Investigation of soil water retention effects of wood-biochar application on a tropical Ferralsol and reflects on *Eucalyptus urograndis* growth

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SUMMARY

The incorporation of wood-biochar into the soil, which is prevenient of the pyrolysis of wood, has been shown as a sustainable alternative to improve its physical attributes, augmenting water availability. This effect benefits *Eucalyptus* plantation in rainfed condition, since water scarcity suppress gas exchanges and growth. Thus, the aims of this study were to avail the effects of wood-biochar incorporation on a Ferralsol used to cultivate *Eucalyptus urograndis*. Soil water retention curve, leaf gas exchanges and morphology of *E. urograndis* cultivated under the absence and presence of 1 kg plant^{-1} of wood-biochar were investigated. The experiment was conducted in São Jerônimo da Serra, Parana, Brazil. Soil cores were collected three months after transplantation of seedlings for density trace, with no significant differences. However, at nine months after transplantation, a second observation of soil values revealed that field capacity and total available water were suppressed in 16 and 27%, respectively when biochar was present. At three, six and twelve months after transplantation, leaf gas exchanges were insensible to biochar application, as well as height, diameter at breast height and volume of trees at eighteen months. The investigation evidenced that, until the moment, biochar had a negative influence on water availability with no impact on plants. Nonetheless, further investigations might reveal different results under larger time among observations.

Keywords: Biochar; Gas Exchanges; Water retention curve; Tropical Soil.

INTRODUCTION

Biochar has been suggested as a soil conditioner (or product) to improve ecosystem functions and soil fertility, increasing plant productivity and soil carbon storage (GLASE, 2007; OMONDI et al., 2016). Essentially, biochar is a carbon rich solid obtained by heating biomass in a low-oxygen atmosphere, avoiding ignition and resulting in the rearranging of carbon bonds from low to high energy (DEMIRBAS & ARIN, 2002; KEILUWEIT et al., 2010). The biomass for pyrolysation is vast and under different contexts a wide range of sources might be suitable. In the present study, wood of a commercial forest was submitted to pyrolysis in order to improve soil water availability for *Eucalyptus urograndis* plantation.

Water is retained to soil through capillarity, a resulting phenomenon of electrical charges distributed on a surface area that attract water molecules that are accommodated into soil porosity. Biochar also features such properties, which are formed when intern carbon is volatilized from organic matter during pyrolysis (BATISTA et al., 2018). When it is applied to soil, biochar might increase water retention as captured by Omondi et al. (2016) on its meta-analysis, showing that water availability for plants was increased.

Eucalyptus generous is the world main source of biomass, wherein over 100 of countries rely on its production (MYBURG et al., 2014), and in Brazil it is widely cultivated due to its adaptability (GONÇALVES et al. 2013). Even though the generous adapt to various climes, its growth is severe limited to water availability. The consequence is a reduction of the photosynthetic process, limiting carbon assimilation due to the stomata closure, affecting plant production (WHITEHEAD & BEADLE, 2004). Hence, increase soil water availability through biochar incorporation might contribute to *Eucalyptus* growth, indicated by leaf gas exchanges as liquid assimilation of carbon, stomata conductance and transpiration rate (WHITE, 2000; WHITEHEAD & BEADLE, 2004, GONÇALVES et al. 2013).

Size effect of biochar application in forest ecosystems has been explored and meta-analysis pointed that in tropical regions, for hardwood trees and in field experiments superior effects with greater variability were verified, thus arising excitement of the biochar benefits (THOMAS; GALE, 2015). Other trend is the experiment time, which allows biochar to mineralize and effectively modify the soil conditions (Wang et al. (2016)). In addition, effect size and variability depends on the soil features, mainly soil texture (LIU et al., 2013;

OMONDI et al., 2016). Therefore, it is necessary a previous investigation of plant and soil responses to biochar incorporation to support final decision of large application.

The present study hypothesizes that the application of wood-biochar on a Ferralsol increases water retention, thus supporting higher gas exchanges and wood production of plants of *Eucalyptus urograndis* than its absent counterpart. The objectives of the study were (i) investigate the effects of biochar application on the water retention of a Ferralsol; (ii) examine the influence of the presence of biochar on the gas exchanges of *Eucalyptus urograndis*; (iii) evaluate the difference of trees morphology and wood production when biochar is applied.

MATERIAL AND METHODS

Site characterization

The investigation took place at Esperança Farm, area appurtenant to Urophylla Agroflorestal LTDA., in São Jerônimo da Serra, Paraná, Brazil (50° 39' 14.022" W, 23° 47' 32.295" S and 1.114 m above sea level). The clime is characterized as Cfb according to Köppen classification, humid subtropical, without dry season with temperate summer (ALVARES et al., 2013). Average temperature and rainfall are 22 °C and 1510 mm, respectively. The monthly rainfall during the study is present in Figure 1.

The soil was classified as Latossolo (=Ferralsol). Previously the experiment, the land was used to grow *Brachiaria spp.* for grazing. Initial soil particles size distribution and chemical properties were obtained from a bulk sample composed of 16 subsamples (Table 1). In addition, it was determined the soil particle density using helium in a pycnometer model AccuPyc II 1340 (Micrometrics, EUA), resulting in 2.63 Mg m^{-3}. Based on such results, it was decided to apply 1250 kg ha^{-1} of lime in July 8, 2017.

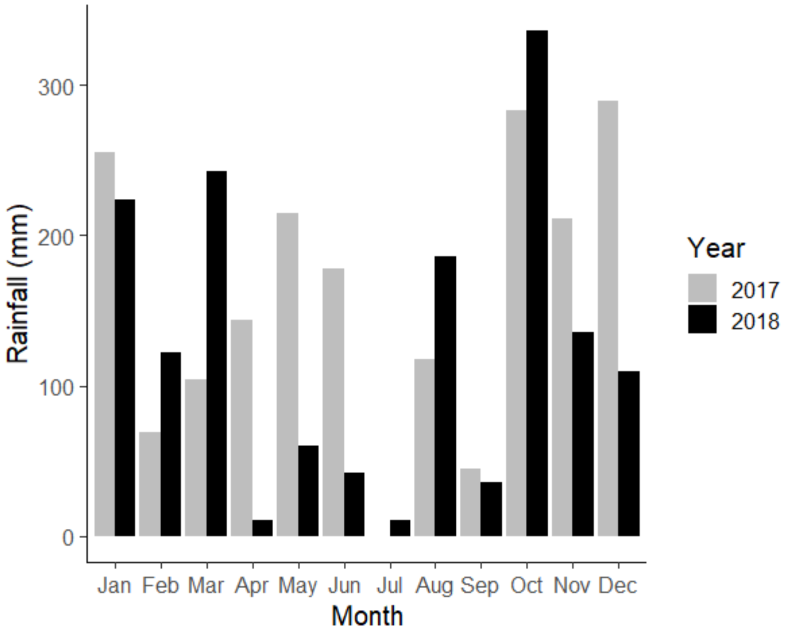

Figure 1 –Monthly rainfall (mm) from 2017 to 2018 recorded at meteorological station of São Jerônimo da Serra. Waters of Paraná Institute, www.sih-web.aguasparana.pr.gov.br.

Table 1 – Initial soil chemical properties and particle distribution.

Soil properties										
pH	CEC	$H+Al^{+3}$	Al^{3+}	Ca^{2+}	Mg^{2+}	P	C	Clay	Sand	Silt
	------------------ ($cmol_c\ dm^{-3}$) ------------------					--($mg\ dm^{-3}$)--	------------------($g\ kg^{-1}$)------------------			
5.09	13.54	11.23	1.43	1.27	0.72	3.75	3.88	463	430	107

Determination methods: pH – $CaCl_2$; P – Melich-1; C – combustion and infrared determination; Clay, Sand and Silt: sifting and sedimentation; $H+Al^{3+}$ – pH-SMP; Al^{3+}, Ca^{2+}, and Mg^{2+} – saturation with KCl and titration; CEC – sum of extractable cations.

Experimental design

The source of variation was the presence or absence of incorporation of 1 kg per tree of wood-biochar, which was obtained by pyrolysis of eucalyptus chips under 450 °C for 8 hours of residence. The solids showed 8.34% of ashes, 3.63% of humidity, 27.75% of volatile matter, 0.16 Mg m^{-3} of bulk density and 1.57 Mg m^{-3} of particles density. The experimental site was divided in two based on the similar clay content. The decision whether incorporate biochar was completely randomized. Firstly, the soil was chiseled, and then wood-biochar was incorporated with a plow disk at about 15 cm depth. The soil that did not receive wood-biochar addition was also plowed to avoid bias.

Clones of *Eucalyptus urograndis* (*Eucalyptus grandis* x *Eucalyptus urophylla*) were transplanted on November 7th, 2017 under a 3 x 3 m spacing. Each area was composed of 66 trees, 6 rows of 11 plants. However, the border rows were not considered for sampling, resulting in 36 useful plants, 4 rows of 9 plants. The fertilization was applied fallowing the standards of operation from Urophylla Agroflorestal LTDA.: 150 g plant^{-1} of fertilizer formula 04-42-06 (N%, P_2O_5%, K_2O%), 200 g plant^{-1} of fertilizer formula 15-05-30 + 1% of B and 1% Zn, and 110 g plant^{-1} of KCl were applied at 15 days, 90 days and 9 months after transplantation, respectively.

Soil sampling and analysis

Intact soil cores were sampled in a radius of 50 cm from plants in 100 cm^3 cylinders for physical characterization. Three months after transplantation, fifteen soil cores were taken from each area. Bulk soil density were obtained by oven drying at 105 °C and total porosity was calculated using the particle density, as suggested by Hillel (1998). At nine months after transplantation, four soil cores were taken from each area to represent the water retention curve. These soils were saturated during three days, then submitted to water suction under the potentials -3, -6, -10, -30 and -50 kPa on suction plates (echoTech, DE), -100 and -300 kPa in Richard’s extractor (Soil Moisture, USA), and the soil moisture at -1000 and -1500 kPa was determined with WP4-C (Decagon, USA). The soil water retention curves (SWRC) were fitted using the mathematical model suggested by van Genuchten (1980).

$$\theta = \theta_r + [\frac{\theta_s - \theta_r}{1 + (\alpha {\Psi_m}^n)}]^m$$

Where θ is the volumetric water content (m^3 m^{-3}), θ_r and θ_s are the residual and saturated water content, respectively, Ψ is the matric suction (kPa), α, n and m are fitting parameters, taken that m = 1-1/n.

The soil wetness was qualitatively descripted following Weil and Braddy (2016): maximum retentive capacity (MRC) was considered as the total porosity, calculated as *MRC* = 1 – Soil density/Particle Density; field capacity (FC) considered at -10 kPa; permanent wilting point (PWP) considered at -1500 kPa; and total available water (TAW) considered the extractable water between -10 and -1500 kPa.

Gas exchanges and plant morphology

At three (Feb/2018), six (May/2018) and nine (Nov/2018) months after transplantation, eight useful plants were selected by zig-zag walking into the areas. It were obtained the leaf instantaneous liquid assimilation of CO_2 (A, µmol CO2 m^{-2} s^{-1}), stomatal conductance (gs, mol H2O m^{-2} s^{-1}) and leaf transpiration (E, mmol H2O m^{-2} s^{-1}) using an infrared gas analyzer (IRGA) model LI-6400XT (LI-COR, USA). The chamber atmosphere was set to 25°C, photosynthetic photon flux density to 1200 µmol photons m^{-2} s^{-1}, CO_2 concentration to 400 µmol mol^{-1}, and gases flow to 400 µmol s^{-1}. Each trait were obtained during the noon of a day that was fallowed of at least five full sunny days, on a recently full-expanded leaf that faced north, positioned in the middle of the crown.

The diameter at breast height (*DBH*, cm) and plant height (*H*) were obtained by direct measurement and using a hypsometer model PM-5/1520 (Suunto, EUA), respectively. The data acquisition occurred at eighteen months after transplantation. The wood volume was calculated using the model suggested by Meyer (1984) with adjusted coefficients fitted for *Eucalyptus urograndis* obtained by Miranda et al. (2015), which shows an R^2aj. of 0.978.

$$V = \beta_0 + \beta_1 DBH + \beta_2 DBH^2 + \beta_3 DBH\, H + \beta_4 DBH^2\, H + \beta 5\, H$$

Where V is the volume of unpeeled wood (m^3), DBH and H are given in m, β_0, β_1, β_2, β_3, β_4, and $\beta 5$ are equal to -0.04767, -0.00607, 0.00096, -0.00103, 0.00003, and 0.01288, respectively.

Statistical analysis

Traits were averaged and plotted with 95% confidence intervals. Whenever intervals did not overlap, means were considered significantly different. The nonlinear fitting program by Seki (2007) was used for coefficients acquisition of the water retention curves. Environment R with package ggplot2 was used for plotting and analysis (R Core Team, 2018; Wickham, 2016).

RESULTS

Soil water retention

Three months after *Eucalyptus urograndis* transplantation, soil density was significantly lower when wood-biochar was present, with reduction near to 7%. Although the mean differences were 8%, contrasts of soils could not be addressed to the application of wood-biochar due to its high variability. Confidence interval when wood-biochar was present changed from 0.04 at three months to 0.17 at nine months after transplantation, an increment of 425%.

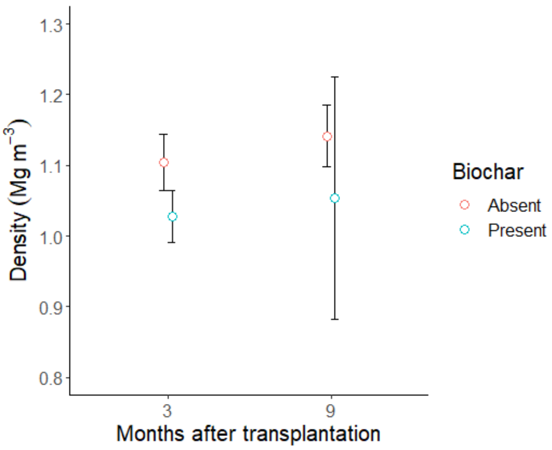

Figure 2 – Soil bulk density. Above and below bars are 95% confidence interval with N = 15 and 4 for 3 and 9 months, respectively.

When comparing the SWRC at nine months after transplantation, the model evidenced a reduction of water retention through all the operational range of matric suction (Figure 3). In addition, a higher variability was found. The R^2 difference is 0.34 points, meaning a determination capacity 68% higher when wood-biochar is absent (Table 2).

Table 2 – Water retention curve coefficients obtained for the soils under absence or presence of wood-biochar.

Biochar	θs	θr	α	n	R^2
Absent	0.55451	0.000031351	0.63661	1.1147	0.82901
Present	0.44743	0.000047091	0.31907	1.1012	0.49189

θs: effective saturation, θr: residual water; α and n: empirical coefficients, R^2: coefficient of determination.

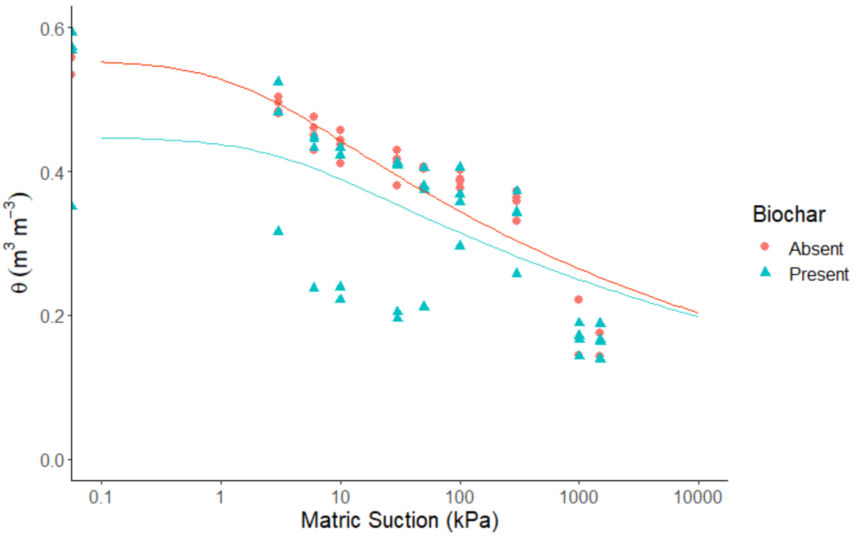

Figure 3 – Water retention curves under the absence and presence of biochar with N = 4 for each matric suction. The lines are the fitted water retention and circles and triangles are the observed soil humidity.

The qualitatively description of SWRC indicates that the MRCs were 0.56±0.01 and 0.60±0.06 m^3 m^{-3} when wood-biochar was absent and present, respectively, a non-significant difference. Although was found in the model MRCs of 0.55 and 0.44 m^3 m^{-3} when wood-biochar is absent and present, respectively, the coefficient of determination indicates a bias to affirm a significant difference due to the high variability when biochar was present (Table 2). The FC when wood-biochar was absent was 0.44±0.03 and present was 0.38±0.15 m^3 m^{-3}, a significant difference of 16%. Under the absence or presence of wood-biochar, PWP was 0.16±0.03 m^3 m^{-3}. Finally, TAWs were 0.28±0.04 and 0.22±0.15 m^3 m^{-3} when wood-biochar was absent and present, respectively, differing significantly by 27%.

***Eucalyptus urograndis* morphology and physiology**

No significant difference was observed for all gas exchanges traits analyzed (Figure 4 A, C and E). Variable *A* exhibited a confidence interval relatively lower at 6 months after transplantation by 258% when wood-biochar was present. For *gs* and *E*, it was also possible to distinguish superior means at 6 months relatively to 3 and 9 months.

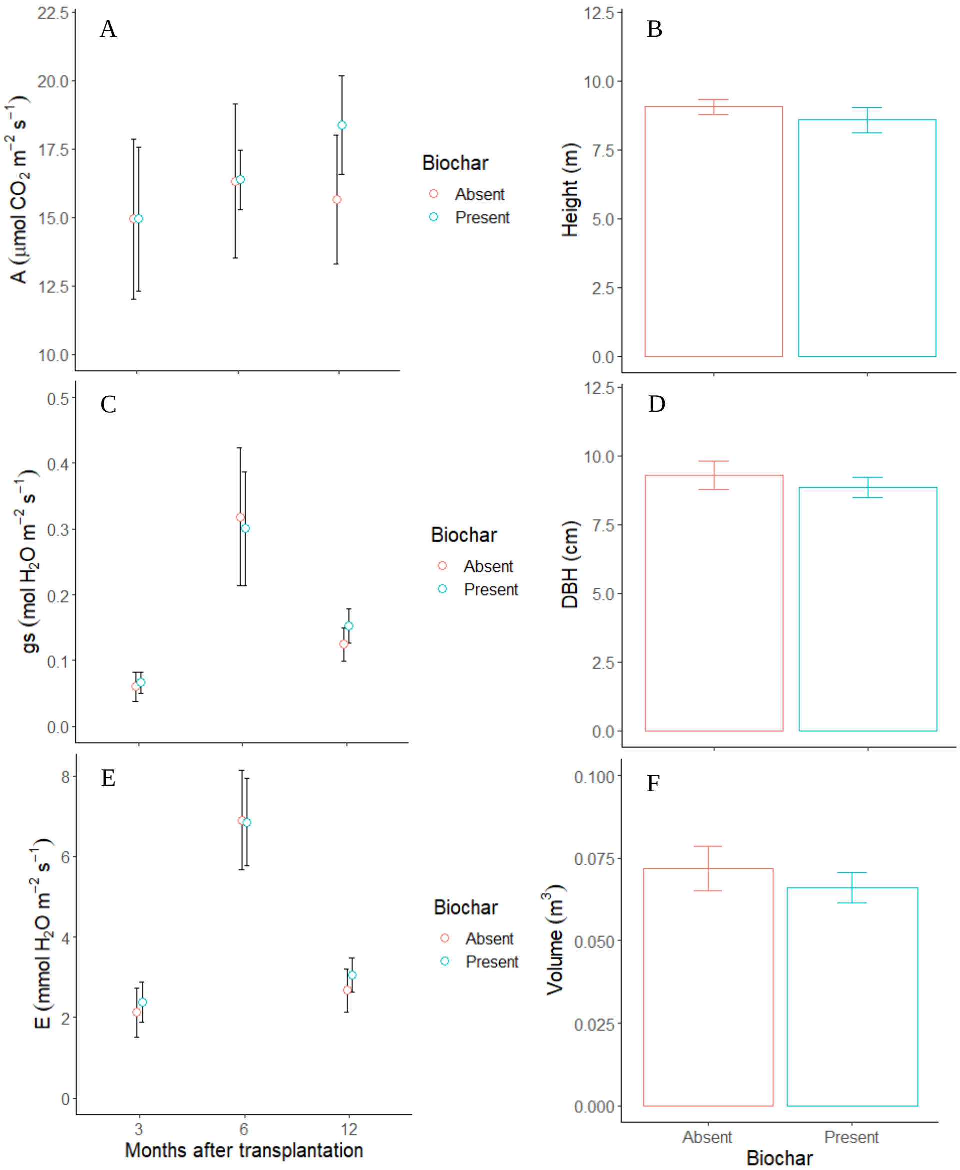

Figure 4 – Leaf instantaneous liquid assimilation of CO_2 (A), stomata conductance (C), and transpiration (E) were measured at 3, 6 and 12 months after transplantation. Plant height (B) and diameter at breast high (D) were measured at 18 months after transplantation and yielded the unpeeled-wood volume estimation (F). Above and below bars are 95% confidence interval with N = 8.

The average of morphological traits did not differ significantly when soils had the presence or absence of biochar (Figure 4 B, D and F). However, when biochar was present, all traits showed lower averages and lower confidence intervals, pointing a negative trend on *Eucalyptus urograndis* morphology.

DISCUSSION

Biochar influence on soil physical parameters are dependent on surface charges that are generated during pyrolysis as Batista et al. (2018) have demonstrated. Such characteristic results on the formation of stable particle aggregation due to cationic bonds of biochar functional-groups and clay. This effect was not captured by monitoring the soil density (Figure 2). However, it was possible to verify an increment on variability, probably an aftereffect of the simple addition of a new body in the soil. This result also suggest that the interval of observations could not capture an effect of wood-biochar mineralization, as observed by Wang et al (2016).

Soil initial features greatly affect biochar incorporation results as suggested by Omondi et al. (2016). Authors quantified biochar effects on soil hydrological properties and results pointed that fine-textured soil shows minors responses to biochar application. In addition, available water content is a sensible indicator to examine biochar effects on soil hydrology. The observed Ferralsol featured 463 and 3.88 g kg^{-1} of clay and carbon and 13.54 $cmol_c$ dm^{-3}, what suggest a high abundance of negative charges on a high surface area previously wood-biochar incorporation. This condition might have suppressed desirable wood-biochar effects and even shift outcomes to negative values as seen for FC and TAW. This investigation indicates that wood-biochar had negative effects on water retention on the soil of study at this moment.

Admitting that genotype *Eucalyptus urograndis* (*E. grandis x E. urophylla*) is sensible to water deficit and responses of gas exchanges are immediate (STAPE, 2002), no water restriction occurred during the observation events. This response demonstrate no relation to soil observations and suggest that deeper soil layers were source of water uptake as seen in previous experiments by Chirstina et al. (2017). The low rainfall during the second and third observation of gas exchanges and the methodology of data collection, after five days of full sun, support such notation. Furthermore, morphological parameters are integrative traits that account of all events during the plant life, mainly carbon assimilation, implying that the present practice of application of wood- biochar into the soil had no influence on plants.

Investigations point that, so far, wood-biochar have not had influenced plants, although soil data showed a negative influence on SWRC. Traits variability and time influence indicates that sample size and intervals should be higher and longer, respectively. Trends verified in this study and literature meta-analysis (OMONDI et al., 2016) indicates that biochar might have negative influence on such Ferralsol in future observations. Thus, further investigation might find new results, given a trend of depression of eucalyptus morphology under wood-biochar application.

CONCLUSION

The investigation of the application of 1 kg per plant of woof-biochar in a Ferralsol evidenced a reduction of water availability through the operational matric suctions. When examining the *Eucalyptus urograndis* growth in this soils, its gas exchanges and morphology showed no differences. Although wood-biochar application was negative to the soil water retention, the culture showed to be insensible and data analysis of wood volume resulted in no significant differences.

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