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Research paper

Influence of positioning on the adaptability of vegetation in an experimental rain garden in a tropical urban environment

Influência do posicionamento na adaptabilidade de vegetação em jardim de chuva experimental em ambiente tropical urbano

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ABSTRACT*:* Rain gardens have emerged as an alternative in stormwater management through infiltration and retention of precipitation on-site. The current literature shows a lack of studies evaluating the vegetation development processes in rain gardens and plant species exhibit better adaptation to the system, especially in tropical climate regions. In this context, this article aims to assess the influence of vegetation positioning on the adaptability of four native tropical climate species, namely, Mexican petunia (*Ruellia simplex*), song of India (*Dracaena reflexa*), spider plant (*Chlorophytum comosum*), and snake plant (*Sansevieria trifasciata*). For this purpose, plant growth was monitored biweekly for one year through measurements of height and diameter of the species cultivated in an experimental rain garden on a field scale. Analysis of Variance (ANOVA) was applied to verify the effect of plant location within the bioretention cell, evaluating whether certain microenvironments or specific positions favor or inhibit the species' development. Additionally, spatial distribution analysis of soil organic matter was conducted to assess potential heterogeneity in nutrient distribution. The evaluated species exhibited good adaptability, showing healthy morphological appearance and satisfactory growth. No statistically significant difference was identified in the interspecies growth rate in the monitored rain garden.

Keywords*:* Bioretention, plant growth, organic matter, nature-based solutions.

RESUMO: Os jardins de chuva surgiram como alternativa para o manejo de águas pluviais através de infiltração e retenção de volumes de água precipitada no local. A literatura vigente apresenta carência de estudos que avaliem processos de desenvolvimento da vegetação em jardins de chuva e quais espécies vegetais apresentam melhor adaptação ao sistema, especialmente em regiões de clima tropical. Neste contexto, este artigo visa avaliar a influência do posicionamento da vegetação na adaptabilidade de quatro espécies nativas de clima tropical: petúnia mexicana (*Ruellia simplex*), dracena-malaia (*Dracaena reflexa),* clorofito (*Chlorophytum comosum*) e espada-de-são-jorge (*Sansevieria trifasciata*). Para isso, monitorou-se quinzenalmente o crescimento vegetal durante um ano, por meio de medidas de altura e diâmetro das espécies cultivadas em um jardim de chuva experimental implantado em escala de campo. A Análise de Variância (ANOVA) foi aplicada para verificar o efeito da localização das plantas dentro da célula de biorretenção, avaliando se determinados microambientes ou posições específicas favorecem ou inibem o desenvolvimento das espécies. Além disso, análise da distribuição espacial da matéria orgânica do solo foi conduzida com o intuito de avaliar a potencial de heterogeneidade na distribuição de nutrientes. As espécies avaliadas exibiram boa adaptabilidade, apresentando aparência morfológica saudável e crescimento satisfatório. Não foi identificada uma diferença estatisticamente significante na taxa de crescimento interespécies no jardim de chuva monitorado.

Palavras-chave: Biorretenção, crescimento vegetal, matéria orgânica, soluções baseadas na natureza.

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INTRODUCTION

Increasing urbanization, combined with disorderly population growth, has resulted in serious environmental consequences, including excessive soil impermeability, inadequate occupation of water resource protection areas, deforestation, river channeling and increased solid waste disposal in water bodies. These impacts contribute significantly to the intensification of flooding events during periods of heavy rainfall, causing substantial material, human and environmental damage and compromising the quality of life of the affected population (Christofidis; Assumpção; Kligerman, 2019).

The growing vulnerability of urban areas to flooding cannot be ascribed solely to climate change. Silva Junior *et al*. (2020) pointed out that this phenomenon has also been worsened by the population growth, poor urban planning, and the improper government management. Tucci and Bertoni (2003) explained that disorderly urbanization, which concentrates large populations in specific regions, worsens the problem of excess surface runoff, historically treated with the installation of drainage networks. However, these traditional solutions often transfer the problem to more vulnerable areas, mainly in the downstream portion of river basins, creating challenges instead of effectively solving them (Tucci; Bertoni, 2003;Tucci; Porto; Barros, 1995).

The population spatial distribution also influences directly their socioenvironmental vulnerability, since their social position determines their exposure to associated risks (Girão *et al*., 2018). Given these challenges posed by accelerated urbanization, it is crucial to explore strategies that can mitigate its adverse impacts (Oliveira, 2021).

Among the emerging alternatives, Compensatory Drainage Techniques stand out, aiming to replicate natural processes of infiltration, evapotranspiration, retention and storage (Davis, 2008). In this context, bioretention systems, particularly rain gardens, gain relevance. These systems play a fundamental role in the management of urban stormwater, while contributing to landscaping and promoting ecological benefits (Dietz; Clausen, 2006).

The vegetation used in rain gardens is essential for nutrient recycling and pest and disease control, especially when native species are chosen, which are generally more adapted to the local environment and require less use of chemical inputs (Gobat *et al*., 2004). However, these plants must be able to tolerate extreme conditions, such as periods of flooding and water scarcity. Species that are sensitive to seasonal variations in rainfall may suffer physiological disorders, such as root hypoxia or anoxia, resulting in reduced photosynthesis, growth inhibition and leaf wilting (Oliveira; Gualtieri, 2017).

Vegetation plays a relevant role in rain gardens, once they contribute to the increase in soil infiltration rate, causing the appearance of macropores and preferential flow. Some of the main interactions are related to the influence of plant roots on the arrangement of soil pores, which has consequences for infiltration and storage capacity (Skorobogatov *et al*., 2020).

Proper selection of plant species, considering their morphology and environmental conditions, as well as the arrangement of these plants within the rain garden, is essential to achieve a balance between the functionality of the system and plant health (Greksa *et al*., 2023). However, the current literature presents gaps regarding the identification of plant species most adaptable to rain gardens and the influence of positioning, especially in tropical climate regions (Chaves *et al.*, 2024).

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Considering this context, this article aims to evaluate the adaptability of four tropical climate native species (*Sansevieria trifasciata, Chloropytum comosum, Ruellia simplex* and *Dracaena reflexa*) and the influence of their positioning in an experimental rain garden, installed on a field scale on a campus of the Federal Institute of Education, Science and Technology of Ceará.

Snake plant (*S. trifasciata*) is a rhizomatous geophyte native to Africa that grows mainly in the seasonally dry tropical biome (Lorenzi, 2015). *C. comosum*, popularly known as spider plant, is a small herbaceous plant that resembles grass and is native to South Africa. Its size varies from 15 to 20 cm in height and is cultivated in subtropical areas and in partial shade (Lorenzi, 2015). Mexican petunia (*R. simplex*), according to Ezcurra and Daniel (2007), is a species from the neotropical region that develops best in humid environments and is resistant to flooding. Song of India (*D. reflexa*) is a tropical plant with moderate growth that presents a defense mechanism when exposed to flooding (Yang *et al*., 2024).

This research seeks to contribute to the evaluation of such compensatory technology in tropical climate regions, where studies are scarce, by providing input for the sustainable management of urban rainwater in those regions.

MATERIAL AND METHODS

STUDY AREA

The species under study were planted in a rain garden located on the Fortaleza campus of the Federal Institute of Ceará. The rain garden has an area of 4.24 m², which receives surface runoff from roofs with an effective contribution area of approximately 180 m² (**Figure 1**). From bottom to top, it contains 15 cm of medium sand, which will have the function of filtering the water, serving as a transition between the rain garden system and the natural soil; 43 cm of type 2 gravel, used as an internal reservoir for the water infiltrated into the system; an RT10 geotextile blanket, to prevent the material from the upper layer from passing into the storage area, acting to prevent its clogging; 45 cm of planting soil, which will allow the development of vegetation in the garden and a 40 cm puddle layer, which will allow the formation of a superficial layer of water during rainfall events, increasing the storage capacity of the garden and reducing the possibility of water overflow.

The planting soil of the surface layer was classified as sandy loam according to the triangular diagram of textural classes proposed by the USDA. This soil is mainly composed of sandy material, corresponding to 82% of its composition (11% fine sand, 55% medium sand and 16% coarse sand), with approximately 12% of fine materials (silt and clay) and 6% gravel. Other soil features included: 31% porosity, 2.63 g/cm^3 specific particle mass, and 1.81 g/cm^3 apparent specific dry mass.

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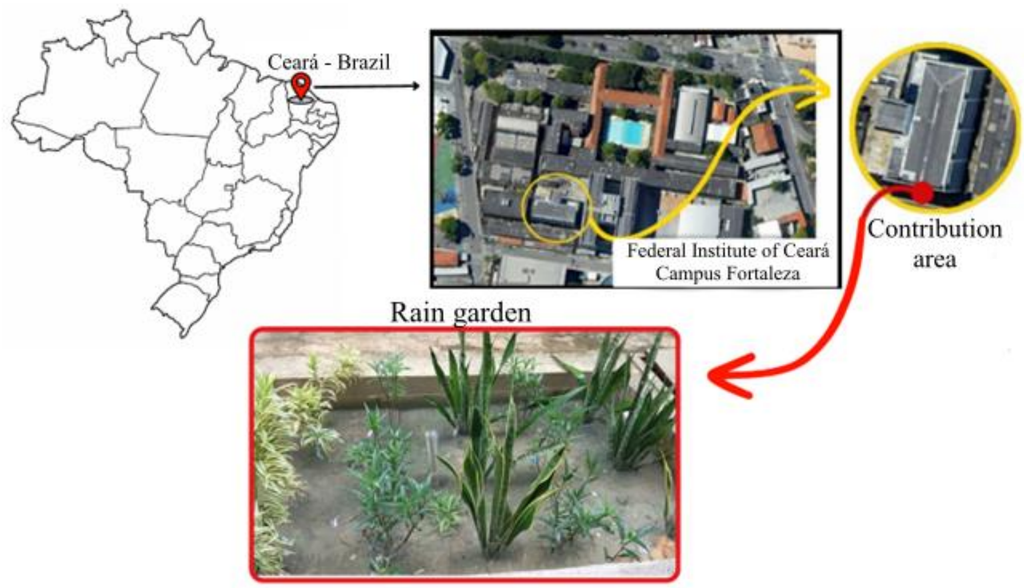
Figure 1. Location of the study area



SPECIES STUDIED

The following species were planted on the rain garden surface layer: Snake plant (*S. trifasciata*), also used by Aguirre-Álvarez (2023), Akther (2020), Lopes and Silva (2021), Moura (2013) and Macedo *et al*. (2017) in rain gardens; Spider plant (*C. comosum*), also employed by Fensterseifer (2020), Li *et al*. (2016), Pivetta, Tassi and Piccilli (2023), and Yang *et al*. (2024) in bioretention; Mexican petunia (*R. simplex*), used by Silva (2016), Li and Liu (2023), and Yan *et al*. (2023); and Song of India (*Dracaena reflexa*), found in studies by Galagoda *et al*. (2018), Hunt *et al*. (2015), and Macedo *et al*. (2022). Snake plant, spider plant, and Mexican petunia were also used by the city hall of Belo Horizonte and São Paulo in rain gardens installed in public areas (**Figure 2**).

When selecting the plants, we prioritized popularly grown species that already existed on campus to prevent rejection to the local ecosystem and make the planting, plant management and plant behavior analysis simpler and easier.

The species were distributed in the rain gardens as indicated (**Figure 3**), where "E" is the snake plant, "C" is the spider plant, "R" is the Mexican petunia, and "D" is the song of India.

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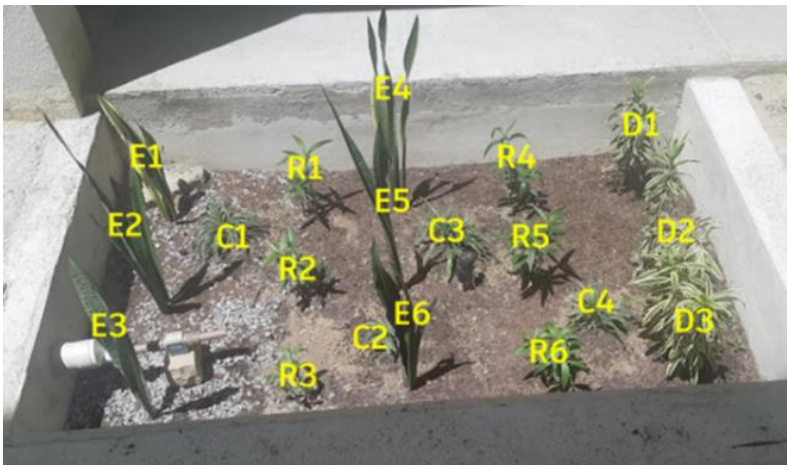
Figure 2. Rain gardens (*Jardim de chuva*) in Belo Horizonte and São Paulo using the species *Sansevieria trifasciata*, *Chloropytum comosum* and *Ruellia simplex*

Figure 3. Positioning of the vegetation in the rain garden, where "E" is the snake plant, "C" is the spider plant, "R" is the Mexican petunia, and "D" is the song of India



MONITORING

In order to monitor the development of the species planted in the rain garden and assess whether they can withstand water stress due to seasonal rainfall, measurements were taken of the height of the four species studied and the perimeter of the stems of the song of India and Mexican petunia species. Monitoring began in April 2023, when they were planted and continued until May 2024.

Height measurements were taken using a tape measure, from the soil surface to the highest apical bud of the plant, and with a caliper, to measure the diameter of the stems, at their thickest part.

Measurements were taken every 15 days, depending on the growth observed. In addition, an analysis was carried out based on the construction of monitoring graphs

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according to the standards considered.

The rainfall data was obtained using a Vantage Vue Davis Weather Station installed on campus, located around 65m from the contribution area.

ORGANIC MATTER DISTRIBUTION ANALYSIS

Six equidistant soil samples were collected on the surface of the rain garden to determine the organic matter content. The soil organic matter content was estimated by the burning method at 440°C, as described in NBR 13600 (ABNT, 2022).

STATISTICAL ANALYSIS

Analysis of Variance (ANOVA) was used to assess the differences in development between plant species within the bioretention cell, as well as to analyze the impact of spatial positioning within the structure on plant growth. This statistical method allowed us to identify whether there were statistically significant differences in daily growth rate values between the four species studied, both for height and diameter.

In addition, the analysis considered the effect of the location of the plants within the bioretention cell, allowing us to assess whether certain microenvironments or specific positions favor or inhibit the development of the species. This statistical approach allows for a more in-depth understanding of the interactions between the variables studied, contributing to the identification of growth patterns that may be influenced by both the intrinsic characteristics of the species and their positioning within the system.

RESULTS AND DISCUSSIONS

LOCAL PRECIPITATION ANALYSIS

The time interval analyzed (March 2023 to May 2024) included a period of concentrated rainfall from March to May 2023 and from February 2024 to May 2024. Figure 04 shows the hyetogram corresponding to the period under analysis.

The graphic representation (**Figure 4**) is in line with the information collected by Zanella and Sales (2016), which indicate that approximately 70% of the rainfall in the city of Fortaleza occurs between February and May. During this period, concentrated rainfall events with values greater than 100 mm/day are frequently observed.

The period of concentrated rainfall coincides with the period of lowest solar irradiance rates. According to Carvalho, Oliveira and Aguiar Junior (2008), March and April have the highest rates of irradiance variability, thus becoming the months with the lowest average values of irradiance collected on the earth's surface. On the other hand, September and October are characterized by higher values and lower variability of solar irradiance.

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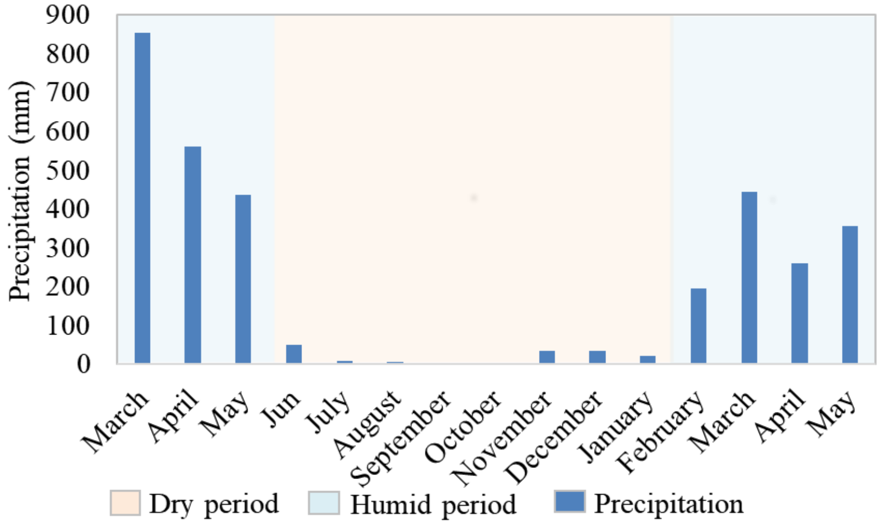
Figure 4. Hyetogram of the period analyzed (March/2023-May/2024)



STATISTICAL ANALYSIS

The values presented in **Table 1** show that no significant statistical difference was found in the growth rate regarding the height measurements of three of the species monitored in the bioretention cell (snake plant, mexican petunia and spider plant), all with p-value > 0.05.

Table 1. Interspecies variance analysis (ANOVA) of growth rate (height) referring to the four monitored species

	Species	Mean growth rate (mm/day)	Standard deviation	P-Value
Snake plant	E1	1.12	1.60	0.84
	E2	0.63	1.07	
	E3	0.83	0.98	
	E4	0.45	1.17	
	E5	0.85	1.61	
	E6	0.88	2.02	
Mexican petunia	R1	0.45	0.12	0.80
	R2	0.53	0.31	
	R3	0.53	0.33	
	R4	0.55	0.35	
	R5	0.43	0.21	
	R6	0.48	0.27	
Spider plant	C1	0.05	0.14	0.24
	C2	0.62	1.10	
	C3	0.55	1.01	
	C4	0.62	0.78	
Song of India	D1	0.16	0.17	0.04
	D2	0.13	0.11	
	D3	0.06	0.06	

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Regarding the song of India species, a significant difference was identified in the growth rate (height) of individual D3, which at the end of the monitoring period showed a cumulative growth of 24 cm, while its pairs D1 and D2 obtained a growth of 53.0 cm and 46.5 cm, respectively. However, due to the positioning of the plants, this difference in interspecies growth was probably not caused by the dynamics of the rain garden.

As for the diameter growth rates (**Table 2**), no statistically significant difference was found in the species evaluated, Mexican petunia and song of India.

The results of this analysis show that the effect of the location of the plants within the bioretention cell did not favor or inhibit the development of the species selected in the context of this study.

Table 2. Interspecies variance analysis (ANOVA) of growth rate (diameter) referring to the monitored species

	Species	Mean growth rate (mm/day)	Standard deviation	P-Value
Mexican petunia	R1	0.05	0.09	0.93
	R2	0.03	0.04	
	R3	0.04	0.07	
	R4	0.04	0.08	
	R5	0.04	0.07	
	R6	0.03	0.05	
Song of India	D1	0.01	0.01	0.67
	D2	0.01	0.02	
	D3	0.01	0.02	

This suggests that there was no substantial difference in the availability of moisture and nutrients that caused differential growth. According to Champagne-Caron *et al*. (2024), species can vary in their physiological ability to adapt to different levels of light, water and nutrients, which may explain the lack of relationship between growth and the position of the individual in the experiment.

In general, no significant differences in height and diameter were observed between individuals of the species located in the regions closest and furthest from the water inlet. This suggests that there was no substantial difference in the availability of moisture and nutrients that caused differential growth. The same behavior was reported in the study by Muerdter et al. (2016) for the species *Eutrochium dubium*, *Solidago rugosa*, *Cephalanthus occidentalis*, *Lobelia sifilítica* and *Cornus amomum* installed in a bioretention system. Champagne-Caron et al. (2024) also indicated that the plant survival rate was not affected by the location, however, growth was more pronounced in the sloping positions, where there was a higher concentration of moisture. Bortolini and Zanin (2018) also identified the influence of humidity on the growth of the species *Echinacea purpúrea*, *Iris pseudacorus*, *Carex buchananil*, *Rudbeckia fulgida*, *Aster novi-beigil*, *Molínia caerulea*, *Bernenia purpurescens*, *Hemerocallis hybrida* and *Lythrium salicaria* in rain gardens.

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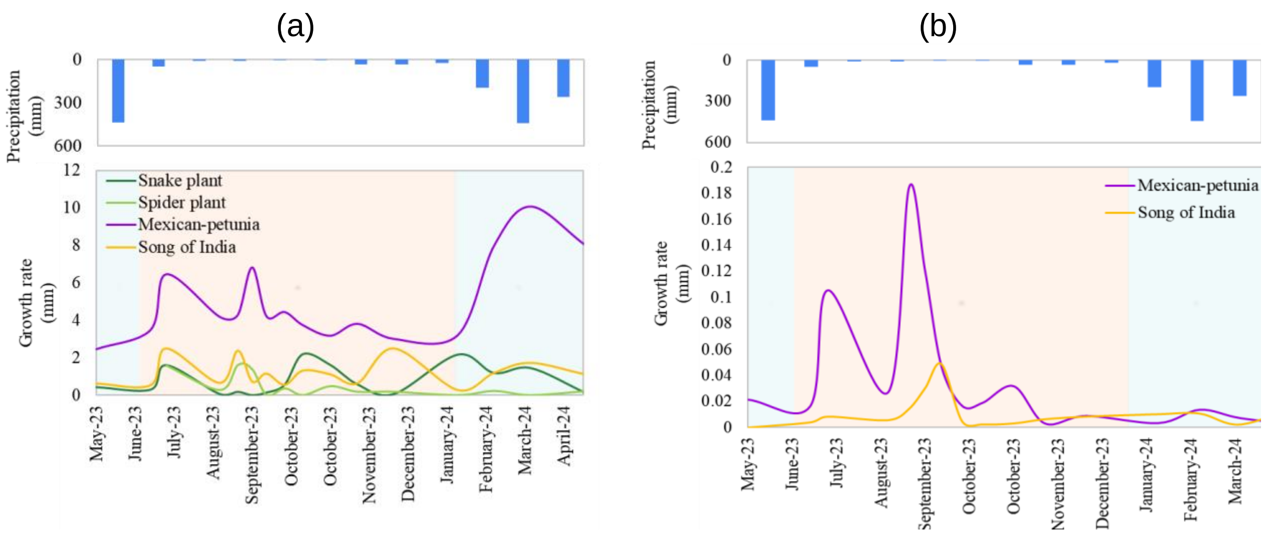
PLANT GROWTH ANALYSIS

The city of Fortaleza presents relatively stable temperatures all over the year, with slight variations. Therefore, the analysis of the influence of these weather parameters in the development of the species under study might be considered of little relevance. The comparative mean growth rate (height and diameter) between the species throughout the hydrological year is shown below (**Figure 5**).

When analyzing the **Figure 5a**, we observed that the snake plant showed a higher growth rate during the dry period. This fact might be associated with the positioning of the plants that are immediately in front of the inlet flow. According to Yang *et al*. (2024), growth rate reduction might be a self-protection mechanism when a non-resistant plant is exposed to adverse conditions.

Figure 5. Variation of the mean growth rate (a) height and (b) diameter per species during the hydrological year monitored (May/2023-May/2024)



The result analysis (**Figure 5b**) suggests that the diameter growth rate of the species under study was higher during the dry period, which might be a consequence of the great water volume received during the rainfall period by the bioretention cell. According to Daniel *et al.* (2023), some species might present lower trunk diameter mean when subjected to excess irrigation.

The spider plant showed good growth rate soon after planted; however, over the year, the rate decreased, revealing the specie's lack of adaptation to the environment, probably due to the local high sun incidence rates since this behavior was identified in the dry period (**Figure 5a**).

Figures 6 and **7** show the individual behavior of the selected species regarding height and diameter growth, respectively. All species showed good adaptability, thus presenting satisfactory growth (**Figure 6**).

When considering individuals of the snake plant species, all showed similar development (**Figure 6c**). From November onwards, noticeable increase was observed in

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the cumulative growth of the plants in the rain garden, probably related to the increased rainfall from that month onwards.

At the end of the second semester of 2023, the snake plant obtained a cumulative total of four new sprouts, while the Mexican petunia showed two, and the song of India one in the rain garden. Such occurrence highlights the remarkable adaptability of the species to the bioretention device conditions.

Up to the beginning of September 2023, the mean height of the spider plant in the rain garden was 19 cm (with a 5 cm mean cumulative growth), this is typical of *Chlorophytum comosum* plants grown outside bioretention devices, which range between 15 and 20 cm high according to Lorenzi (2015). However, from that date onwards, the species showed a decrease in height, ending the monitoring period measuring 21 cm high. The same behavior was observed by Fensterseifer (2020) in the summer in Southern Brazil. Such reduction is related to the burning of the leaves by solar irradiance, which causes them to dry out and fall, influencing the reduction in plant height. Individual C1 (**Figure 6a**) died affected by external agents. This may indicate that this species is not recommended for environments where there is a flow of people and animals.

The mean height of the petunias in the rain garden reached 126 cm, which exceeds the typical value for *Ruellia simplex* plants grown outside bioretention devices, which generally reach up to 90 cm in height, according to Sikarwar *et al*. (2023) and Ezcurra and Daniel (2007). It seems important to highlight that during the rainy season, the petunias found the rain garden were susceptible to attacks by caterpillars, ants and crickets and parts were affected by Cochineal (*Dactylopius coccus*). After the rainy season, the pests disappeared naturally. Based on the high growth rate of this species, the need for regular pruning is evident, and it is not recommended for areas where this type of constant maintenance is not feasible.

It seems reasonable to mention that trimming of the petunias was required in December, and the height set for all individuals of this species was 40 cm. In the individual development analysis of the song of India species, we observed uniform behavior, with similar growth rates throughout the hydrological year (**Figure 5a**). The interspecies diameter regarding diameter was also similar for the three individuals (**Figure 7a).**

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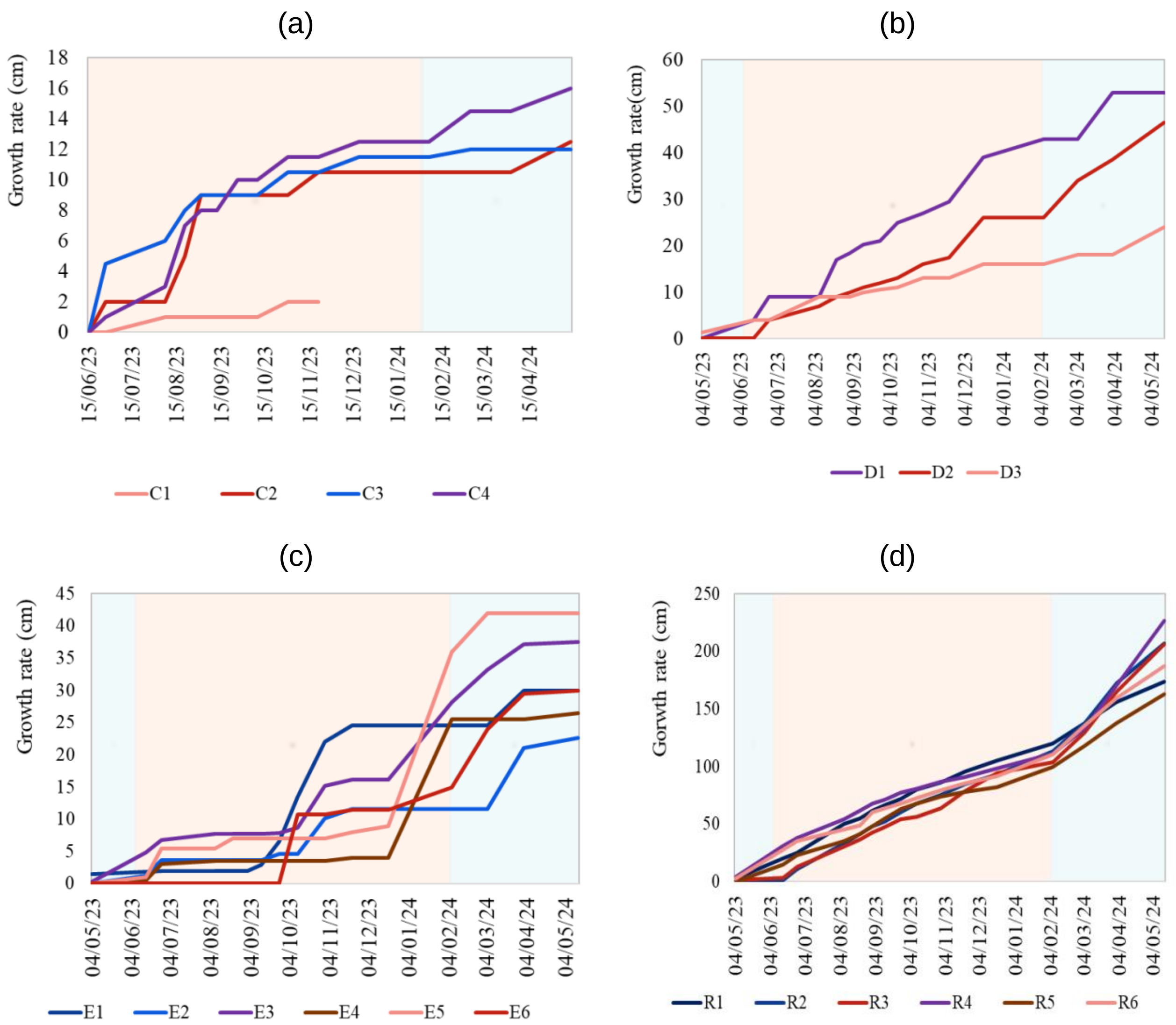
Figure 6. Individual cumulative growth (height) during the monitored hydrological year (a) spider plant, (b) song of India, (c) snake plant, and (d) Mexican petunia



The mexican petunia showed a good growth rate throughout the monitoring period, mainly in the rainy season of 2024 (**Figure 5a**). This result reinforces the statement by Ezcurra and Daniel (2007) that *Ruellia simplex* is a species resistant to flooding and presents a more pronounced development in soils with high humidity. The interspecies behavior was similar in terms of height (**Figure 6d**) but presented a greater variation in diameter (**Figure 7b**).

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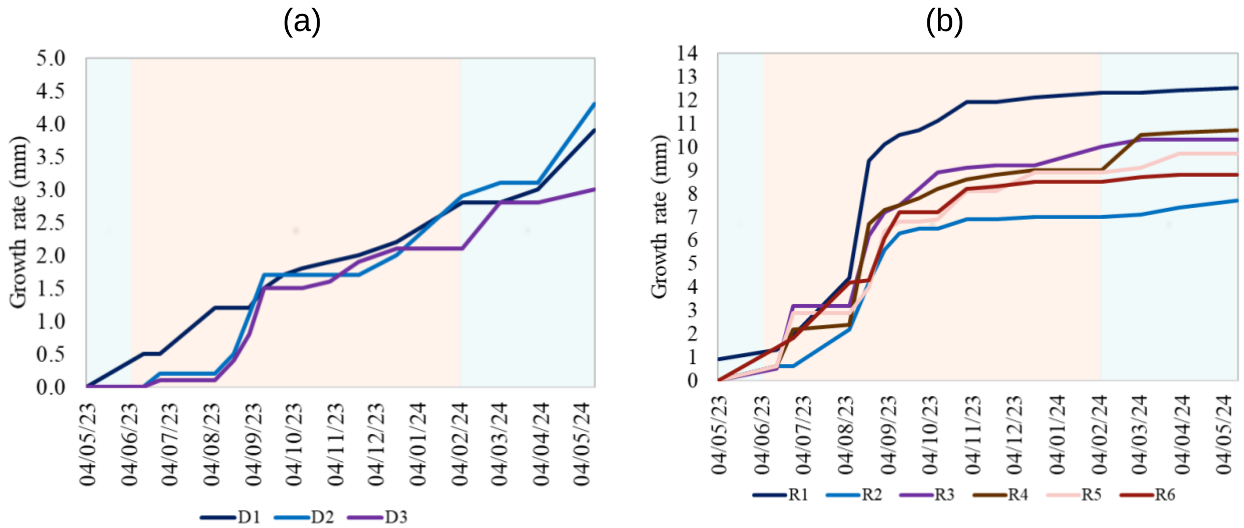
Figure 7. Individual cumulative growth (diameter) during the monitored hydrological year (a) song of India and (b) Mexican petúnia



ORGANIC MATTER DISTRIBUTION ANALYSIS

The organic matter distribution analysis was conducted to assess the potential heterogeneity in nutrient distribution resulting from the inlet flow into the bioretention system. Organic matter influences properties such as water absorption and retention. Ayes and Kangas (2018) highlight that the organic matter content tends to be higher in the surface layer of bioretention cells and to decline with depth.

Considering the main function of the rain garden as a device for infiltration and treatment of rainwater, uniform distribution of organic matter is important to ensure homogeneous vegetative development and efficient removal of pollutants.

The organic matter content values in the rain garden surface layer were low, ranging between 0.78% and 2.26%, with a 1.27% mean value (**Figure 8**).

The results indicated a variation in the concentration of organic matter in different areas of the garden, suggesting that the inflow may influence the distribution of nutrients. Areas located close to the inflow presented higher concentrations of organic matter, which can be ascribed to the greater accumulation of sediments and organic residues transported by the rainwater.

According to Costa *et al.* (2011), the constant water flow can cause a leaching of nutrients in the soil, affecting the growth of the species. By increasing the water content in the soil, irrigation can intensify the rate of the organic matter microbial decomposition, thus reducing the C content present in the soil (Bona *et al*., 2006).

However, as discussed in the previous sections, this difference in the organic matter distribution was not sufficient to cause a statistically significant difference in the interspecies growth.

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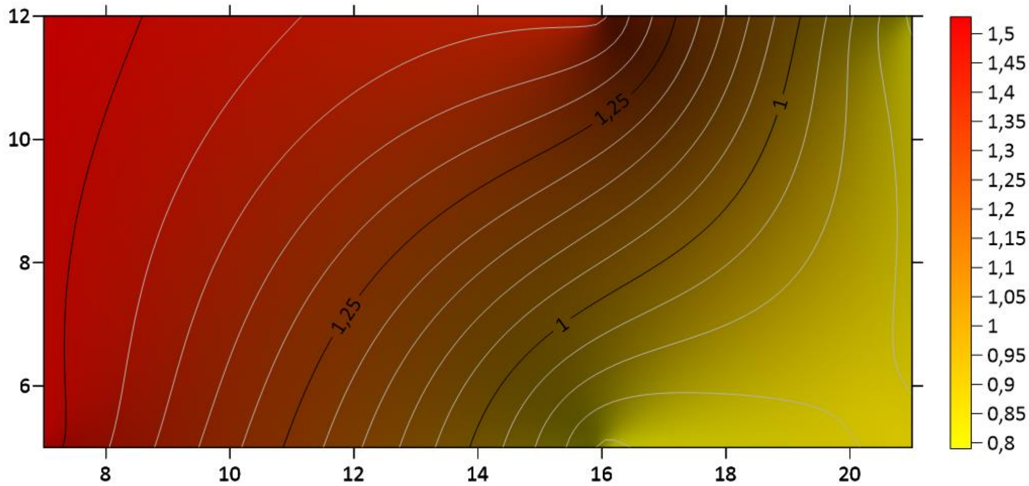
Figure 8. Spatial distribution of the soil organic matter in the rain garden



CONCLUSIONS

This study evidenced that the selected species (*Ruellia simplex, Dracaena reflexa, Chlorophytum comosum* and *Sansevieria trifasciata*) presented good adaptability and satisfactory growth in a rain garden subjected to seasonal natural rainfall conditions in tropical climate. Based on the influence of the position of the plants in their adaptability to the rain garden environment, the following conclusions were drawn:

- The ANOVA indicated that the vegetation positioning in the rain garden did not affect the Mexican petunia, spider plant, and snake plant growth rate.
- Regarding the song of India species, using the ANOVA allowed the identification of significant statistical difference in the height of individual D3. However, due to the position of the species, it was not possible to ascribe this difference to the rain garden dynamics.
- Areas located close to the inflow showed higher concentrations of organic matter, which might be ascribed to the greater accumulation of organic sediments and waste carried by the rainwater.
- The growth rate of the diameter of the species investigated (song of India and Mexican petunia) was higher during the dry period, probably due to the high volume of water flowing into the garden during the concentrated rainfall period.

The results reported contributed to the proper selection of species for bioretention cells, thus supporting the implementation of such devices in tropical climate regions, where the technology is still incipient. In addition to the species investigated, vegetation that presents similar behavior might produce similar results, thus broadening the options for future projects.

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