

THE DYNAMICS OF SOIL ORGANIC CARBON IN THE CAATINGA: IMPACT OF EDAPHOCLIMATIC CHARACTERISTICS, DEGRADATION, AND VEGETATION REGENERATION

A DINÂMICA DO CARBONO ORGÂNICO NO SOLO DA CAATINGA: IMPACTO DAS CARACTERÍSTICAS EDAFOCLIMÁTICAS, DEGRADAÇÃO E REGENERAÇÃO VEGETAL

LA DINÁMICA DEL CARBONO ORGÁNICO DEL SUELO EN LA CAATINGA: IMPACTO DE LAS CARACTERÍSTICAS EDAFOCLIMÁTICAS, LA DEGRADACIÓN Y LA REGENERACIÓN VEGETAL



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ABSTRACT

The Caatinga, one of the most representative biomes in Brazil, occupies an extensive area in the Semi-arid region, characterized by severe edaphoclimatic limitations, such as a semi-arid climate, high temperatures, and shallow, low-fertility soils. Nevertheless, this biome has high ecological potential, especially in regulating the carbon cycle, being capable of storing

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organic carbon in the soil when its xerophilous vegetation is preserved. This book chapter explores the crucial interactions between vegetation cover, edaphoclimatic conditions, and the dynamics of soil organic carbon (SOC) in the Caatinga. It analyzes how irregular rainfall patterns, intense evapotranspiration, and poor soils influence carbon storage. It discusses the effects of anthropogenic pressure (deforestation and overgrazing), which accelerate degradation and transform the soil into a source of CO₂. In contrast, it highlights the strategic role of natural vegetation regeneration in restoring SOC stocks, soil fertility, and ecosystem resilience. The observations reinforce the need for sustainable management strategies for the conservation of native vegetation, essential for mitigating climate change and maintaining ecosystem services.

Keywords: Semi-arid Region. Xerophilous Vegetation. Ecosystem Services. Desertification. Biogeochemical Cycles.

RESUMO

A Caatinga, um dos biomas mais representativos do Brasil, ocupa extensa área no Semiárido, caracterizando-se por limitações edafoclimáticas severas, como o clima Semiárido, altas temperaturas e solos rasos de baixa fertilidade. No entanto, este bioma possui um elevado potencial ecológico, especialmente na regulação do ciclo do carbono, sendo capaz de estocar carbono orgânico no solo quando sua vegetação xerófila é preservada. Este capítulo de livro explora as interações cruciais entre a cobertura vegetal, as condições edafoclimáticas e a dinâmica do carbono orgânico do solo (COS) na Caatinga. Analisa como o regime de chuvas irregular, a intensa evapotranspiração e a pobreza dos solos influenciam a estocagem de carbono. Discute os efeitos da pressão antrópica (desmatamento e sobrepastoreio), que aceleram a degradação e transformam o solo em fonte de CO₂. Em contrapartida, evidencia o papel estratégico da regeneração natural da vegetação na recuperação dos estoques de COS, da fertilidade e da resiliência dos ecossistemas. As observações reforçam a necessidade de estratégias de manejo sustentável para a conservação da vegetação nativa, essencial para a mitigação das mudanças climáticas e a manutenção dos serviços ecossistêmicos.

Palavras-chave: Semiárido. Vegetação Xerófila. Serviços Ecossistêmicos. Desertificação. Ciclos Biogeoquímicos.

RESUMEN

La Caatinga, uno de los biomas más representativos de Brasil, ocupa una extensa área en el Semiárido, caracterizándose por limitaciones edafoclimáticas severas, como el clima semiárido, las altas temperaturas y los suelos poco profundos y de baja fertilidad. No obstante, este bioma posee un elevado potencial ecológico, especialmente en la regulación del ciclo del carbono, siendo capaz de almacenar carbono orgánico en el suelo cuando su vegetación xerófila es preservada. Este capítulo de libro explora las interacciones cruciales entre la cobertura vegetal, las condiciones edafoclimáticas y la dinámica del carbono orgánico del suelo (COS) en la Caatinga. Analiza cómo el régimen irregular de lluvias, la intensa evapotranspiración y la pobreza de los suelos influyen en el almacenamiento de carbono. Discute los efectos de la presión antrópica (deforestación y sobrepastoreo), que aceleran la degradación y transforman el suelo en una fuente de CO₂. En contraste, evidencia el papel estratégico de la regeneración natural de la vegetación en la recuperación de las reservas de COS, la fertilidad del suelo y la resiliencia de los ecosistemas. Las observaciones refuerzan la necesidad de estrategias de manejo sostenible para la conservación de la vegetación nativa, esencial para la mitigación del cambio climático y el mantenimiento de los servicios ecossistémicos.



Palabras clave: Semiárido. Vegetación Xerófila. Servicios Ecosistémicos. Desertificación. Ciclos Biogeoquímicos.

1 INTRODUCTION

The Caatinga is one of the most representative biomes in Brazil, occupying about 850,000 km² in the Northeast and parts of the Southeast, characterized by its xerophilous vegetation, semi-arid climate, and generally shallow soils with low natural fertility (Alves *et al.*, 2023). Even in the face of edaphoclimatic limitations, this biome has high ecological potential, especially in the regulation of biogeochemical cycles such as carbon, being able to store organic carbon in the soil when its vegetation is preserved (Giongo *et al.*, 2011; Montenegro *et al.*, 2020). From a climatic point of view, the Caatinga is located in a semi-arid region, characterized by high average annual temperatures, generally between 26 °C and 28 °C, and low and irregular rainfall, ranging from 300 mm to 800 mm per year (EMBRAPA, 2021; WWF-BRAZIL, 2024). The rainy season is usually short, concentrated in a few months, and followed by long periods of drought (Nagaishi, 2011). In addition, the region has high evapotranspiration rates, low relative humidity, and intense solar radiation (Moura *et al.*, 2023). These conditions pose significant ecological challenges, directly affecting soil biogeochemical processes and making Caatinga ecosystems highly vulnerable to environmental degradation (Menezes *et al.*, 2012).

The soils of the Caatinga, for the most part, are shallow, stony, with low water retention capacity and limited natural fertility, which compromises their intensive agricultural use and contributes to desertification when inadequately managed (Costa, 2012). Even so, these soils play a strategic role as carbon reservoirs, especially in the surface layers, as long as they are protected by vegetation cover. The presence of vegetation contributes to the incorporation of organic matter, improves soil structure, favors aggregate stability, and expands its infiltration and water retention capacity, reducing the risks of erosion and nutrient depletion (Sun *et al.*, 2024).

In this context, understanding the interactions between vegetation cover and soil organic carbon stocks is essential for the development of sustainable management strategies, especially in areas susceptible to degradation. As highlighted by Alves *et al.* (2021), the balance of the Semi-arid climate and the maintenance of the Caatinga's ecosystem services depend directly on the conservation of its native vegetation and the rational use of natural resources.

2 THE CAATINGA AND ITS EDAPHOCLIMATIC CHARACTERISTICS

Vegetation plays a central role in the stability of the Caatinga soils. Through litter deposition, root activity, and interactions with microorganisms, it contributes to the increase of soil organic matter, which is the main form of carbon storage in this environment (Giongo

et al., 2011). According to Montenegro *et al.* (2020), the continuous presence of vegetation promotes shading, reduces evaporation, and stabilizes soil temperature, creating a microenvironment conducive to the accumulation and conservation of organic carbon. The soils of the Caatinga, although initially poor in organic matter, demonstrate high resilience when managed in a conservationist manner, especially in areas where vegetation regenerates naturally (Santos *et al.*, 2019; Montenegro *et al.*, 2020).

Regarding the carbon cycle, it is known that the dynamics of organic carbon in the soil is determined by inputs of plant residues, root exudates and dead organisms, which are transformed and stabilized through microbial action (Giongo *et al.*, 2011; Lal, 2004). The accumulated organic matter can be mineralized and released as CO₂ or stabilized into more resistant humic forms. This dynamic is directly affected by the characteristics of land use, vegetation cover, and management practices adopted (Santos *et al.*, 2024). In studies conducted by Silva *et al.* (2024), it was observed that areas previously used as degraded pastures and that are in the process of regeneration with native vegetation of the Caatinga showed significant increases in carbon, nitrogen and phosphorus stocks in the soil, highlighting the role of natural regeneration in improving soil fertility and carbon sequestration.

The influence of vegetation on carbon dynamics is also observed in the quantity and quality of accumulated organic matter. Giongo *et al.* (2011) showed that areas under tree and shrub vegetation in the Caatinga had higher total carbon contents and a higher presence of stable carbon associated with the mineral fraction of the soil. This more stable carbon is crucial for maintaining soil fertility and for the resilience of ecosystems in the face of climate change. Plant diversity favors the constant entry of organic material with different chemical characteristics, which prolongs the decomposition time and, consequently, the permanence of carbon in the soil (Chen *et al.*, 2018; Zhang *et al.*, 2024).

However, intensive land use, especially deforestation and overgrazing, compromises this dynamic. According to Santos *et al.* (2024), soils from degraded areas show marked losses of organic matter, physical structure, and water retention capacity. This makes them more vulnerable to erosion and the desertification process. Santos *et al.* (2019) warns that the removal of vegetation directly exposes the soil to solar radiation and the impact of rainfall, accelerating the physical degradation and mineralization of organic matter. Under these conditions, the stored carbon is quickly converted into CO₂ and lost to the atmosphere, turning the soil into a source of greenhouse gases.

On the other hand, the natural regeneration of the Caatinga, that is, the spontaneous recovery of vegetation after the interruption of human activities, has proven to be an effective

strategy for ecological restoration. Silva *et al.* (2024) observed that after a few years of regeneration, there is an increase in root density, soil cover, and carbon content in the light fraction of organic matter. Pessoa *et al.* (2022) found that regeneration promotes the recomposition of microbial activity and the formation of stable aggregates, which protect organic carbon against degradation.

These observations reinforce the strategic role of vegetation in mitigating climate change and recovering soil ecosystem services. The process of natural regeneration is, therefore, an opportunity to recompose lost ecological functions, with low cost and high potential for environmental return. Pessoa *et al.* (2022) also highlights that the regeneration time directly influences the quality of accumulated organic matter. In more advanced stages, there is a greater presence of recalcitrant carbon, which is difficult to decompose, which contributes to the stability of stocks in the long term.

Finally, the scientific literature reveals that carbon stocks in the Caatinga soil are directly related to the type and degree of vegetation cover. Studies such as those by Silva *et al.* (2024) and Santos *et al.* (2024) quantify these differences, pointing to average increases of more than 50% in carbon (C) stocks in areas with regenerated vegetation. Santos (2020) and Giongo (2011) reinforce that the structural and functional diversity of vegetation is directly associated with the complexity of soil organic matter. Montenegro (2020) warns that the absence of public policies aimed at the conservation of the Caatinga tends to aggravate carbon loss, harming not only the environment, but also the food security of local communities.

These authors, such as Santos *et al.* (2020, 2024), Silva *et al.* (2024), Pessoa *et al.* (2022), Giongo *et al.* (2011) and Montenegro (2023) make up the theoretical basis that underlies the present study, whose proposal is to investigate how the presence of vegetation influences the amount and stability of organic carbon in the Caatinga soil. Understanding these processes is essential to guide conservation strategies and sustainable use of the biome in the face of global environmental changes.

3 CARBON DYNAMICS IN THE CAATINGA SOIL

The carbon cycle in the soil involves the entry of organic material (plant residues, dead roots, root exudates) and its decomposition by microorganisms. Some of this carbon is stabilized in the form of humus, while another part is released as carbon dioxide (CO₂) in microbial respiration. The capacity to store carbon in the soil depends on factors such as texture, clay content, water regime and, especially, the presence of vegetation (Santos *et al.*, 2024).

According to Silva *et al.* (2024), the natural regeneration of the Caatinga promotes the increase of organic carbon in the soil due to the continuous deposition of litter and the reduction of erosion. The formation of shaded microenvironments and the lower thermal oscillation favor biological activity and the incorporation of organic matter into the soil.

Vegetation acts as the main source of organic matter in the soil. Through root growth, leaf fall and the death of plant organisms, there is a constant contribution of carbon to the surface and interior of the soil. In Caatinga soils, this dynamic is particularly sensitive to changes in land use.

Giongo *et al.* (2011) demonstrated that areas with native vegetation maintain significantly higher levels of total soil carbon compared to degraded areas. The diversity of plant species and the permanence time of vegetation are associated with greater complexity of organic matter, which favors its stability. Deforestation, overgrazing and unsustainable agricultural use are common practices in the semi-arid region, which lead to soil degradation. This degradation results in loss of organic matter, compaction, reduced soil biodiversity, and decreased water retention capacity (Santos *et al.*, 2024).

Santos *et al.* (2020) highlights that the removal of vegetation cover exposes the soil to the direct action of climatic agents, promoting erosion and leaching of nutrients. Under these conditions, organic carbon is mineralized more quickly, decreasing inventories and increasing CO₂ emissions.

Studies indicate that, after the interruption of degrading activities, it is possible to observe the gradual recovery of vegetation and carbon stocks. This process of natural regeneration, when well conducted, can result in significant improvements in the physical, chemical, and biological attributes of the soil (Silva *et al.*, 2024).

According to Pessoa *et al.* (2022), areas in the process of regeneration show an increase in carbon associated with the light fraction of organic matter, in addition to a higher density of fine roots and stable aggregates. The continuous presence of vegetation reduces the thermal amplitude of the soil, promoting environments more conducive to the accumulation of organic matter.

Recent research has highlighted the centrality of native vegetation in the maintenance of organic carbon stocks in Caatinga soils. Silva *et al.* (2024) demonstrate that areas with natural regeneration accumulate, on average, 50% more carbon than areas with degraded pasture. Santos *et al.* (2024), in turn, associate carbon loss with the level of anthropogenic intervention in landscapes.

Santos *et al.* (2024) reinforces that the abandonment time and the degree of ecological connectivity are key factors for the success of regeneration. Giongo *et al.* (2020) points out

that soils with perennial shrub vegetation have a higher stable carbon fraction. Pessoa *et al.* (2022) observes that the organic matter associated with the clay fraction tends to be preserved for a longer time in soils under vegetation. Zhang *et al.* (2024) emphasizes that the structural quality of the soil improves significantly after the recovery of the vegetation cover, favoring the retention of water and nutrients.

4 SEMI-ARID X CAATINGA

The Caatinga biome, entirely located in the Brazilian semi-arid region, has a set of peculiar climatic characteristics that make it one of the most challenging ecosystems from an ecological point of view. Among these aspects are the irregular and concentrated distribution of rainfall, the high average annual temperatures, ranging between 26 °C and 28 °C, the high evapotranspiration rates (often exceeding 2,000 mm/year) and the extensive periods of drought that affect most of the year (Silva *et al.*, 2024; Moura *et al.*, 2023). Due to these conditions, the Caatinga aridity index is among the lowest in South America, which defines an environment with chronic water deficit and intense limitation to primary productivity (Brito *et al.*, 2021).

Such constant water restrictions act as the main selective force on vegetation, conditioning the occurrence of species with specific physiological and morphological adaptations. Strategies such as deciduousness, tissue thickening, diurnal stomatal closure, the presence of trichomes, and water storage capacity in underground structures or stems are widely observed in the predominant species (Nascimento *et al.*, 2023; Lima *et al.*, 2022; Accioly *et al.*, 2024). The vegetation of the Caatinga, therefore, expresses a functional structure shaped by millennia of selection under water scarcity, being composed mostly of woody plants, with a discontinuous canopy and great heterogeneity of life forms (Araújo and Albuquerque, 2024; Sousa *et al.*, 2022).

The distribution of rainfall in the Caatinga is generally concentrated between the months of February and May, which configures an intense seasonality that regulates ecological cycles, energy flows and the dynamics of chemical elements, such as carbon. This pattern directly influences the processes of carbon input and output in both biomass and soil, since the peaks of plant production and decomposition are concentrated in this short rainy interval (Almeida *et al.*, 2023). Seasonal rainfall also conditions the germination, growth and senescence of vegetation, resulting in marked fluctuations in the amount of organic matter incorporated into the soil throughout the year.

Despite its uniqueness and ecological relevance, the Caatinga remains among the most threatened biomes in the Brazilian territory. The intense anthropogenic pressure,

resulting from deforestation for energy use (firewood and charcoal), the expansion of extensive cattle ranching, subsistence agriculture, mining, and the recurrence of fires has caused rapid environmental degradation (Alves *et al.*, 2023; Medeiros *et al.*, 2021). These factors act directly on the structural simplification of vegetation, the loss of biodiversity and the reduction of carbon stocks in biomass and soil.

According to recent data from the Ministry of the Environment (MMA, 2024), approximately half of the original vegetation cover of the Caatinga has already been suppressed or altered, and it is common to find extensive areas in advanced processes of degradation and desertification. These degraded territories have intense laminar erosion, soil compaction, loss of organic matter, and a drop in productive capacity, which compromises the ecosystem services provided by the biome (Ferreira *et al.*, 2023). Reducing organic carbon in the soil, in particular, harms the natural fertility and structure of the soil, as well as contributing to increased greenhouse gas emissions.

In addition to deforestation, inadequate soil management, such as the use of plowing in sensitive areas and overgrazing, have accelerated degradation processes. Practices such as these lead to surface soil sealing, promote reduced water infiltration, increased salinization, and decreased carbon retention capacity (Guimarães *et al.*, 2023; Lima *et al.*, 2022). As a result, areas that previously functioned as carbon sinks now act as sources, intensifying the release of CO₂ into the atmosphere.

The vulnerability of the Caatinga is even more pronounced when considering the context of global climate change. The increase in average temperatures, associated with the greater frequency and intensity of extreme events, such as prolonged droughts, represents a growing threat to the ecological stability of the region (IPCC, 2023; Nobre *et al.*, 2024). According to projections from medium- and long-term climate models, a reduction of up to 40% in annual precipitation is expected in parts of the northeastern semi-arid region, with direct implications for the regenerative capacity of vegetation and soil resilience (Nobre *et al.*, 2024; Rodrigues *et al.*, 2022).

This combination of environmental degradation and climate change can establish negative feedback loops, in which the loss of vegetation cover and the consequent exposure of the soil promote a rapid mineralization of organic matter, releasing carbon that was previously stored. This phenomenon further aggravates the region's carbon balance and contributes to the increase in greenhouse gas emissions (Guimarães *et al.*, 2023; Ferreira *et al.*, 2023). Understanding these processes becomes fundamental for the development of public policies for conservation and ecological restoration, as well as for planning the sustainable use of the natural resources of the Caatinga.

5 CONCLUSION

The scientific literature shows that the organic carbon stocks in the Caatinga soil are directly conditioned by the edaphoclimatic characteristics and, mainly, by the conservation status of the vegetation cover. Vegetation represents the main route of carbon entry into the soil, promoting structural stability, increasing organic matter and maintaining fertility.

Degrading practices such as deforestation, overgrazing, and inappropriate agricultural use intensify the mineralization of organic matter, reduce carbon stocks, and accelerate erosion and desertification processes, turning soils into sources of CO₂ emissions. On the other hand, the natural regeneration of the Caatinga demonstrates high potential in the recovery of the physical, chemical and biological attributes of the soil and in the increase of carbon stocks, with increases of more than 50% compared to degraded areas.

In the face of the advance of climate change and anthropogenic pressure on the biome, it is essential to implement public policies aimed at the conservation, sustainable use of natural resources and the ecological restoration of the Caatinga. The understanding of soil carbon dynamics, associated with the conservation of native vegetation, is one of the main ways to mitigate greenhouse gas emissions and to the environmental and socioeconomic sustainability of the Brazilian semi-arid region.

REFERENCES

- Accioly, A. do N., Farias, R. de P., & Arruda, E. C. P. de. (2024). Plants in the Caatinga possess multiple adaptative leaf morphoanatomical traits concurrently, a pattern revealed from a systematic review. *Journal of Arid Environments*, 222, Article 105162. <https://doi.org/10.1016/j.jaridenv.2024.105162>
- Almeida, T. S., et al. (2023). Dinâmica hídrica e ciclagem biogeoquímica em ecossistemas semiáridos: Implicações para o carbono no solo. *Revista Brasileira de Ecologia e Sustentabilidade*, 8(1), 32–46.
- Alves, C. M., et al. (2023). Pressões antrópicas e degradação ambiental no bioma Caatinga: Uma análise regionalizada. *Revista GeoNordeste*, 34(2), 120–134.
- Araújo, E. L., & Albuquerque, U. P. (2024). Vegetação e diversidade funcional da Caatinga: Uma abordagem ecofisiológica. *Acta Botanica Brasilica*, 38, 1–12.
- Brito, L. T. L., et al. (2021). Aridez e vulnerabilidade ambiental na Caatinga: Avaliação do índice de aridez e implicações para a desertificação. *Cadernos de Geografia*, 31(2), 130–147.
- Chen, W. S., Wang, W., Xu, Y., Wang, H., Wan, D., Chen, Z., Tang, X., Tang, G., Zhou, Z., Xie, D., Zhou, Z., Shangguan, J., Huang, J., He, Y., Wang, J., Sheng, L., Tang, X., Li, M., Dong, Y., Wu, Q., Wang, Z., Wang, J., Wu, F. S., Chapin, & Bai, Y. (2018). Plant diversity enhances productivity and soil carbon storage. *Proceedings of the National Academy of Sciences of the United States of America*, 115(16), 4027–4032. <https://doi.org/10.1073/pnas.1700298114>

- Costa, C. A. G. da. (2012). *Umidade do solo e disponibilidade hídrica na zona das raízes em condições naturais de Caatinga preservada* [Tese de doutorado, Universidade Federal do Ceará]. <https://repositorio.ufc.br/handle/riufc/18822>
- Embrapa. (2021). Temperatura e umidade relativa - Bioma Caatinga. Agência Embrapa de Informação Tecnológica. <https://www.embrapa.br/agencia-deinformacao-tecnologica/tematicas/bioma-caatinga/clima/temperatura-e-umidade-relativa>
- Ferreira, M. F., et al. (2023). Serviços ecossistêmicos e estoques de carbono em ambientes semiáridos sob degradação. *Ciência e Sustentabilidade*, 10(1), 85–99.
- Giongo, V., et al. (2011). Estoques de carbono no solo em diferentes sistemas de uso da terra no semiárido brasileiro. *Revista Brasileira de Ciência do Solo*, 35, 1141–1149.
- Giongo, V., et al. (2020). Optimizing multifunctional agroecosystems in irrigated dryland agriculture to restore soil carbon - Experiments and modelling. *Science of the Total Environment*, 725, Article 138072. <https://doi.org/10.1016/j.scitotenv.2020.138072>
- Giongo, V., et al. (2011). Carbono no sistema solo-planta no Semiárido Brasileiro. *Revista Brasileira de Geografia Física*, 6, 1233–1253. www.alice.cnptia.embrapa.br/alice/bitstream/doc/923066/1/Vanderlise2011.pdf
- Guimarães, A. G., et al. (2023). Mudanças climáticas e perdas de carbono em solos do semiárido: Revisão crítica e perspectivas. *Revista Ciência do Solo e Clima*, 5(3), 201–214.
- Intergovernmental Panel on Climate Change. (2023). *AR6 synthesis report: Climate change 2023*. IPCC.
- Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1–2), 1–22. <https://doi.org/10.1016/j.geoderma.2004.01.032>
- Lima, J. F., & Gomes, T. R. (2022). Estratégias adaptativas da flora semiárida: Respostas fisiológicas à limitação hídrica. *Biodiversidade Brasileira*, 12(1), 49–61.
- Medeiros, R. A., et al. (2021). Dinâmica do uso da terra e seus efeitos sobre a vegetação da Caatinga. *Sociedade & Natureza*, 33(1), 1–20.
- Menezes, R., Sampaio, E., Giongo, V., & Pérez-Marin, A. (2012). Biogeochemical cycling in terrestrial ecosystems of the Caatinga Biome. *Brazilian Journal of Biology*, 72(3), 643–653. <https://doi.org/10.1590/S1519-69842012000400004>
- Ministério do Meio Ambiente. (2022). *Bioma Caatinga: Caracterização e importância ecológica*. <http://www.mma.gov.br>
- Ministério do Meio Ambiente. (2024). *Relatório sobre a Situação Ambiental dos Biomas Brasileiros*.
- Montenegro, A. A. A., et al. (2020). Solos e desertificação no Semiárido brasileiro: Causas, consequências e estratégias de combate. *Revista Brasileira de Geografia Física*, 13(2), 670–686.
- Moura, A. C., et al. (2023). Padrões climáticos da Caatinga: Variação térmica e precipitação nas últimas três décadas. *Climatologia Brasileira*, 17(2), 55–70.
- Nagaishi, C. (2011). Ambientes da Caatinga. *Blog Nagaishi Caatinga*. <https://nagaishicaatinga.blogspot.com/>
- Nascimento, A. P., et al. (2023). Fisiologia vegetal em ambientes semiáridos: Adaptações em espécies da Caatinga. *Revista Brasileira de Fisiologia Vegetal*, 35(1), 88–102.

- Nobre, C. A., et al. (2024). Projeções climáticas para o Nordeste brasileiro e os desafios da adaptação. *Revista Brasileira de Meteorologia*, 39(1), 23–39.
- Pessoa, L. G. M., et al. (2022). Estabilidade dos agregados e carbono orgânico em solos sob diferentes coberturas vegetais da Caatinga. *Revista de Ciências Ambientais*, 16(2), 113–124.
- Pessoa, V. G., Guiselini, C., Montenegro, A. A. de A., Pandorfi, H., Barbosa Filho, J. A. D., & Vicente, T. F. da S. (2022). Carbon sequestration by plant species used in green roofs across different periods. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 26(6), 407–411. <https://doi.org/10.1590/1807-1929/agriambi.v26n6p407-411>
- Rodrigues, R. F., et al. (2022). Simulações climáticas e cenários futuros de precipitação na Caatinga. *Meteorologia e Sustentabilidade*, 7(2), 117–131.
- Santos, U. J. dos, Duda, G. P., Marques, M. C., Valente de Medeiros, E., de Sousa Lima, J. R., Soares de Souza, E., ... Hammecker, C. (2019). Soil organic carbon fractions and humic substances are affected by land uses of Caatinga forest in Brazil. *Arid Land Research and Management*, 33(3), 255–273. <https://doi.org/10.1080/15324982.2018.1555871>
- Santos, W. R. dos, et al. (2024). Carbon and nutrient dynamics in landscapes under different levels of anthropogenic intervention in the semiarid region of Brazil. *Agriculture, Ecosystems & Environment*, 368, Article 109020. <https://doi.org/10.1016/j.agee.2024.109020>
- Silva, L. F. D. S., et al. (2024). Alterações nas concentrações e estoques de C, N e P no solo após a regeneração natural da Caatinga sobre área de pastagem degradada. *Preprints*. <https://doi.org/10.20944/preprints202406.1883.v1>
- Sousa, C. M., et al. (2022). Estrutura da vegetação lenhosa em áreas de Caatinga com diferentes graus de antropização. *Revista Biociências*, 18(1), 44–59.
- Sun, Y., Wang, X., Zhang, Y., Duan, W., Xia, J., Wu, J., & Deng, T. (2024). Vegetation types can affect soil organic carbon and $\delta^{13}\text{C}$ by influencing plant inputs in topsoil and microbial residue carbon composition in subsoil. *Sustainability*, 16, Article 4538. <https://doi.org/10.3390/su16114538>
- WWF-Brasil. (2024). Caatinga. https://www.wwf.org.br/natureza_brasileira/questoes_ambientais/biomas/bioma_caatinga/
- Zhang, J.-R., Duan, X.-Y., Lan, T.-X., Surigaoge, Surigaoge, Liu, L., Guo, Z.-Y., Lü, H.-R., Zhang, W.-P., & Li, L. (2024). Advances in the role of plant diversity in soil organic carbon content and stability. *Chinese Journal of Plant Ecology*, 48(11), 1393–1405. <https://www.plant-ecology.com/EN/10.17521/cjpe.2023.0370>