Destination of urban pruning organic waste by means of biochar applied to the soil: Analysis of the compactation curve

Destinação de resíduos orgânicos de poda urbana por meio de biochar aplicado no solo: Análise de curva de compactação

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ABSTRACT
Urban pruning waste can have multiple uses from direct burning wood as energy to its use as organic fertilizers in the composting process. However, the lack of suitable places for the disposal of this type

of waste is a problem for municipalities with large urbanization. Thus, "biochar" presents itself as an alternative proposal for the disposal of urban pruning organic waste. In this context, the present work aimed to verify the behavior of soil compaction curves through the application of biochar as a form of conditioning and waste disposal. Soil collection was carried out at the Institute of Science and Technology of Sorocaba (ICTS –UNESP Sorocaba) followed by drying and sieving for soil characterization through particle size analysis. The tests were performed with application of biochar in the soil using the Proctor Normal Compaction Test (NBR 7182/1986) at 35 t/ha and 70 t/ha in different textures. The data of the compaction curves and comparative statistical analysis presented satisfactory results. The results expose a maximum specific weight reduction and optimum humidity increase in all samples with application of biochar. Thus, the proposal for the redestination of urban pruning organic waste by means of biochar applied to the soil can be considered an alternative for urban management of pruning organic waste and may help in integrated solid waste management.

Keywords: Urban afforestation; Waste Management; Sustainability; Science Environmental.

RESUMO
Resíduos de podas urbanas podem ter múltiplos usos, desde a queima direta de madeira como energia até seu uso como fertilizantes orgânicos no processo de compostagem. Porém, a falta de locais adequados para o descarte desse tipo de resíduo é um problema para municípios com grande urbanização. Assim, o "biochar" se apresenta como uma proposta alternativa para a destinação de resíduos orgânicos de podas urbanas. Nesse contexto, o presente trabalho teve como objetivo verificar o comportamento das curvas de compactação do solo por meio da aplicação do biochar como forma de condicionamento e disposição de resíduos. A coleta de solo foi realizada no Instituto de Ciência e Tecnologia de Sorocaba (ICTS –UNESP Sorocaba) seguida de secagem e peneiramento para caracterização do solo por meio de análise granulométrica. Os ensaios foram realizados com aplicação de biochar no solo por meio do Teste de Compactação Normal Proctor (NBR 7182/1986) a 35 t/ha e 70 t/ha em diferentes texturas. Os dados das curvas de compactação e da análise estatística comparativa apresentaram resultados satisfatórios. Os resultados expõem uma redução máxima de peso específico e um aumento ótimo de umidade em todas as amostras com aplicação de biochar. Assim, a proposta de redestinação de resíduos orgânicos de poda urbana por meio de biochar aplicado no solo pode ser considerada uma alternativa para o manejo urbano de resíduos orgânicos de poda e pode auxiliar no manejo integrado de resíduos sólidos.

Palavras-Chave: Arborização urbana; Gestão de resíduos; Sustentabilidade; Ciências Ambientais.

1 INTRODUCTION

In the same trend of urban population growth, there is also an increase in the volume of solid waste generated in cities. The problem related to solid waste is part of an economic, political, social and ecological, whose complexity involves a wide network of interrelations that demand comprehensive approaches on various aspects (Silva et al, 2020; MEDEIROS et al, 2020). In this context, urban pruning waste, even with multiple uses ranging from burning as firewood for power generation to use as organic fertilizers, presents a major management and disposal challenge within the municipalities. In this scenario, it highlights the volume of material and the lack of adequate places for the disposal of this type of waste.

Considering these factors, there is a shortage of efficient models for the management of pruning residues from urban afforestation and also the high cost of some techniques for their treatment, resulting in numerous environmental problems, due to the inadequate disposal of these materials (CHALUPE, 2016). According to NBR 10.004/2004 (ABNT, 2004), pruning waste is classified as solid class II waste, that is, non-hazardous. If this type of waste is disposed of in open places, such as landfills, it can cause a series of problems, because in addition to reducing the capacity of the landfill, it can mix with other pre-existing waste, causing environmental impacts, such as increased risk fire in landfills and vacant lots, landscape degradation and air and water pollution. In this way, the search for alternatives for the use and redestination of organic waste, especially tree pruning, has become a challenge for sustainable urbanization (ANDREOLI et al, 2014).

In this context, the placement of biochar in soil conditioning can have good results in the environmental management of organic waste in cities. Studies carried out in the last decade prove the capacity of "black earth" or "biochar" to accumulate organic matter, allowing for increased fertility and carbon storage in tropical soils. Among the benefits of applying charcoal as a soil conditioner, in addition to high fertility, are high content of stable carbon in its organic fraction and increased biological activity, contributing to the formation and growth promotion characteristics of these soils (SCHOENHOLTZ et al, 2014; KIM et al, 2019).

Currently, the intensification of the urbanization process can be considered one of the major inducers of environmental problems due to the use and occupation of land, leading to the removal of vegetation and soil degradation (KIM et al, 2017, STEFANOSK et al, 2013; STANGANINI and LOLLO, 2018). In that context, knowledge of the dynamics of land use and land cover is increasingly important for understanding space, planning and management of natural resources, which contributes to the conservation and environmental sustainability (Maidjelele et al, 2020).Thus, the biochar incorporated into the soil presents itself as an alternative management practice with great potential for soil improvement, contributing to soil recovery and conservation (TIECHER, 2016; GUILHEN, 2018; Kumar et al, 2019).

The term "biochar" results from "biomass + charcoal" (biomass + coal). This idea arose from the observation of the existence of our "black land of the Indians" in soils of the Brazilian Amazon. The "biochar" is produced basically by burning organic matter in environments with little or no oxygen. The process is known as pyrolysis or gasification, the same process that is used to create wood charcoal (Kumar et al, 2019; MANGRICH et al, 2011). The main function of Biochar is based on the following benefits: (1) soil improvement, (2) carbon sequestration, (3) carbon neutral energy production, (4) waste management and (5) water quality protection through greater efficiency in the use of nutrients (BRICK and MADISON, 2010).

Although several studies deal with changes in soil properties resulting from the use of biochar, few assess the effects of applying biochar to the soil's response to compaction and its potential for use in sustainable management (VERHEIJEN et al, 2010). In this scope, the present work aimed to verify the behavior of soil compaction curves through the application of biochar, as a way of conditioning and disposal of waste.

2 MATERIAL AND METHODS

The soil used in the present study was collected at the Campus of UNESP Sorocaba/SP. Approximately 40 kg of sub-surface soil was removed, disregarding the organic horizon, as organic matter can influence the results of specific weight. The soil remained on drying for 15 days before test. Then, the soil was sieved through a 4.75 mm sieve (ASTM 4 / TYLER 4) and soil characterization through granulometric analysis.

The biochar used in the tests was eucalyptus charcoal (*Eucalyptus grandis*, first the charcoal was broken until it reached a finer texture. Then the charcoal grains were separated into four different diameters, using 2 mm sieves (ASTM 10), 1.18 mm (ASTM 16), 600μm (ASTM 30), 300μm (ASMT 50), 150μm (ASTM 100) and 75μm (ASTM 200). The biochar plots with a diameter between 75μm e 600μm “fine texture”, and between 600μm and 2 mm “thick texture.” As a descriptive element, the letter Ø was used as a symbol of the diameter retained in the sieving, for example: 75 μm <Ø <600 μm.

The rates of application of biochar in the soil were 35 t/ha and 70 t/ha. In this way, it was sought through these dosages to identify the contrast between applications, that is, quantities [tons] and particle sizes [size of coal particles]. The quantity and texture were adjusted according to the surface area of the 0.79 cm^2 cylinder and its depth 12.75 cm with the Proctor Normal Compaction Test cylinder following NBR 7182/1986 (ABNT, 1986) and the calculation of the proportion of Biochar applied to the soil in each test he followed the equation below:

$$M_{bio} = \frac{M_{biocil} . M_{soil}}{M_{1000cm^3}}$$

Where:
Mbio = Biochar mass to be applied (g);
Mbiocil = Biochar mass for the cylinder surface (g);
Msoil = Mass of soil (g);
M1000cm³ = Mass of dry and sieved soil in the 1000 cm³ (1288g).

For each compaction test the soil mass used was 3 kg, +/- 0.1g and the mass of Biochar used was described in Table 1.

Table 1 - Amount of Biochar applied to the soil

Rate of application (t/ha)	**Mass of coal (g)**	**Percentage over total soil mass (%)**
35	65,2	2,2
70	130,4	4,4

2.1 PROCTOR NORMAL COMPACTION TEST

The normal proctor test was performed using a Soiltest brand CN-4230 device, the sample being compacted in a metallic ring of approximately 0.001 m^3 according to the ABNT/NBR 7182/86 (VERHEIJEN et al, 2010. Technical Standard the test was performed in three layers of soil and each layer received 26 hits from a 2.50 kg socket falling from a height of 0.305 m corresponding to a compaction energy close to 60.2 kJ m^3. Thus, using approximately 3 kg of sieved and dried soil in the previous step, 5% water (from the total mass of soil) was added, until it reached a homogeneous consistency. In this way, the first compaction test begins without the addition of biochar and successively with the variation of humidity.

The procedure was carried out for different textures and quantities of biochar, being classified with the abbreviations that differ in S (Soil core without application), B (thick biochar), b (fine biochar), t (lowest application rate 35 kg/ha) and T (highest application rate 70 kg/ha). Four repetitions were performed for each treatment:

- Sample 1 (“S”): 3kg of soil;
- Sample 2 (“SBt”): 3kg soil + 65g of biochar (600µm <Ø <2mm);
- Sample 3 (“SBT”): 3kg soil + 130g of biochar (600µm <Ø <2mm);
- Sample 4 (“Sbt”): 3kg soil + 65g of biochar (75µm <Ø <600µm);
- Sample 5 (“SbT”): 3kg soil + 130g of biochar (75µm <Ø <600µm);

The compaction curve was obtained from the dry specific weight ((γ_d) graph in the ordinates and Humidity content (w) in the abscissa of each sample. Being:

- **Humidity Content (%)**

$$w = \frac{(Mu - Ms)}{Ms} \times 100$$

Where:
w = Humidity Content (%);
Mu = mass of moist soil stored in the drying capsule (g);
Ms = dry soil mass stored in the drying capsule (g);

- **Dry specific weight**

$$\gamma_d = \frac{\gamma \cdot 100}{100 + w}$$

Where:
γ_d= Dry specific weight (kg/m³);
γ = Wet specific weight (kg/m³);
w = Humidity Content (%).

2.2 STATISTICAL ANALYSIS OF THE DATA

The statistical analysis of the data was performed with the aid of the ASSISTAT Version 7.6 beta software (2012) in a completely randomized design (DIC). Therefore, the analysis of variance (ANOVA) was carried out, ending with the application of an average test (Tukey, 5%). The variables analyzed were maximum specific weight and optimum humidity for each trial, treatments were (S, SBt, SBT, Sbt, SbT), and 4 repetitions were performed.

3 RESULTS AND DISCUSSION

The Optimal humidity and Maximum Dry Specific Weight were analyzed and in each test the values where it reached the highest specific weight for a certain humidity, the values of the optimum moisture content (w) and maximum specific weight were verified according to Table 2.

Tab. 2 Optimal Humidity and Maximum Dry Specific Weight

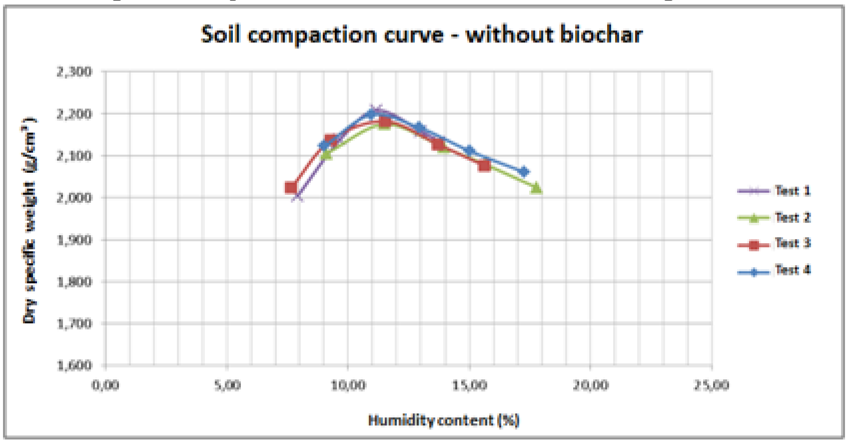
Test	Treatment	Repeat	Data	
			$w_{ótima}$ (%)	$\gamma_{d\ máximo}$ (g/cm³)
1	1 “S”	1	11,19	2,21
2	1 “S”	2	11,53	2,17
3	1 “S”	3	11,53	2,18
4	1 “S”	4	10,95	2,20
5	2 “SBt”	1	11,76	2,13
6	2 “SBt”	2	12,31	2,14
7	2 “SBt”	3	13,85	2,11
8	2 “SBt”	4	13,59	2,12
9	3 “SBT”	1	12,80	2,06
10	3 “SBT”	2	12,77	2,07
11	3 “SBT”	3	14,21	2,04
12	3 “SBT”	4	14,19	2,05
13	4 “Sbt”	1	12,50	2,15
14	4 “Sbt”	2	12,36	2,13

15	4 “Sbt”	3	13,86	2,13
16	4 “Sbt”	4	13,91	2,15
17	5 “SbT”	1	13,91	2,09
18	5 “SbT”	2	13,86	2,07
19	5 “SbT”	3	14,75	2,08
20	5 “SbT”	4	14,41	2,07

S”: Soil; “SBt”: Soil + thick biochar (35 t/ha); “SBT”: Soil + thick biochar (70 t/ha); “Sbt”: Soil + fine biochar (35 t/ha); “SbT”: Soil + fine biochar (70 t/ha).

With the values of humidity and the specific weight of the dry soil, the graphs were constructed referring to the compaction curves for each test. Figure 1 represents the compaction curves for Tests 1 to 4, referring to the soil without Biochar (Fig. 1).

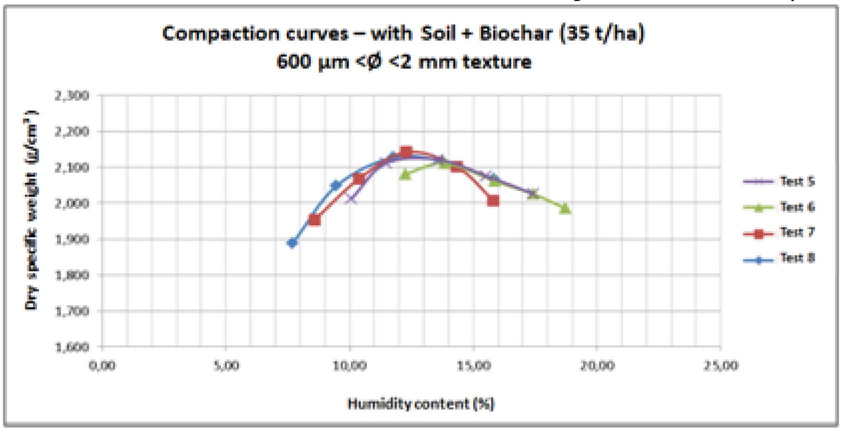
Fig. 1 – Compaction Curves: 1 to 4 test without adding biochar



The Compaction Curves of the same soil tests were similar to each other as expected due to the control of the test. The greatest variation between maximum specific weight was 0.033 g/cm³ between tests 1 and 2. The optimum humidity content also had little variation in tests 1 to 4, with 0.58% being the difference between tests (2 and 4) with greater divergence of optimum humidity.

Figure 2 presents the graph referring to tests 5,6,7 and 8 represent the soil incorporated with thick biochar at the application rate of 35 t/ha, the curves shown show the maximum specific weights and the optimum humidity content for the same samples.

Fig. 2 - Compaction curves for tests 5 to 8 with the addition of 35 tons per hectare and 600 µm <Ø <2 mm texture



The compaction curves for the soil incorporated with coarse biochar at the rate of 35 t/ha also showed few variations from one test to another, except for test 7, which showed a certain specific weight reduction in the first humidity content. However, the biggest difference between the maximum values of specific weight was 0.031 g/cm³ obtained in tests 6 and 7. The biggest difference between the values of optimum humidity was 2.09%.

Figure 3 shows the compaction curves for Proctor Normal Tests 9 to 12, performed with coarse biochar in the amount of 70 t/ha. The compaction curves obtained from the tests with soil and coarse Biocarbon in greater quantity converge more for the wet branch (after reaching the maximum specific weight) than for the dry branch, even though the greatest difference in maximum dry specific weight was 0.026 g/cm between tests 10 and 11. The greatest variation in optimum humidity between tests 10 and 11 was 1.44%.

Fig. 3 - Compaction curves for tests 9 to 12 with the addition of 70 tons per hectare and 600 µm <Ø <2 mm texture

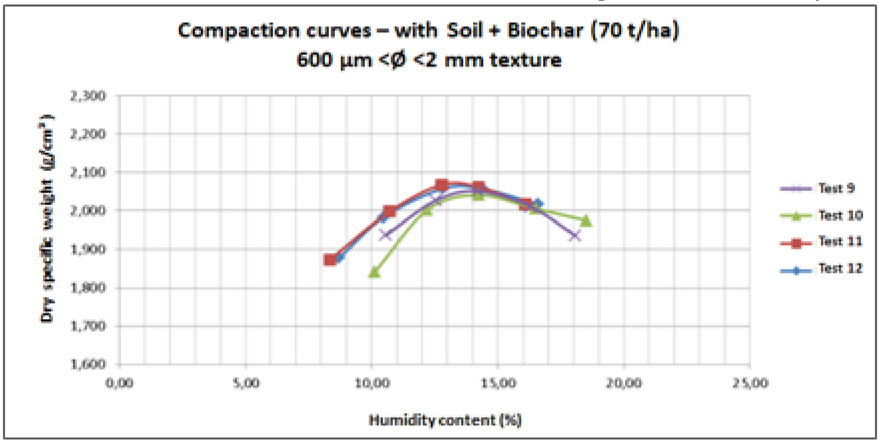


Figure 4 shows the compaction curves for Tests 13 to 16, performed with fine biochar in the amount of 35 t/ha. For the soil with thinner Biochar at the rate of 35 t/ha, the maximum variation in dry specific weight was even smaller than the previous ones, showing a difference of 0.020 g/cm³ between tests 13 and 15. The biggest difference between the variation of optimum humidity was 1.55%.

Fig. 4 - Compaction curves for tests 13 to 16 with the addition of 35 tons per hectare and texture of 75 µm <Ø <600 µm

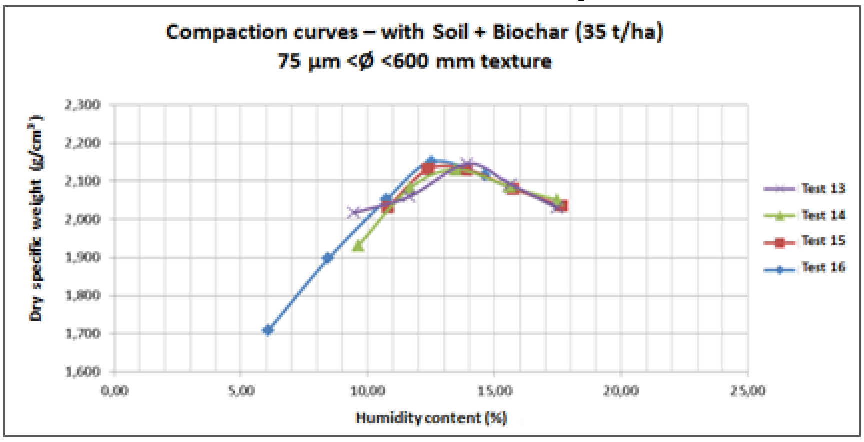
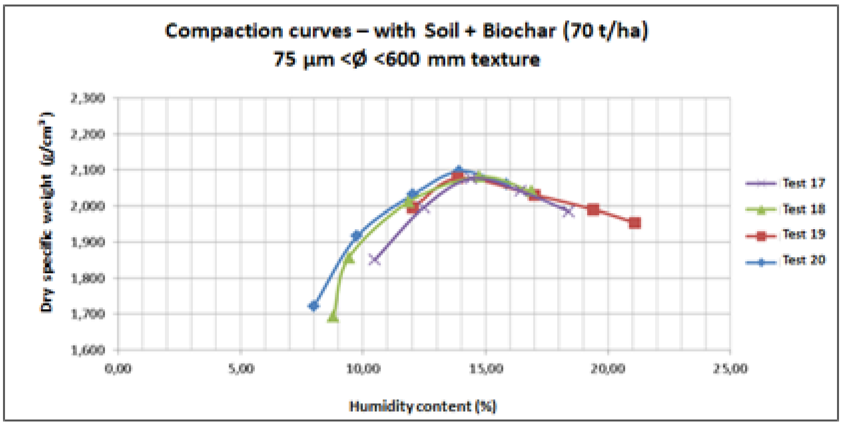


Figure 5 shows the compaction curves for tests 17 to 20, performed with fine biochar in the amount of 70 t/ha. The soil compaction curves with fine biochar at 70 t/ha showed the most uniform behavior between them, with the greatest variation in maximum specific weight being 0.020 g/cm³ as in Graph 4, and the optimum humidity varying in only 0.89% between trials 18 and 19.

Fig. 5 - Compaction curves for tests from 17 to 20 with addition of 70 tons per hectare and texture of 75 µm <Ø <600 µm



In addition to the reduction in specific weight and increase in optimum humidity in the soil with the application of biochar, there is also a lower slope in the wet branch (right side) of the curves of the soil with biochar, demonstrating a smaller variation in specific weight with the variation of moisture. This property may be associated with a lower susceptibility of these soils to compaction according to the increase in humidity. The retention of water by fine clay particles showed similar characteristics described by VERHEIJEN et al. 201).

To understand the variations of the proposed treatments, a univariate statistic was performed with the assistance of the ASSISTAT software version 7.6 betas (2011) in order to identify the differences between the means in the interpretation of the data obtained from optimum humidity and maximum specific weight in the 5 treatments with 4 repetitions each. The comparison of the averages selected in the program was based on the Tukey test.

The results generated by the program for the statistical analysis of the optimum moisture content in different samples are shown in Table 3.

Table 3 - Fully Randomized Moisture Analysis

FV	GL	SQ	QM	F
Treatments	4	18.76282	4.69070	8.8641 **
Residue	15	7.93770	0.52918	
Total	19	26.70052		

* significant at the level of 5% probability (.01 = <p <.05) ** significant at the level of 1% probability (p <.01) ns not significant (p> = .05)

The results generated by the program for the statistical analysis of the maximum specific weight in different samples are shown below in table 4.

Table 4 - Specific Randomized Weight Experiment Analysis

FV	GL	SQ	QM	F
Treatments	4	0.04420	0.01105	78.2113 **
Residue	15	0.00212	0.00014	
Total	19	0.04632		

* significant at the level of 5% probability (.01 = <p <.05) ** significant at the level of 1% probability (p <.01) ns not significant (p> = .05)

Comparative analysis for the verification between changes in soil compaction in relation to the application of different amounts and textures of biochar can be seen in figures 6 and 7 that elucidate bar graphs for the treatments. Differences can be observed between the average optimum humidity [%] and also in the average maximum specific weight [g/cm3] for the different treatments. Thus, according to table 6, a Tukey test was applied at a significance level of 5%.

Table 6 - Treatment averages: optimal humidity.

Treatment	Significance values
S	11.30 b
SBt	12.88 ab
SBT	13.49 a
Sbt	13.16 a

SbT	14.23 a
dms =	1.58947
MG = 13.01 CV% = 5.59 Midpoint = 12.85	

* averages followed by the same letter do not differ statistically, using the Tukey test at 5% probability.

Considering the average moisture content, a significant increase in optimum moisture was observed in almost all applications of biochar to the soil. Sample 5 of Soil + fine biochar 70 t/ha was the one that most increased the optimum humidity. This means greater water retention in the soil made possible by coal fines, which for the same amount of water in a soil without biochar and another with biochar, the former will be more likely to reach greater densities when it undergoes some application of energy. Table 6 shows that the means followed by the same letter do not differ statistically from each other by means of the Tukey test at the 5% significance level.

Table 7 -Treatment averages: maximum specific dry weight

Treatment	**Significance values**
S	2.19 a
SBt	2.13 b
SBT	2.05 d
Sbt	2.14 b
SbT	2.08 c
dms =	0.02597
MG = 2.12 CV% = 0.56	
Midpoint = 2.12432	

* averages followed by the same letter do not differ statistically, using the Tukey test at 5% probability.

Fig. 6 - Averages of optimum moisture content of different soil treatments plus biochar

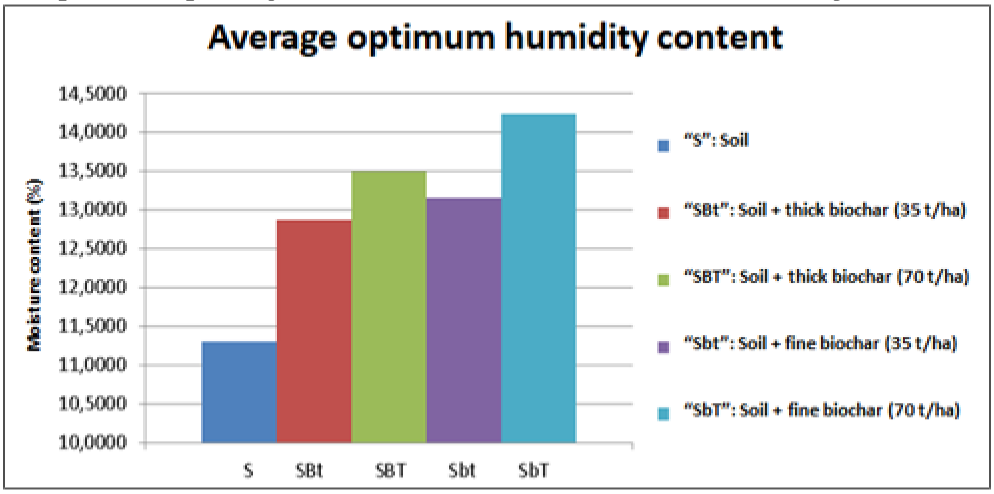
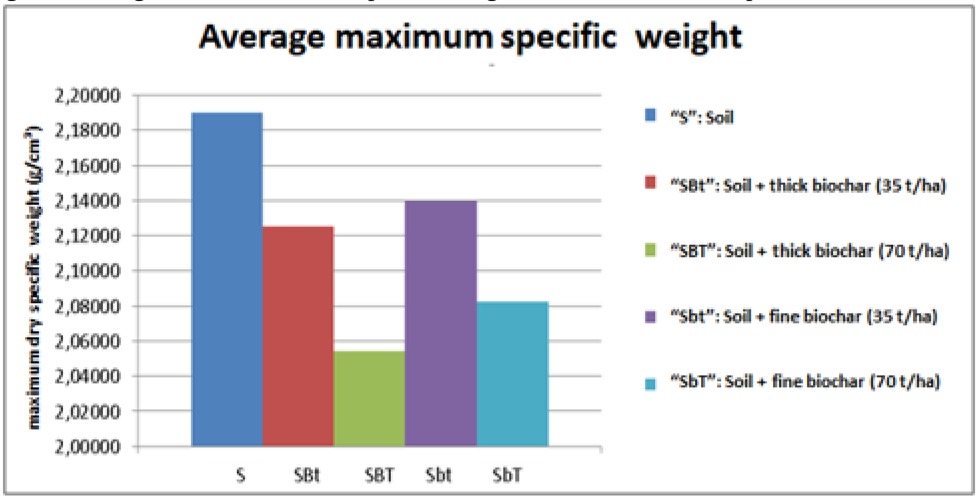


Fig. 7 - Averages of the maximum specific weights of the different samples of soil and biochar



The averages between the maximum specific weights of the different soil treatments with Biochar were reduced considerably when compared to the soil without Biochar, mainly for the applications of Biochar of 70 t/ha. The "SBT" sample (Soil+Biochar coarse 70 t/ha) was the one that most reduced the maximum specific weight of the soil-Biocarbon system, promoting a mass reduction greater than 6%.

Although the specific weight of the Biochar is much less than that of the soil, it can increase the specific weight when incorporated, since the maximum compaction capacity depends on the particle size of the system. As important as disposal and appropriate treatments, it is necessary to produce less and less waste and reuse more and more waste generated, reducing the high rate of waste, thus contributing to a more balanced and responsible society (Silva et al, 2020).The explanation for the thicker Biocarbon grains being better in reducing specific weight may be in the arrangement between the Biocarbon coarse particles with the soil particles and the friction between them. In a study on erodibility and compaction (GUILHEN, 2014), observed similar effects in analysis and highlighted that the addition of biochar to the soil resulted in decreased erosion throughout the dry state, while the opposite was observed in the wet state.

4 CONCLUSION

The results represented by the compaction curves and the statistical analysis of the data show a reduction in specific weight in all soil samples with incorporation of biochar, with the application of thick biochar (600 µm <Ø <2 mm) in the concentration of 70 t/ha more efficient in reducing soil compaction under the same energy as the rest of the tests.

It is also noted that the optimum moisture content, for the maximum specific weight, increases in all additions of biochar in the soil, and samples containing fine biochar (75 µm <Ø <600 µm) reached optimum humidity levels, more higher than other tests. This represents greater water retention in soils with biochar fines, which can be very interesting in very permeable soils. In addition, the increase in optimum humidity content can minimize the risk of maximum compaction in agricultural soil preparation in very rainy regions.

Thus, biochar has the potential to reduce soil compaction and increase water retention. These properties allow the biochar to be used for the disposal of urban organic waste and soil conditioning. As an indication for the production of future works, it is suggested that tests be carried out in the field, based on biochar from different plant residues and applications on larger scales, as the proposal for the destination of organic urban residues originating from pruning applied to the soil can assist in urban waste management in an integrated manner and with more sustainability.

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