Carbon sequestration by plant species used in green roofs across different periods[1]

Sequestro de carbono em espécies de plantas utilizadas em telhado verde em diferentes períodos

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HIGHLIGHTS:
Different periods of the year influence the content of CO_2 in the substrate.
Green roofs contribute to reducing atmospheric CO_2.
The concentration of organic carbon in the substrate differed between plant species and periods.

ABSTRACT: This study evaluated the influence of three plant species and two periods on the amount of carbon stored in the substrate in an extensive green roof. The study was carried out in March and September 2020 at Charles Darwin Business Garage Building, Recife, Pernambuco state, Brazil. A completely randomized design with a split-plot scheme was adopted, with plant species (zoysia grass [*Zoysia japonica*], inch plant [*Tradescantia zebrina*], and fountain grass [*Pennisetum setaceum*]) allocated to plots and the material collection periods (March and September) to subplots. The CO_2 and organic carbon concentrations in the substrate were quantified. Thirty samples were obtained from the substrate during each period. No statistically significant difference was observed in CO_2 content among species treatments; however, there was a significant difference between the two periods evaluated, with average values of 14.05 and 96.97 mg in March and September, respectively. Therefore, September has the greatest potential for CO_2 storage in the substrate. Significant differences were observed in organic carbon concentrations among species and between periods, with average values of 95.05 and 129.22 g kg^{-1} for fountain grass and inch plant, respectively, and 131.15 and 100.81 g kg^{-1} in March and September, respectively.

Key words: urbanization, CO_2 emission, sustainability

RESUMO: A presente pesquisa objetivou avaliar a quantidade de carbono estocado no substrato sob influência de espécies de plantas presentes em um telhado verde extensivo em dois períodos. A pesquisa foi desenvolvida nos meses de março e setembro de 2020, no Edifício Garagem do Empresarial Charles Darwin, Recife, Pernambuco, Brasil. Adotou-se o delineamento inteiramente casualizado em esquema de parcelas subdivididas, com as espécies de plantas (Grama Esmeralda (*Zoysia japonica*), Lambari roxo (*Tradescantia zebrina*), and Capim-do-texas (*Pennisetum setaceum*)) alocadas nas parcelas e os períodos de coleta dos materiais (março e setembro) nas subparcelas. Para isso, foram quantificados o teor de CO_2 e concentração de carbono orgânico no substrato. Trinta amostras de substrato foram retiradas em cada período. Para o teor de CO_2, não houve diferença estatística entre as espécies, apenas entre os períodos avaliados, com médias de 14.05 e 96.97 mg, para os meses de março e setembro, respectivamente. Sendo assim, setembro apresentou o maior potencial de armazenamento de CO_2 no substrato. Para a concentração de carbono orgânico, houve diferença estatística entre as espécies e períodos, com valores médios de 95.05 e 129.22 g kg^{-1} para as espécies Capim-do-texas e Lambari roxo, respectivamente, e 131.15 e 100.81 g kg^{-1}, para março e setembro, respectivamente.

Palavras-chave: urbanização, emissão de CO_2, sustentabilidade

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INTRODUCTION

The urbanization process has drastically intensified in recent decades, interfering with the landscape and local weather patterns. As a result, one of the most noticeable changes is the large removal of vegetation cover, which in turn ends up directly interfering with the impermeability of soils, increase in local temperature, formation of heat islands, in addition to accelerating the greenhouse effect through the emission of greenhouse gases (GHG), in particular carbon dioxide (CO_2) (Lima, 2013).

Among GHGs, CO_2 is the most abundant and primary anthropogenic contributor to global warming (Rei et al., 2017). In this sense, green roof application is an effective alternative for reducing the effect of the urban heat islands, habitat restoration, rainwater management, energy efficiency improvements (Talebi et al., 2019), and GHG reduction, especially CO_2 (Agra et al., 2017).

Green roofs are constituted by a vegetal covering implanted in conventional roofs or slabs (Souza et al., 2015). These are classified into three types: extensive green roofs, semi-intensive and intensive, whose main difference is in the vegetation kind and the substrate thickness used (IGRA, 2017).

Plant species such as *Sedum floriferum*, *Sedum album*, *Allium schoenoprasum*, *Cynodon dactylon*, *Paspalum vaginatum* and *Zoysia japonica* have been used in studies involving the theme of green roofs (Ismail et al., 2012; Heusinger & Weber, 2017; Ntoulas et al., 2017). However, research involving the use of different species of plants is required as they can contribute to a better performance of green roofs.

In this way, the current research aimed to evaluate the amount of carbon stored in the substrate influenced by three different plant species found in an extensive green roof in two different periods.

MATERIAL AND METHODS

The study was conducted in March and September 2020 at the Charles Darwin Business Garage Building, Rio Ave Empreendimentos Construction Company, Recife, Pernambuco state, Brazil (8º 04' 03" S, 34º 55' 00" W, at an altitude of 4 m). The building is eight floors high. According to the Köppen climate classification, the climate of the region is an As type, tropical wet (Pereira et al., 2002), with a rainy season from May to August and an annual accumulated rainfall of 2263.4 mm. The annual average air temperature is 25.9 °C, with maximum and minimum average temperatures of 29.5 and 22.3 °C, respectively. The relative air humidity is 78.3% (INMET, 2020).

To enhance the characterization of the two periods, data from the Meteorological Database for Teaching and Research (BDMEP), managed by the National Institute of Meteorology, were obtained from the Recife (Curado) meteorological station in Pernambuco state (8º 04' 03" S, 34º 55' 00" W, and altitude of 4 m) and used for analysis. Monthly data related to maximum and minimum air temperatures, and relative air humidity for the two periods were selected (Table 1).

Table 1. Maximum and minimum air temperature, relative air humidity and precipitation data, recorded at the meteorological station in Recife, PE, Brazil, in the months of March and September 2020

Months	Maximum temperature	Minimum temperature	Relative air humidity	Precipitation (mm)
	(ºC)		(%)	
March	32	22	74	96
September	33	20	72	74

Source: Meteorological Database for Teaching and Research, INMET (2020)

The installed green roof was extensive with an area of 2.800 m² and three plant species, including zoysia grass (*Zoysia japonica*), inch plant (*Tradescantia zebrina*), and fountain grass (*Pennisetum setaceum*). In addition, the roof had a 7.5-cm thick substrate layer of treated sewage sludge from the Charles Darwin Business Garage Building, a drainage system formed by a geotextile drainage fabric (bidim), a 2.5-cm thick stone layer (made from recycled concrete debris), as well as a bidim fabric and asphalt layers for slab waterproofing. In addition, the green roof had a retractable sprinkler irrigation system that could supply 9.2 mm of water per day, and a reservoir with a storage capacity of 380 m³.

The substrate used was derived from treated sewage sludge (C/N ratio: 15.2; pH: 7.0; total nitrogen: 21.5 g kg^{-1}; phosphorus: 16.75 g kg^{-1}; potassium: 2.27 g kg^{-1}), with a dry density of 781.35 kg m^{-3}, a density of 1130 kg m^{-3} at the maximum water retention level, and a maximum volumetric retention of 49.6%.

The experimental design adopted was a completely randomized design in a split-plot scheme, with plant species (FG: fountain grass [*Pennisetum setaceum*]; ZG: zoysia grass [*Zoysia japonica*]; IP: inch plant [*Tradescantia zebrina*]) allocated to the plots and the material collection periods (March and September) to the subplots, with five replicates for each treatment. The FG, ZG, and IP flower beds had areas of 39.00 m² (13.00 × 3.00 m), each corresponding to an experimental area of 117.00 m².

The plant species used in the present study are recommended for green roofs due to their aesthetic, functional, and recreational properties (Beard & Green, 1994), in addition to their air pollution reduction capacity (Lu et al., 2016). Furthermore, the plants have diminished root systems so that they are suitable for application as extensive green hedges.

The variables analyzed were organic carbon concentration and content of CO_2 evolution from the substrate. The analyses were performed in March and September 2020.

A square of known area (0.5 × 0.5 m) was used to select the location where the substrate samples were obtained. The square was randomly selected within each replicate, with five replicates in each treatment, yielding 15 substrate samples during each period of evaluation, and 30 samples per period for each variable analyzed.

The substrate samples on the green roof were collected from a depth of 0 to 5 cm to determine CO_2 evolution. The samples were packed in plastic bags and subjected to chemical characterization analyses. The chemical method described by Grisi (1978) was used to determine the variable based on

the CO_2 amounts absorbed from the soil. The substrate was incubated in a closed container with 10 mL of potassium hydroxide (0.5 N KOH).

Sample collection for organic carbon and CO_2 evolution determination in both periods were carried out on the same day. The substrate samples were collected using a garden shovel from a depth of 0 to 5 cm. Afterward, the samples were transferred to previously labeled plastic bags and sent to the laboratory. Organic carbon concentration was determined using the standard method established by Yeomans & Bremner (1988) based on dichromate ($Cr_2O_7^{2-}$) reduction by organic carbon compounds and subsequent determination of the remaining $Cr_2O_7^{2-}$ by titration of excess chromium with ferrous ammonium sulfate.

The percentages of organic matter in the substrate associated with each plant species and period were also determined (Table 2). The value obtained for each treatment was multiplied by a factor of 1.724 because generally, carbon accounts for 58% of the average humus composition (Claessen, 1997).

The data obtained were subjected to Analysis of Variance, and if the F-test detected significance, the average values were subjected to Tukey's test (p ≤ 0.05). Statistical analyses were performed using SISVAR 5.0 (Ferreira, 2011).

RESULTS AND DISCUSSION

No significant interactions (p > 0.05) were observed between plant species and collection periods. In addition, no significant difference was observed in CO_2 content among the species based on microbial respiration. However, CO_2 content across the different periods differed significantly, with average values of 14.05 and 96.97 mg in March and September, respectively (Table 3).

Precipitation was experienced in Recife, Pernambuco state, Brazil, on the week preceding sample collection and on the collection day in the second period, which could explain the relatively high CO_2 evolution values observed. According to data acquired from BDMEP (BDMEP, 2020; INMET, 2020), a total precipitation of 11 mm was observed in Recife, Pernambuco state, hours before sample collection in September. In contrast, no rainfall was observed on the collection day in March. Such rainfall increased water supply to the green roof, which justifies the high CO_2 production. Soil moisture is one of the main factors influencing microbial activity, and enhances CO_2 content.

Similar results have been observed by Santos et al. (2016), who investigated soil microbial respiration within a research area located in Olho D'Água do Casado municipality in Alagoas State, Brazil. In addition to the results of Azevedo et al. (2019), analysis of various sources of organic fertilizers in an area under agroforestry systems in the Brazilian semiarid region revealed that CO_2 evolution was higher in the rainy season than in the dry season.

Soil moisture regulates CO_2 release (Macleod et al., 2008; Correia et al., 2009). Seasonal fluctuations in microbial development are more relevant to the soil surface, where humidity and temperature fluctuations are the most notable (Cattelan & Vidor, 1990). Therefore, varying soil conditions and their environments can generate fluctuations in carbon content (Araújo et al., 2011).

A significant difference was observed in organic carbon concentrations among species and between the research periods (Table 3). Inch plant and fountain grass organic carbon concentrations differed significantly, with mean average values of 129.22 and 95.06 g kg⁻¹, respectively. Furthermore, the mean organic carbon concentrations in March and September were significantly different, with average values of 131.15 and 100.81 g kg⁻¹ in March and September, respectively.

Soil organic carbon concentrations indicate the amount of organic matter accumulated in soil (Monteiro, 2020). Similarly, the organic carbon concentration (Table 3) was higher in the period when substrate organic matter was high, in March, than in September (Table 2).

A similar result was observed by Brown & Coton (2011) who investigated total organic carbon deposition, available nutrients, soil nitrogen, and microbial activity, among other trends, in agricultural soils in California. The researchers observed that as the soil organic matter concentration increased with the addition of organic waste, the organic carbon concentration also increased. In addition, the authors observed that microbial activity in soils treated with organic residues was approximately 2.3-fold higher than that in the control soil (p ≤ 0.009). In the present study, microbial activity increased significantly following the addition of organic matter to the soil, which provided nutrients to the microorganisms.

Table 2. Average concentration of organic matter in the substrate for the species ZG (Zoysia Grass - *Zoysia japonica*), FG (Fountain Grass - *Pennisetum setaceum*), and IP (Inch Plant - *Tradescantia zebrina*), and for the periods of March and September 2020

Plant especies	Organic matter concentration (g kg⁻¹)
	March
Pennisetum setaceum	246.73
Zoysia japonica	247.30
Tradescantia zebrina	184.25
	September
Pennisetum setaceum	179.66
Zoysia japonica	198.27
Tradescantia zebrina	143.50

Table 3. Average content of CO_2 and concentration of organic carbon in the substrate, for the species zoysia grass (*Zoysia japonica*), fountain grass (*Pennisetum setaceum*), and inch plant (*Tradescantia zebrina*), and periods of March and September

Variable	Species – Sp				Period - Pe			P-Value		
	ZG[1]	FG[2]	IP[3]	SEM[4]	MAR[5]	SEP[6]	SEM	Sp	Pe	Sp × Pe
CO_2[7] (mg)	56.69 a	57.68 a	52.15 a	2.08	14.05 b	96.97 a	1.86	0.1786	0.0000	0.7605
OC[8] (g kg⁻¹)	123.66 a	95.05 b	129.22 a	4.60	131.15 a	100.81 b	3.82	0.0004	0.0001	0.5185

Means followed by different lowercase letters in the line are statistically different by the Tukey test at p ≤ 0.05. [1]ZG - Zoysia Grass (*Zoysia japonica*); [2]FG - Fountain Grass (*Pennisetum setaceum*); [3]IP - Inch Plant (*Tradescantia zebrina*); [4]SEM - Standard error of the mean; [5]MAR - March; [6]SEP - September; [7]CO_2 – Content of CO_2; [8]OC - Concentration of organic carbon

Good management practices can increase soil organic matter concentration and enhance soil carbon, in addition to reducing CO_2 content in the atmosphere and potentially mitigating global climate change (Wells et al., 2019).

Over the years, it has increasingly become evident that greenhouse gas emissions have considerable detrimental effects on populations and cause climate change, which adversely affects plant growth and development, and in turn global agriculture production (Wargent & Jordan, 2013). Therefore, carbon sequestration in soils as CO_2 considerably reduces the greenhouse effect. In addition, organic matter concentrations in soil sequestered with high carbon levels would also be high (Trombetta et al., 2020).

Notably, carbon dynamics have been studied extensively in natural, agricultural, urban, and community forests. However, understanding of the the carbon sequestration potential of green roofs remains poor.

Conclusions

1. The content of CO_2 in the substrate does not differ between plant species, but it differs between the periods, with September showing the greatest potential for CO_2 storage in the substrate.

2. The organic carbon concentration does differ between species and periods, with higher values for the species Inch Plant and Zoysia Grass, and for March, which was the period with higher water content in the substrate.

Acknowledgments

Literature Cited

Agra, H. E.; Klein, T.; Vasl, A.; Kadas, G.; Blaustein, L. Measuring the effect of plant-community composition on carbon fixation on green roofs. Urban Forestry & Urban Greening, v.24, p.1-4, 2017. https://doi.org/10.1016/j.ufug.2017.03.003

Araújo, K. D.; Dantas, R. T.; Andrade, A. P. de; Parente, H. N. Cinética de evolução de dióxido de carbono em área de caatinga em São João do Cariri-PB. Revista Árvore, v.35, p.1099-1106, 2011. https://doi.org/10.1590/S0100-67622011000600016

Azevedo, W. dos S. L.; Perez-Marin, A. M.; Ferreira, T. C. Opuntia sp., fertilidade e sazonalidade climática podem influenciar a microbiologia do solo em área com SAF?. Jour-nal of Biology & Pharmacy and Agricultural Management, v.15, p.373-386, 2019.

Beard, J. B.; Green, R. L. The role of turfgrasses in environmental protection and their benefits to humans. Journal of Environmental Quality, v.23, p.452-460, 1994. https://doi.org/10.2134/jeq1994.00472425002300030007x

BDMEP - Banco de Dados Meteorológicos para Ensino e Pesquisa. Dados meteorológicos, 2020. Available on: <https://portal.inmet.gov.br/>. Accessed on: Nov. 2020.

Brown, S.; Cotton, M. Changes in soil properties and carbon content following compost application: results of on-farm sampling. Compost Science & Utilization, v.19, p.87-96, 2011. https://doi.org/10.1080/1065657X.2011.10736983

Cattelan, A. J.; Vidor, C. Flutuação na biomassa, atividade e população microbiana do solo, em função de variações ambientais. Revista Brasileira de Ciência do Solo, v.14, p.133-142, 1990.

Claessen, M. E. C. Manual de métodos de análise de solo. 2.ed. rev. atual. Rio de Janeiro: Embrapa-CNPS, 1997. 212p.

Correia, K. G.; Santos, T. da S.; Araujo, K. D.; Souto, J. S.; Fernandes, P. D. Atividade microbiana do solo em quatro estágios sucessionais da Caatinga no munícipio de Santa Terezinha, Paraíba, Brasil. Engenharia Ambiental, v.6, p.534-549, 2009.

Ferreira, D. F. Sisvar: A computer statistical analysis system. Ciência e Agro-tecnologia, v.35, p.1039-1042, 2011. https://doi.org/10.1590/S1413-70542011000600001

Grisi, B. M. Método químico de medição da respiração edáfica: alguns aspectos técnicos. Ciência e Cultura. v.30, p.82-88, 1978.

Heusinger, J.; Weber, S. Extensive green roof CO_2 exchange and its seasonal variation quantified by eddy covariance measurements. Science of the Total Environment, v.607, p.623-632, 2017. https://doi.org/10.1016/j.scitotenv.2017.07.052

IGRA - International Green Roof Association. Green roof types, 2017. Available on: <http://www.igra-world.com/types_of_green_roofs/index.php>. Accessed on: May 2019.

INMET - Instituto Nacional de Meteorologia, 2020. Available on: <http://www.inmet.gov.br/portal/index.php?r=clima/normaisClimatologicas>. Accessed on: Sept. 2020.

Ismail, A.; Samad, M. H. A.; Rahman, A. M. A.; Yeok, F. S. Cooling potentials and CO_2 uptake of *Ipomoea pes-caprae* installed on the flat roof of a single storey residential building in Malaysia. Procedia-Social and Behavioral Sciences, v.35, p.361-368, 2012. https://doi.org/10.1016/j.sbspro.2012.02.099

Lima, G. C. de O. Avaliação do desempenho de telhados verdes: capacidade de retenção hídrica e qualidade da água escoada. Caruaru: UFPE, 2013. 51p. Dissertação Mestrado

Lu, M.; Zhao, X. M.; Ding, Z.; Zhao, J.; Jing, R. R.; Gao, P. Research on purification capacity of nine kinds of indoor plant against benzene pollution. Journal Shandong Jianzhu University, v.31, p.527-535, 2016.

Macleod, I.; Savage, A. L.; Baird, J. Decline in microbial activity does not necessa-rily indicate an end to biodegradation in MSW-biowaste: A case study. Bioresource Technology, v.99, p.8626-8630, 2008. https://doi.org/10.1016/j.biortech.2008.04.011

Monteiro, A. P. Atributos químicos de latossolo vermelho em função de plantas de cobertura e adubação nitrogenada. Jaboticabal: UNESP, 2020. 44p. Dissertação Mestrado

Ntoulas, N.; Nektarios, P. A.; Kotopoulis, G.; Ilia, P.; Ttooulou, T. Quality assessment of three warm-season turfgrasses growing in different substrate depths on shallow green roof systems. Urban Forestry & Urban Greening, v.26, p.163-168, 2017. https://doi.org/10.1016/j.ufug.2017.03.005

Pereira, A. R.; Angelocci, L. R.; Sentelhas, P. C. Agrometeorologia: fundamentos e aplicações práticas. Guaíba: Agropecuária, 2002. 478p.

Rei, F. C. F.; Gonçalves, A. F.; Souza, L. P. de. Acordo de Paris: Reflexões e desafios para o regime internacional de mudanças climáticas. Revista Veredas do Direito, v.14, p.81-99, 2017. https://doi.org/10.18623/rvd.v14i29.996

Santos, G. R. dos; Santos, E. M. C.; Lira, E. S.; Gomes, D. L.; Araujo, K. D. Respiração microbiana do solo relacionada ao conteúdo de água no solo e a temperatura do solo, na época do Equinócio de primavera, em Olho D'Água do Casado, Semiárido de Alagoas. Revista de Geociências do Nordeste, v.2, p.885-893, 2016. https://doi.org/10.21680/2447-3359.2016v2n0ID10549

Souza, R. O. L.; Ferreira, M. L. S. S.; Vasconcellos, C. A. B. Telhado verde de baixoinvestimento composto por plantas medicinais e aromáticas. Revista Semioses, v.9, p.48-58, 2015. https://doi.org/10.15202/1981996X.2015v9n2p48

Talebi, A.; Bagg, S.; Sleep, B. E.; O'carroll, D. M. Water retention performance of green roof technology: A comparison of canadian climates. Ecological Engineering, v.126, p.1-15, 2019. https://doi.org/10.1016/j.ecoleng.2018.10.006

Trombetta, L. J.; Turchetto, R.; Da Rosa, G. M.; Volpi, G. B.; Barros, S.; Da Silva, V. R. Resíduos orgânicos e suas implicações com o carbono orgânico e microbiota do solo e seus potenciais poderes poluentes. Brazilian Journal of Development, v.6, p.43996-44005, 2020. https://doi.org/10.34117/bjdv6n7-134

Wargent, J. J.; Jordan, B. R. From ozone depletion to agriculture: understanding the role of UV radiation in sustainable crop production. New Phytologist, v.197, p.1058-1076, 2013. https://doi.org/10.1111/nph.12132

Wells, T.; Hancock, G. R.; Martinez, C.; Dever, C.; Kunkel, V.; Gibson, A. Differences in soil organic carbon and soil erosion for native pasture and minimum till agricultural management systems. Science of the Total Environment, v.666, p.618-630, 2019. https://doi.org/10.1016/j.scitotenv.2019.02.097

Yeomans, J. C.; Bremner, J. M. A rapid and precise method for routine determination of organic carbon in soil. Communications in Soil Science and Plant Analysis, v.19, p.1467-1476, 1988. https://doi.org/10.1080/00103628809368027