1						
	0.0332							
TDWG	-0.4333	0.63337	1					
	0.0168	0.0002						
pH_{H2O}	-	0.39795	0.43557	1				
	-	0.0294	0.0161					
pH_{KCl}	-	0.46732	0.49202	0.96738	1			
	-	0.0092	0.0058	<.0001				
ΔpH	-	-	-	-	-	1		
	-	-	-	-	-			
pH_{PZC}	-0.37865	0.50413	0.51559	0.88223	0.97273	0.40733	1	
	0.0391	0.0045	0.0035	<.0001	<.0001	0.0255		
pH_{CaCl2}	-	0.39267	0.41815	0.98121	0.97849	-	0.92009	1
	-	0.0318	0.0215	<.0001	<.0001	-	<.0001	
Al	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
H+Al	-	-0.472	-0.5026	-0.94309	-0.93045	-	-0.86572	-0.91439
	-	0.0085	0.0046	<.0001	<.0001	-	<.0001	<.0001
m	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
V	-	0.35874	0.47241	0.8996	0.8924	-	0.83481	0.88727
	-	0.0516	0.0084	<.0001	<.0001	-	<.0001	<.0001

Continue...

	germ	NG	TDWG	pH_{H2O}	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
Mg	-	-0.37331	-	-	-	-	-	-
	-	0.0422	-	-	-	-	-	-
Ca	-	-0.52673	-0.48544	-0.68533	-0.67014	-	-0.61794	-0.60359
	-	0.0028	0.0065	<.0001	<.0001	-	0.0003	0.0004
K	-	0.43856	0.43459	0.83621	0.82796	-	0.7731	0.77392
	-	0.0153	0.0164	<.0001	<.0001	-	<.0001	<.0001
Na	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
SB	-	-0.45628	-0.37895	-	-0.35851	-	-	-
	-	0.0113	0.0389	-	0.0517	-	-	-
CEC	-	-0.54068	-0.53669	-0.87293	-0.8683	-	-0.81444	-0.82616
	-	0.002	0.0022	<.0001	<.0001	-	<.0001	<.0001
P	-	0.41584	-	0.67162	0.67017	-	0.63055	0.60623
	-	0.0223	-	<.0001	<.0001	-	0.0002	0.0004
C	-	-	0.36761	0.63016	0.59663	-	0.53183	0.52164
	-	-	0.0457	0.0002	0.0005	-	0.0025	0.0031
EC	-	-0.44439	-0.40694	-0.61233	-0.61718	-	-0.58635	-0.5431
	-	0.0139	0.0256	0.0003	0.0003	-	0.0007	0.0019
Zn	-	-	0.37046	0.7075	0.70874	-	0.66937	0.65716
	-	-	0.0439	<.0001	<.0001	-	<.0001	<.0001
Cu	-	-0.4201	-	-	-	-	-	-
	-	0.0208	-	-	-	-	-	-
Fe	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-

Continue...

	germ	NG	TDWG	pH_{H2O}	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
Mn	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
TP	-	0.37525	-	0.56933	0.61811	-	0.62745	0.56466
	-	0.041	-	0.001	0.0003	-	0.0002	0.0012
MA	-	0.48166	0.48901	0.74805	0.76697	-	0.74047	0.72578
	-	0.007	0.0061	<.0001	<.0001	-	<.0001	<.0001
MI	-	-0.41084	-0.45313	-0.6647	-0.67099	-	-0.63841	-0.64302
	-	0.0241	0.0119	<.0001	<.0001	-	0.0001	0.0001
BD	-	-0.47382	-0.47435	-0.85555	-0.83942	-	-0.77668	-0.80185
	-	0.0082	0.0081	<.0001	<.0001	-	<.0001	<.0001

Continue...

	Al	H+Al	m	V	Mg	Ca	K	Na	SB
Al	1								
H+Al	-	1							
	-								
m	0.85506	-	1						
	<.0001	-							
V	-	-0.93632	-	1					
	-	<.0001	-						
Mg	-	-	-	-	1				
	-	-	-	-					
Ca	-	0.74494	-	-0.53984	0.64985	1			
	-	<.0001	-	0.0021	0.0001				
K	-	-0.90516	-	0.86777	-0.38169	-0.78381	1		
	-	<.0001	-	<.0001	0.0374	<.0001			
Na	-	-	-	0.36439	-	-	0.4512	1	
	-	-	-	0.0477	-	-	0.0123		
SB	-	0.41223	-0.4852	-	0.85338	0.86956	-0.42882	-	1
	-	0.0236	0.0066	-	<.0001	<.0001	0.0181	-	
CEC	-	0.94303	-	-0.79441	0.55921	0.9079	-0.87393	-	0.69186
	-	<.0001	-	<.0001	0.0013	<.0001	<.0001	-	<.0001
P	-	-0.7444	-	0.63933	-	-0.73688	0.88948	-	-0.40972
	-	<.0001	-	0.0001	-	<.0001	<.0001	-	0.0245
C	-	-0.68888	-	0.65273	-	-0.61373	0.79746	-	-
	-	<.0001	-	<.0001	-	0.0003	<.0001	-	-
EC	-	0.71854	-	-0.62329	-	0.72588	-0.83129	-	0.4359
	-	<.0001	-	0.0002	-	<.0001	<.0001	-	0.016

Continue...

	Al	H+Al	m	V	Mg	Ca	K	Na	SB
Zn	-	-0.76079	-	0.77759	-	-0.61134	0.88349	0.48853	-
	-	<.0001	-	<.0001	-	0.0003	<.0001	0.0062	-
Cu	-	-	-	-	-	-	-	-	--
	-	-	-	-	-	-	-	-	-
Fe	-	-	0.38329	-0.4514	-0.45291	-	-	-	-0.57304
	-	-	0.0365	0.0123	0.012	-	-	-	0.0009
Mn	-0.49801	-	-0.39801	-	-	-	-	-	-
	0.0051	-	0.0294	-	-	-	-	-	-
TP	-	-0.62478	-	0.58939	-0.48155	-0.56609	0.67202	-	-0.41494
	-	0.0002	-	0.0006	0.0071	0.0011	<.0001	-	0.0226
MA	-	-0.75197	-	0.78716	-0.37771	-0.58438	0.73392	0.54657	-0.36147
	-	<.0001	-	<.0001	0.0396	0.0007	<.0001	0.0018	0.0497
MI	-	0.63181	-	-0.6915	-	0.45544	-0.58063	-0.55448	-
	-	0.0002	-	<.0001	-	0.0114	0.0008	0.0015	-
BD	-	0.89728	-	-0.85379	0.38241	0.7768	-0.92385	-0.4796	0.46211
	-	<.0001	-	<.0001	0.037	<.0001	<.0001	0.0073	0.0101

Continue...

	CEC	P	C	EC	Zn	Cu	Fe	Mn	TP	MA	MI	BD
CEC	1											
P	-0.73956	1										
	<.0001											
C	-0.66734	0.75737	1									
	<.0001	<.0001										
EC	0.72862	-0.88203	-0.74816	1								
	<.0001	<.0001	<.0001									
Zn	-0.69767	0.77565	0.58578	-0.71995	1							
	<.0001	<.0001	0.0007	<.0001								
Cu	-	-0.48904	-0.39813	0.35981	-	1						
	-	0.0061	0.0293	0.0508	-							
Fe	-	-	-	-	-	-	1					
	-	-	-	-	-	-						
Mn	-	-	-	-	-	-	-	1				
	-	-	-	-	-	-	-					
TP	-0.64666	0.572	0.40403	-0.58771	0.64079	-	-	-	1			
	0.0001	0.001	0.0268	0.0006	0.0001	-	-	-				
MA	-0.72793	0.45474	0.53171	-0.43934	0.6943	-	-	-	0.62426	1		
	<.0001	0.0116	0.0025	0.0151	<.0001	-	-	-	0.0002			
MI	0.59243	-	-0.46095	-	-0.5442	-	-	-	-	-0.92502	1	
	0.0006	-	0.0104	-	0.0019	-	-	-	-	<.0001		
BD	0.87984	-0.75223	-0.70501	0.71072	-0.80452	-	-	-	-0.59894	-0.82407	0.72236	1
	<.0001	<.0001	<.0001	<.0001	<.0001	-	-	-	0.0005	<.0001	<.0001	

Finished

- **Control-Organic compost treatments**

	germ	NG	TDWG	pH_{H2O}	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
germ	1							
NG	-0.55908	1						
	0.0013							
TDWG	-0.60482	0.92453	1					
	0.0004	<.0001						
pH_{H2O}	-	-	0.53245	1				
	-	-	0.0025					
pH_{KCl}	-0.61281	0.85089	0.86429	0.45328	1			
	0.0003	<.0001	<.0001	0.0119				
ΔpH	-0.51662	0.77462	0.69804	-	0.89067	1		
	0.0035	<.0001	<.0001	-	<.0001			
pH_{PZC}	-0.5836	0.8381	0.80826	-	0.97542	0.96896	1	
	0.0007	<.0001	<.0001	-	<.0001	<.0001		
pH_{CaCl2}	-0.56113	0.71468	0.80622	0.79482	0.84769	0.54558	0.72535	1
	0.0013	<.0001	<.0001	<.0001	<.0001	0.0018	<.0001	
Al	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
H+Al	0.41968	-0.74163	-0.74286	-0.50722	-0.83082	-0.67335	-0.7781	-0.82929
	0.021	<.0001	<.0001	0.0042	<.0001	<.0001	<.0001	<.0001

Continue...

	germ	NG	TDWG	pH_{H2O}	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
m	-	-0.37219	-	-	-0.40189	-0.42862	-0.42626	-
	-	0.0428	-	-	0.0277	0.0181	0.0188	-
v	-0.57224	0.84338	0.82391	0.41332	0.91694	0.81786	0.89497	0.82504
	0.001	<.0001	<.0001	0.0232	<.0001	<.0001	<.0001	<.0001
Mg	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
Ca	-0.68796	0.88195	0.88295	0.40853	0.92817	0.83291	0.90837	0.80319
	<.0001	<.0001	<.0001	0.025	<.0001	<.0001	<.0001	<.0001
K	-0.72421	0.88391	0.92591	0.45022	0.91159	0.79305	0.88003	0.80177
	<.0001	<.0001	<.0001	0.0125	<.0001	<.0001	<.0001	<.0001
Na	-0.7242	0.8829	0.91557	0.43005	0.9141	0.80615	0.88775	0.79909
	<.0001	<.0001	<.0001	0.0177	<.0001	<.0001	<.0001	<.0001
SB	-0.69407	0.86326	0.8745	0.42804	0.90894	0.80139	0.88263	0.80711
	<.0001	<.0001	<.0001	0.0183	<.0001	<.0001	<.0001	<.0001
CEC	-0.62164	0.80432	0.79792	0.43593	0.86241	0.74516	0.83008	0.80799
	0.0002	<.0001	<.0001	0.016	<.0001	<.0001	<.0001	<.0001
P	-0.6757	0.90771	0.94352	0.52388	0.89944	0.74184	0.84861	0.83811
	<.0001	<.0001	<.0001	0.003	<.0001	<.0001	<.0001	<.0001
C	-0.50631	0.44316	0.44309	-	0.47052	0.47614	0.48661	-
	0.0043	0.0142	0.0142	-	0.0087	0.0078	0.0064	-

Continue...

	germ	NG	TDWG	pH_{H2O}	pH_{KCl}	ΔpH	pH_{PZC}	pH_{CaCl2}
EC	-0.74602	0.90434	0.89358	-	0.89966	0.8444	0.89844	0.7459
	<.0001	<.0001	<.0001	-	<.0001	<.0001	<.0001	<.0001
Zn	-0.68825	0.8416	0.89869	0.40422	0.8869	0.7888	0.86455	0.74831
	<.0001	<.0001	<.0001	0.0267	<.0001	<.0001	<.0001	<.0001
Cu	-0.64817	0.75518	0.7479	-	0.72476	0.78167	0.77293	0.5032
	0.0001	<.0001	<.0001	-	<.0001	<.0001	<.0001	0.0046
Fe	-0.62064	0.75597	0.85885	0.53884	0.73306	0.54756	0.66398	0.7536
	0.0003	<.0001	<.0001	0.0021	<.0001	0.0017	<.0001	<.0001
Mn	-0.67146	0.83751	0.91854	0.50349	0.86846	0.71749	0.81996	0.78883
	<.0001	<.0001	<.0001	0.0046	<.0001	<.0001	<.0001	<.0001
TP	-	0.4015	0.48462	-	0.49078	0.40072	0.46107	0.40839
	-	0.0279	0.0066	-	0.0059	0.0282	0.0103	0.0251
MA	-0.59789	0.81771	0.78471	-	0.8279	0.79896	0.8374	0.65174
	0.0005	<.0001	<.0001	-	<.0001	<.0001	<.0001	<.0001
MI	0.50828	-0.72627	-0.61272	-	-0.65617	-0.706	-0.69897	-0.49734
	0.0041	<.0001	0.0003	-	<.0001	<.0001	<.0001	0.0052
BD	-	-0.60413	-0.6029	-	-0.64091	-0.64909	-0.66308	-0.42202
	-	0.0004	0.0004	-	0.0001	0.0001	<.0001	0.0202

Continue...

	Al	H+Al	m	V	Mg	Ca	K	Na	SB
Al	1								
H+Al	-	1							
	-								
m	0.59517	-	1						
	0.0005	-							
V	-	-0.79571	-0.6248	1					
	-	<.0001	0.0002						
Mg	-	-	-0.48923	0.36958	1				
	-	-	0.0061	0.0444					
Ca	-	-0.70462	-0.51112	0.94072	-	1			
	-	<.0001	0.0039	<.0001	-				
K	-	-0.71902	-	0.86199	-	0.96107	1		
	-	<.0001	-	<.0001	-	<.0001			
Na	-	-0.72953	-	0.8677	-	0.96672	0.99561	1	
	-	<.0001	-	<.0001	-	<.0001	<.0001		
SB	-	-0.68984	-0.52324	0.94405	-	0.99596	0.95521	0.9597	1
	-	<.0001	0.003	<.0001	-	<.0001	<.0001	<.0001	
CEC	-	-0.70381	-0.50814	0.90156	-	0.93766	0.8747	0.8879	0.94128
	-	<.0001	0.0041	<.0001	-	<.0001	<.0001	<.0001	<.0001
P	-	-0.77329	-	0.87006	-	0.94065	0.9691	0.96585	0.93396
	-	<.0001	-	<.0001	-	<.0001	<.0001	<.0001	<.0001
C	-	-	-	0.41496	-	0.59135	0.56775	0.57566	0.5805
	-	-	-	0.0226	-	0.0006	0.0011	0.0009	0.0008
EC	-	-0.70653	-0.3677	0.87227	-	0.96584	0.97376	0.98254	0.95483
	-	<.0001	0.0456	<.0001	-	<.0001	<.0001	<.0001	<.0001

Continue...

	Al	H+Al	m	V	Mg	Ca	K	Na	SB
Zn	-	-0.64812	-	0.81744	-	0.93965	0.97439	0.96678	0.9316
	-	0.0001	-	<.0001	-	<.0001	<.0001	<.0001	<.0001
Cu	-	-0.51603	-0.47654	0.72943	-	0.81563	0.81337	0.81722	0.79828
	-	0.0035	0.0078	<.0001	-	<.0001	<.0001	<.0001	<.0001
Fe	-	-0.67024	-	0.65155	-	0.78848	0.89221	0.88324	0.77906
	-	<.0001	-	<.0001	-	<.0001	<.0001	<.0001	<.0001
Mn	-	-0.66778	-	0.81148	-	0.93204	0.97129	0.96116	0.9256
	-	<.0001	-	<.0001	-	<.0001	<.0001	<.0001	<.0001
TP	-	-0.41738	-	0.3906	-	0.40538	0.39957	0.42707	0.38764
	-	0.0217	-	0.0328	-	0.0263	0.0287	0.0186	0.0343
MA	-	-0.69087	-0.40703	0.79318	-	0.82348	0.81413	0.82983	0.79909
	-	<.0001	0.0256	<.0001	-	<.0001	<.0001	<.0001	<.0001
MI	-	0.54949	0.45762	-0.69706	-	-0.72292	-0.71485	-0.71486	-0.70609
	-	0.0017	0.011	<.0001	-	<.0001	<.0001	<.0001	<.0001
BD	-	0.52503	-	-0.58081	-	-0.58876	-0.54655	-0.5692	-0.55899
	-	0.0029	-	0.0008	-	0.0006	0.0018	0.001	0.0013

Continue...

	CEC	P	C	EC	Zn	Cu	Fe	Mn	TP	MA	MI	BD
CEC	1											
P	0.86328	1										
	<.0001											
C	0.57608	0.5334	1									
	0.0009	0.0024										
EC	0.88199	0.94272	0.59174	1								
	<.0001	<.0001	0.0006									
Zn	0.86992	0.93082	0.56767	0.94253	1							
	<.0001	<.0001	0.0011	<.0001								
Cu	0.75053	0.76752	0.55254	0.86324	0.82043	1						
	<.0001	<.0001	0.0015	<.0001	<.0001							
Fe	0.72869	0.88386	0.44361	0.83138	0.86635	0.70282	1					
	<.0001	<.0001	0.0141	<.0001	<.0001	<.0001						
Mn	0.84713	0.9577	0.55433	0.92105	0.97014	0.77979	0.91525	1				
	<.0001	<.0001	0.0015	<.0001	<.0001	<.0001	<.0001					
TP	-	0.38546	-	0.39983	-	-	-	0.39603	1			
	-	0.0354	-	0.0286	-	-	-	0.0303				
MA	0.7636	0.80142	0.58657	0.84274	0.7554	0.73075	0.71082	0.75592	0.62369	1		
	<.0001	<.0001	0.0007	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002			
MI	-0.70159	-0.70958	-0.54393	-0.75802	-0.69421	-0.74972	-0.62181	-0.64057	-	-0.77705	1	
	<.0001	<.0001	0.0019	<.0001	<.0001	<.0001	0.0002	0.0001	-	<.0001		
BD	-0.51344	-0.55057	-0.35934	-0.5631	-0.51063	-0.46525	-0.47295	-0.55886	-0.79521	-0.73684	-	1
	0.0037	0.0016	0.0511	0.0012	0.0039	0.0096	0.0083	0.0013	<.0001	<.0001	-	

Finished

Appendix I: Analysis of variance of the soil chemical and physical attributes (design 5x2+1)
Note: Cells in gray present significant values of Ftab

pHH2O					
FV	GL	SQ	QM	Fcal	Ftab
Treatment	10	2.80	0.2800	88.00	2.05
Doses	4	1.93	0.4813	151.25	2.58
Cond	1	0.35	0.3480	109.37	4.06
DxC	4	0.52	0.1303	40.94	2.58
FactvsCont	1	0.01	0.0060	1.89	4.06
Residue	44	0.14	0.0032		
Total	54	2.94	0.05		

pPHKCl					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	4.34	0.43	73.45	2.05
Doses	4	3.03	0.76	128.19	2.58
Cond	1	0.90	0.90	152.31	4.06
DxC	4	0.14	0.04	5.92	2.58
FactvsCont	1	0.27	0.27	45.69	4.06
Residue	44	0.26	0.01		
Total	54	4.61	0.09		

pHPCZ					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	11.94	1.19	57.10	2.05
Doses	4	4.56	1.14	54.52	2.58
Cond	1	6.20	6.20	296.52	4.06
DxC	4	0.07	0.02	0.84	2.58
FactvsCont	1	1.11	1.11	53.09	4.06
Residue	44	0.92	0.02		
Total	54	12.86	0.24		

pHCaCl2					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	1.89	0.19	51.98	2.05
Doses	4	1.73	0.43	118.94	2.58
Cond	1	0.03	0.03	9.08	4.06
DxC	4	0.12	0.03	8.11	2.58
FactvsCont	1	0.01	0.01	2.47	4.06
Residue	44	0.16	0.00		
Total	54	2.05	0.04		

DpH					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	3.02	0.30	49.21	2.05
Doses	4	0.21	0.05	8.56	2.58
Cond	1	2.37	2.37	386.22	4.06
DxC	4	0.16	0.04	6.52	2.58
FactvsCont	1	0.28	0.28	45.63	4.06
Residue	44	0.27	0.01		
Total	54	3.29	0.06		

pHsmp					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	4.93	0.49	42.53	2.05
Doses	4	3.50	0.88	75.49	2.58
Cond	1	1.10	1.10	94.90	4.06
DxC	4	0.32	0.08	6.90	2.58
FactvsCont	1	0.01	0.01	0.86	4.06
Residue	44	0.51	0.01		
Total	54	5.44	0.10		

Al					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.06	0.01	1.76	2.05
Doses	4	0.02	0.00	1.25	2.58
Cond	1	0.02	0.02	7.04	4.06
DxC	4	0.01	0.00	0.50	2.58
FactvsCont	1	0.01	0.01	3.58	4.06
Residue	44	0.15	0.00		
Total	54	0.21	0.00		

H+Al					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	70.83	7.08	55.16	2.05
Doses	4	45.39	11.35	88.37	2.58
Cond	1	7.84	7.84	61.05	4.06
DxC	4	13.83	3.46	26.93	2.58
FactvsCont	1	3.77	3.77	29.36	4.06
Residue	44	5.65	0.13		
Total	54	76.49	1.42		

m					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	39.61	3.96	1.38	2.05
Doses	4	3.51	0.88	0.31	2.58
Cond	1	2.11	2.11	0.74	4.06
DxC	4	3.46	0.87	0.30	2.58
FactvsCont	1	30.53	30.53	10.65	4.06
Residue	44	126.17	2.87		
Total	54	165.78	3.07		

Continue…

V					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	10723.11	1072.31	45.11	2.05
Doses	4	7808.20	1952.05	82.12	2.58
Cond	1	86.60	86.60	3.64	4.06
DxC	4	1515.42	378.86	15.94	2.58
FactvsCont	1	1312.89	1312.89	55.23	4.06
Residue	44	1045.87	23.77		
Total	54	11768.98	217.94		

Mg					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.74	0.07	1.89	2.05
Doses	4	0.03	0.01	0.19	2.58
Cond	1	0.45	0.45	11.51	4.06
DxC	4	0.15	0.04	0.96	2.58
FactvsCont	1	0.11	0.11	2.81	4.06
Residue	44	1.72	0.04		
Total	54	2.45	0.05		

Ca					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	230.81	23.08	147.61	2.05
Doses	4	11.26	2.82	18.00	2.58
Cond	1	166.35	166.35	1063.87	4.06
DxC	4	48.36	12.09	77.32	2.58
FactvsCont	1	4.84	4.84	30.95	4.06
Residue	44	6.88	0.16		
Total	54	237.70	4.40		

K					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	6.36	0.64	399.77	2.05
Doses	4	4.87	1.22	765.29	2.58
Cond	1	0.02	0.02	10.06	4.06
DxC	4	0.07	0.02	10.53	2.58
FactvsCont	1	1.41	1.41	884.40	4.06
Residue	44	0.07	0.00159		
Total	54	6.43	0.12		

Na					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	5.88	0.59	517.44	2.05
Doses	4	1.27	0.32	279.40	2.58
Cond	1	3.15	3.15	2767.60	4.06
DxC	4	1.12	0.28	247.21	2.58
FactvsCont	1	0.34	0.34	300.34	4.06
Residue	44	0.05	0.00114		
Total	54	5.93	0.11		

SB					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	274.85	27.49	92.53	2.05
Doses	4	30.28	7.57	25.48	2.58
Cond	1	180.61	180.61	608.02	4.06
DxC	4	54.63	13.66	45.97	2.58
FactvsCont	1	9.34	9.34	31.43	4.06
Residue	44	13.07	0.30		
Total	54	287.92	5.33		

CEC					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	384.11	38.41	55.82	2.05
Doses	4	3.14	0.79	1.14	2.58
Cond	1	238.10	238.10	345.98	4.06
DxC	4	142.11	35.53	51.63	2.58
FactvsCont	1	0.76	0.76	1.10	4.06
Residue	44	30.28	0.69		
Total	54	414.38	7.67		

P					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	773642.59	77364.26	285.13	2.05
Doses	4	193845.49	48461.37	178.61	2.58
Cond	1	361501.13	361501.13	1332.35	4.06
DxC	4	181357.04	45339.26	167.10	2.58
FactvsCont	1	36938.93	36938.93	136.14	4.06
Residue	44	11938.38	271.33		
Total	54	785580.97	14547.80		

C					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	147.40	14.74	7.94	2.05
Doses	4	67.98	17.00	9.15	2.58
Cond	1	22.68	22.68	12.22	4.06
DxC	4	28.91	7.23	3.89	2.58
FactvsCont	1	27.83	27.83	14.99	4.06
Residue	44	81.68	1.86		
Total	54	229.08	4.24		

Continue…

EC					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	38.51	3.851	264.76	2.05
Doses	4	2.95	0.7375	50.70	2.58
Cond	1	29.1	29.1	2000.63	4.06
DxC	4	5.46	1.365	93.84	2.58
FactvsCont	1	1	1	68.75	4.06
Residue	44	0.64	0.0145455		
Total	54	39.15	0.725		

Zn					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	456.83	45.683	170.49	2.05
Doses	4	101.33	25.3325	94.54	2.58
Cond	1	241.65	241.65	901.83	4.06
DxC	4	88.86	22.215	82.91	2.58
FactvsCont	1	24.99	24.99	93.26	4.06
Residue	44	11.79	0.2679545		
Total	54	468.63	8.6783333		

Cu					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.00582	0.00058	65.61	2.05
Doses	4	0.00017	0.00004	4.65	2.58
Cond	1	0.00498	0.00498	561.85	4.06
DxC	4	0.00046	0.00012	13.06	2.58
FactvsCont	1	0.00021	0.00021	23.35	4.06
Residue	44	0.00039	0.00001		
Total	54	0.00621	0.00011		

Fe					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	395.06	39.51	31.06	2.05
Doses	4	103.82	25.96	20.40	2.58
Cond	1	119.72	119.72	94.12	4.06
DxC	4	159.66	39.92	31.38	2.58
FactvsCont	1	11.86	11.86	9.32	4.06
Residue	44	55.97	1.27		
Total	54	451.02	8.35		

Mn					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	927.23	92.72	121.93	2.05
Doses	4	218.05	54.51	71.68	2.58
Cond	1	415.64	415.64	546.57	4.06
DxC	4	251.13	62.78	82.56	2.58
FactvsCont	1	42.41	42.41	55.77	4.06
Residue	44	33.46	0.76		
Total	54	960.69	17.79		

TP					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.013	0.001	1.91	2.05
Doses	4	0.009	0.002	3.14	2.58
Cond	1	0.000	0.000	0.34	4.06
DxC	4	0.002	0.000	0.62	2.58
FactvsCont	1	0.003	0.003	3.73	4.06
Residue	44	0.030	0.001		
Total	54	0.040	0.001		

MA					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.170	0.017	26.71	2.05
Doses	4	0.063	0.016	24.75	2.58
Cond	1	0.085	0.085	133.57	4.06
DxC	4	0.007	0.002	2.75	2.58
FactvsCont	1	0.015	0.015	23.57	4.06
Residue	44	0.028	0.001		
Total	54	0.202	0.004		

MI					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.120	0.012	17.60	2.05
Doses	4	0.027	0.007	9.90	2.58
Cond	1	0.076	0.076	111.47	4.06
DxC	4	0.009	0.002	3.30	2.58
FactvsCont	1	0.008	0.008	11.73	4.06
Residue	44	0.030	0.001		
Total	54	0.150	0.003		

BD					
FV	GL	SQ	QM	Fcal	Ftab
Trat	10	0.106	0.011	9.33	2.05
Doses	4	0.066	0.017	14.52	2.58
Cond	1	0.003	0.003	2.64	4.06
DxC	4	0.013	0.003	2.86	2.58
FactvsCont	1	0.024	0.024	21.12	4.06
Residue	44	0.050	0.001		
Total	54	0.160	0.003		

Finished.