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Evaluation of thermal and optical properties measurements of paspalum in modular green roof in a tropical environment

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R E S U M O

O objetivo desta pesquisa foi avaliar a utilização de medições de propriedades térmicas e ópticas na caracterização do Gênero *Paspalum* para utilização em telhados verdes num ambiente tropical. O experimento foi conduzida na Universidade Federal Rural de Pernambuco - UFRPE de Maio a Junho de 2019. Foi avaliado o número de dezesseis acessos de Paspalum com hábitos de crescimento vertical ou prostrado. Em condições simuladas de um telhado verde, foram avaliadas: Índice de Vegetação Ajustada ao Solo (SAVI); temperatura das folhas (L) e do dossel (C) por termometria (TM); e por termografia (TG). O coeficiente de determinação (R^2) entre SAVI e a área de cobertura dos acessos foi de 0,84, e com matéria verde (R^2 = 0,73) e matéria seca (R^2 = 0,56). Não foi observada diferença significativa entre os acessos de *Paspalum* para a medição da temperatura da folha por TM e TG, e para o dossel TM. No entanto, foi observada uma diferença significativa entre a TG do dossel dos acessos de *Paspalum*, com temperaturas do dossel mais baixas nos acessos com hábito de crescimento vertical do que nos acessos com hábito prostado. A relação entre as técnicas mostrou valores elevados de coeficiente de determinação para TML com TGL (R^2 = 0,85) e TMC com TGC (R^2 = 0,91). Conclui-se que, o SAVI pode ser utilizado para estimar capacidade de área de cobertura vegetal dos acessos. As temperaturas das folhas e das copas podem ser usadas como indicação de déficit hídrico nos acessos de *Paspalum*, utilizando tanto o termómetro de infravermelhos (mais acessível) como a câmara termográfica. A termografia do dossel também pode ser utilizada para avaliar o desempenho térmico dos telhados verdes. As imagens termográficas indicaram que os acessos de *Paspalum* de hábitos de crescimento verticais podem proporcionar um melhor conforto térmico.

Palavras-chave: Infravermelho; termografia; termometria; SAVI; fenotipagem; melhoramento de plantas.

Evaluation of thermal and optical properties measurements of paspalum in modular green roof in a tropical environment

A B S T R A C T

The objective was to evaluate the use of thermal and optical properties measurements in the characterization of the genus *Paspalum* for use on green roofs in a tropical environment. The experiment was conducted at the *Universidade Federal Rural de Pernambuco* – UFRPE from May to June 2019. The number of sixteen *Paspalum* accessions with prostrate and upright growth habits was evaluated. In a simulated modular green roof were evaluated: Soil-Adjusted Vegetation Index (SAVI); leaf (L) and canopy (C) temperature by thermometry (TM); and by thermography (TG). The determination coefficient (R^2) between SAVI and the coverage area are of 0.84, with green matter (R^2 = 0.73) and dry matter (R^2 = 0.56). No significant difference was observed between the accessions for leaf temperature measure by TM and TG, and for canopy TM. Nevertheless, significant difference to canopy TG were observed, with lower canopy temperatures in accessions with upright growth habit than those with prostrate habit. The relationship between the techniques showed high values of determination coefficient to TML with TGL (R^2 = 0.85) and TMC with TGC (R^2 = 0.91). Given the above, the SAVI can be used to estimate the coverage area capacity (CC). Leaf and canopy temperatures can be used as an indication of water deficit in *Paspalum* accessions, using both the infrared thermometer (more accessible) and the

thermographic camera. Canopy thermography can also be used to evaluate the thermal performance of green roofs. Thermographic images indicated that *Paspalum* accessions of upright growth habits may provide better thermal comfort.
Keywords: infrared; thermography; thermometry; SAVI; phenotyping; plant breeding.

Introduction

Phenotyping techniques in plant breeding are promising and contribute significantly to the characterization, selection and plant breeding programs, as it is non-destructive techniques and promote faster results (White et al., 2012) and could be adapted to selected plants to be use in green roofs. These innovative image analysis techniques help to understand plant responses at the leaf, plant and canopy level (Potgieter et al., 2018).

Among phenotyping techniques, image processing has demonstrated the functioning of several plant mechanisms (Li et al., 2014; Tattaris et al., 2016). The study of images allows measuring a phenotype quantitatively through the interaction of plants with light, such as reflected, absorbed or transmitted photons, where each cell component as well as plant tissues, express these properties according to the specific wavelength (Li et al., 2014). The use of spectral techniques through multispectral images in the selection of plants has shown promising results, in which it allows to evaluate the spectral behavior of the leaf, based on the reflectance of the region of the electromagnetic spectrum, where the leaf pigments absorb more radiation (Sousa et al., 2015).

Several vegetation indices have been developed, from spectral images, for plant phenotyping, including indices to assess plant health status, plant water status or water stress, land cover areas capacity, and for disease detection (Ponzoni, 2001; Ampatzidis et al., 2017; Abdulridha et al., 2019a, b). One of the most commonly used and studied crop health indicators is the Normalized Difference Vegetation Index - NDVI (Rouse et al., 1973). Another index used is the Soil-Adjusted Vegetation Index - SAVI, which is an NDVI correction, aiming to minimize the soil effect (Huete, 1988; Silva et al., 2020; Bezerra et al., 2022; Martins et al., 2022; Silva et al., 2023).

Another range of the spectrum used in the new plant phenotyping is the thermal infrared (8-14 μm) measure with equipment such as a thermal camera, for example (Sousa et al., 2015). Infrared thermometry is often used to measure leaf temperature that compares with air temperature and can be used as indicators of plant water conditions (Pires et al., 2015; Costa, 2020). Thermal imaging as well as infrared thermometry are used to measure plant temperatures to assess water stress (Hackl et al., 2012; Martínez et al., 2016; Yu et al., 2016). For lawns, water stress is a type of abiotic stresses that influence the growth and quality of the turfgrasses (Caturegli et al., 2015).

Those phenotyping techniques can contribute with the selection of plants to green roofs, evaluating the functionality and ability of plants to provide ecosystem services, such as reducing local temperature and improving thermal comfort in indoor environments, considering that this capacity may differ between species (Monteiro et al., 2016). For example, thermal imaging makes it possible to measure variations in the temperature of the vegetation layer. This variation can be explained by the different physical configurations of the plants and the number of leaves in a given area (Liz et al., 2018). The potential of the species used can contribute to the energy performance of roofs, and can be evaluated using characteristics such as covering capacity and leaf temperature (Ferrante et al., 2016; Iaria and Susca, 2022). Considered a key feature contributing to surface cooling, studies such as these have been carried out using image analysis (Koyama et al., 2013).

Green roofs can contribute to improving the quality of life of the population, retaining and reusing rainwater, reducing air pollution, rainwater runoff, acoustic and provide visual comfort (Silva et al., 2017). The rapid and disorderly growth of urbanization results in the heat islands, which are pockets of heated air present in the urban environment, caused by greater absorption of radiation, due to the capacity that the different building materials that make up the urban structure have to exchanging energy with the sun. The solar radiation absorbed by these materials is converted into heat waves, being retained and raising the temperature of the environments causing thermal discomfort, which can be mitigated by the inclusion of green areas (Amorim, 2017; Santos et al., 2019; Peng et al., 2020; Silva, 2023).

The use of suitable species on green roofs is the most critical factor for its good performance, especially for extensive green roof type, in which irrigation is not used and has a limited capacity to retain moisture by the small substrate layer, showing the importance of plant selection (Suárez-Cáceres et al., 2022). The selection of grasses of the genus *Paspalum* for different purposes of use has contributed to increase the genetic potential of native species. Castro (2015ab), Souza et al. (2016) and Silva et al. (2018; 2020) highlighted the main characteristics to use as lawn, and its potential use for green roofs, demonstrating the rusticity of the genus *Paspalum*.

For Ignatieva et al. (2015) the lawn is one of the most powerful symbols within a given architectural and landscape approaches in urban landscapes, however it is necessary studies that allow the proper use of these lawns so that they can sustainably promote ecosystem services in cities. Given the above, the objective was to evaluate the performance of thermal and optical properties measurements of paspalum in a simulated modular green roof in a tropical environment.

Material and methods

The experiment was carried out in the experimental area of the Department of Agronomy of the *Universidade Federal Rural de Pernambuco* – UFRPE, located in the municipality of Recife, in the metropolitan region (latitude 8º1'5.87"S, longitude 34º56'37.56"W and altitude of 4 m). The study covered the period from May 23 to June 6, 2019. The genetic materials used in this work were supplied by the *Empresa Brasileira de Pesquisa Agropecuária* - EMBRAPA *Pecuária Sudeste* (Table1).

To simulate the condition of green roof cultivation, the trays were kept in the open on a waterproofed area (cobblestone pavement). The experimental design was in randomized blocks, with four replications.

In May 2018 the seedlings of the *Paspalum* accessions were planted. The upright growth habit ones were standardized with 20 cm, and those with prostrate growth habit were standardized to 10 cm. Six seedlings from each accession were planted at a spacing of 9.0 cm x 7.6 cm in polyethylene trays (27 wide x 38 cm long x 7 cm deep). The trays were filled with low fertility soil, equivalent to a volume of 6.156 cm^3 and an area of 1.026 cm^2.

Daily they were irrigated with 400 ml/tray (based on Field Capacity - FC) and, from 156 DAP, irrigation was started once a week with nutrient solution (concentrations in g L^{-1} of Potassium Nitrate (KNO_3) - 0.55; Monopotassium Phosphate (KH_2PO_4) - 0.22; Quelatec - 0.051; Boric Acid (H_3BO_3) - 0.0017; Calcium Nitrate ($CaNO_3$) - 0.89; Magnesium sulfate ($MgSO_4$) - 0.45; Ultraferre - 0.026) following recommendations Carvalho (2019). In relation to maintenance, no pruning was carried out, only weed removal.

Table 1. Accessions of *Paspalum* spp. evaluated in the experiment.

	Characteristic	Species	Acronym
1	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO1
2	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO2
3	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO3
4	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO5
5	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO6
6	Rhizomatous prostrate growth (creeping)	*Paspalum notatum*	PNO7
7	Rhizomatous prostrate growth (creeping)	*Paspalum* sp.	CE2
8	Rhizomatous prostrate growth (creeping)	*Paspalum* sp.	CE5
9	Rhizomatous prostrate growth (creeping)	*Paspalum* sp.	CE9
10	Cespitoso of upright growth (tuff)	*Paspalum compressifolium*	PCO1
11	Cespitoso of upright growth (tuff)	*Paspalum compressifolium*	PCO2
12	Cespitoso of upright growth (tuff)	*Paspalum compressifolium*	PCO3
13	Cespitoso of upright growth (tuff)	*Paspalum rhodopedum*	PRH1
14	Cespitoso of upright growth (tuff)	*Paspalum rhodopedum*	PRH2
15	Cespitoso of upright growth (tuff)	*Paspalum ionanthum*	PIO1
16	Cespitoso of upright growth (tuff)	*Paspalum rojasii*	PRO1

Based on the time required to execute the reading and image collection with precision to evaluate the use of phenotyping techniques, were selected the trays with the best development and largest number of surviving seedlings. This corresponded to 25% of the experiment, value superior to the adopted by Golzarian et al. (2011) to evaluate a method based on image analysis with grasses of 20% of the images. The accessions of *Paspalum* spp. in the trays were evaluated at 350 days after planting (DAP) at May 23 and 365 DAP at June 6, 2019.

Meteorological Data

An Incoterm digital thermometer was installed at a height of 1.0 m, used to measure the temperature (Tair, °C) and the relative humidity (RH, %) of the air at the time of obtaining the thermal and multispectral images of the accessions of *Paspalum* spp. The characterization of the meteorological conditions of the study area on the days of the experiment was also performed using data from incident solar radiation (Rg, W/m^2), wind speed (Ws, m/s^2), temperature (Tair, °C), and humidity air temperature (RH, %) on an hourly scale, and rainfall (R, mm) and air temperature on a daily scale was also used, observed in the automatic meteorological station of the Agricultural Engineering Department of the UFRPE. The water vapor pressure deficit (VPD, kPa) was calculated, which is the measure of the evaporation capacity of the liquid to the environment, on the days of the experiment, using equations 2, 3, and 4 expressed by (Tetens, 1930; Alvarenga et al., 2013):

$$\text{VPD} = \text{es} - \text{e} \quad (2)$$

$$\text{es}=0{,}61078 \times 10^{\left(\frac{7{,}5\times \text{Tair}}{(237{,}3+\text{Tair})}\right)} \quad (3)$$

$$\text{e}=\frac{\text{es} \times \text{RH}}{100} \quad (4)$$

where: es = water vapor saturation pressure (kPa); e = real water vapor pressure (kPa); RH = relative humidity.

Spectral images

Canopy coverage was measured with a TetraCam®1 ADC Lite multispectral camera suspended in a structure directly above the crop and directed vertically down to a height of 1.35 m based on the guidelines of Fritsche-Neto and Borém (2015). The structure was composed of a 1.0 m x 0.10 m rectangular wooden pole, a photographic tripod, an LCD monitor (Liquid Crystal Display), and a camera. One end of the rod was attached to a photographic tripod and the other end was fitted with the TetraCam®1 ADC Lite camera, directed downwards, that is, towards the nadir.

The camera is designed to capture images in the wavelength bands of light reflected in red (0.63 - 0.69 µm), green (0.52 - 0.60 µm) and near-infrared (0.76 - 0, 90 µm). The trays with the Paspalum accessions were positioned one at a time on top of the black background and below the TetraCam®1 ADC Lite camera. A seven-inch LCD monitor was connected to the camera to allow viewing of the images. For each Paspalum accession, two images were obtained in the DMC (Datamartist Data Canvas Format) format with 10-bit radiometric resolution and 0.54 mm spatial resolution, totalizing 32 images per day. The effect of atmospheric scattering on the images was corrected using a photograph of the white reference plate taken before the start of image collection. Measurements were taken at 350 and 365 DAP, in an open area and clear sky. Spectral images were captured every hour in the morning from 7 am (10 UTC) to 10 am (13 UTC, Central Time Unit).

SAVI Estimate

The images were cropped to dimensions of 1386 x 910 pixels (width x height) and corrected for atmospheric scattering effects, using the image taken from a white calibration plate before taking the measurements. Calibration coefficients were obtained using the index tools of the computer program Tetracam PixelWrench II available at: https://www.tetracam.com. In this program, several indices are also implemented, including the SAVI expressed by Equation 5 given by Huete (1988):

$$SAVI = \frac{(1+L)\times(NIR-R)}{(NIR+R+L)} \quad (5)$$

where: NIR (near-infrared reflectance) and R (red reflectance) and L = 0.1 is the ground adjustment correction factor. SAVI minimizes the effects of soil reflection, ranging from -1 to +1, that is, the closer to +1, the greater the presence of chlorophyll, indicating strong photosynthetic activity (Huete, 1988; Sousa et al., 2015). The Tetracam PixelWrench II program classifies the pixels of the SAVI image in color and assigns to each tone a percentage of area concerning the total area of the image. The SAVI images were exported in CSV (Comma-separated values) format. In the Excel 2010 spreadsheet, the percentages of each shade are grouped into green matter (shades of red), dry matter (shades of yellow), exposed soil (shades of blue), and water (shades of green) (Figure 1C).

To estimate the canopy coverage capacity (CC, %), the multispectral image in false color composition (RGB = Red, Green, Blue) was used, in which red tones were associated with NIR, green tones with R and shades in blue to the reflectance of green (G) (Figure 1A). Then, the colored compositions were imported and binarized (Figure 1B) in ImageJ software© version 1.49, which uses the Java programming language (Silveira et al., 2016).

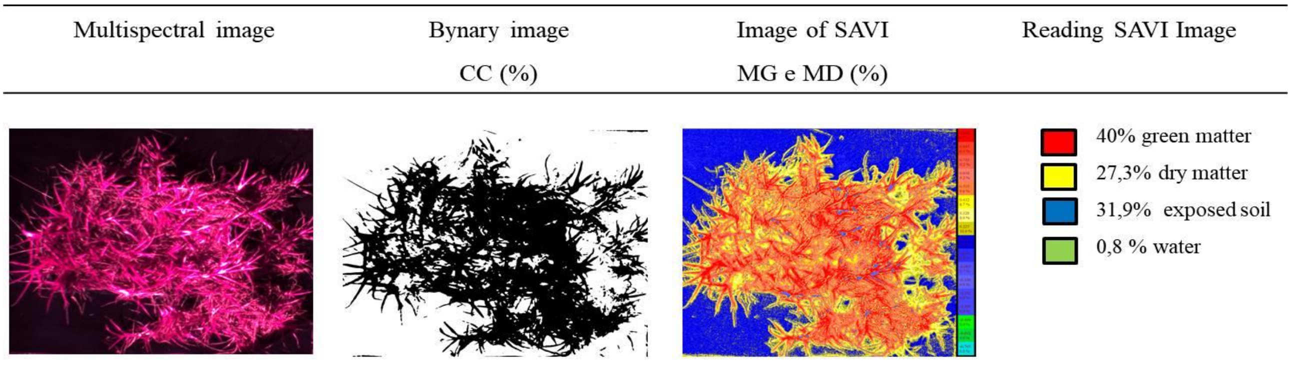

Figure 1. Image processing of the *Paspalum* spp. PNO5 accession in false color composition (a); binarized image (b) and classified SAVI image (c) for 365 days after plantation (DAP).

The totals rainfall of 15 days before the first and the second image collection were analyzed, to verify if there was an interference of the rainfall in the values of the SAVI vegetation index (Pesck, 2017).

Thermometry and Thermography

Thermometry (TM) and thermography (TG) techniques were used to measure leaf (L) and canopy (C) temperature of *Paspalum* spp. Accessions. Thermometry was performed with an infrared thermometer model Kimo Kiray-200, with the double laser sight, the spectral resolution of 8 to 14 µm and surface emissivity maintained at 0.95. Leaf temperature measurements (Tl, ºC) were collected from nine different points distributed over each accession at an approximate 10 cm height from the surface of the leaves, measured at times of exposure to direct solar radiation. The average canopy temperature (Tc, ºC) was taken using two measurements obtained by the infrared thermometer at a height of 1.0 m from the tray (Yu, et al. 2016; Hackl, et al., 2012). Measurements were taken 365 DAP, from 8 am (11 UTC) to 11 am (14 UTC) and from 1 pm (16 UTC) to 4 pm (19 UTC). Through the measurements of the infrared thermometer, it is also possible to estimate the stress of the *Paspalum spp* for which the meteorological characterization of the experimental area was carried out (Pires et al., 2015).

Thermal images were obtained from a FLIR infrared thermal camera model FLIR i50 (FLIR Systems AB, Sweden) with a resolution of 0.01°C, the focal length of 1.0 m and emissivity adjusted to 0.95, which is used following the Quick Report application to adjust the images. The infrared thermographic camera was directed downwards at a height of 1.0 m from the canopy of Paspalum's accessions. For each Paspalum access, two measurements were taken, totaling 32 thermal images.

Thermal images were processed and analyzed using FLIR QuickReport software, version 1.2, with adjustment of emissivity, ambient temperature, and relative humidity values obtained at the time of image recording. Also, the averages of nine-point values of the thermal images of the canopy of the accessions of each Paspalum were extracted and calculated.

Through thermal images, it was also verified which accesses could offer better thermal performance in the condition of green roofs, taking into account the contribution of vegetation cover in reducing the temperature, when compared to a non-vegetated surface (cobblestone pavement). A color scale related to the temperature of the canopy was observed, from blue (warmer temperatures) to yellow (warmer temperatures).

Leaf and canopy temperature measurements were submitted to analysis of variance and means were compared by Tukey test at 5% probability using the statistical program Sisvar version 5.6 (Ferreira, 2011).

Results and discussion

SAVI vegetation index and related characteristics

According to the analysis of variance, it was observed that there was no significant difference between the accessions. The averages of coverage capacity (CC) varied from 34.1 to 56.8%. These in turn were similar with the SAVI averages varying from 0.34 to 0.60, expressing a possible relationship between the characteristics. It was also possible to observe that the SAVI values, in general, indicated that the accessions were in a moderate to the very healthy range (EOS, 2019). For green matter (MG) the averages ranged from 30.4 to 59.4% and for dry matter (MD) ranged from 20.6 to 31.7% (Figure 2). These results indicate that despite being cultivated during one year, conditions of small depth of the tray, low amount of water, and nutritional availability, these accessions demonstrated satisfactory resilience for their survival, possibly due to plants tolerance to stresses and ability to regrow in natural conditions since it is a perennially (Souza et al., 2016; Costa et al., 2004).

The standard deviations of the characteristics average for some accessions were high (as in the case of green matter in PNO1, PNO2, CE5, CE9, PRO1) possibly due to the influence of some climatic elements (excessive radiation, strong winds), as well as, the difference between accessions. Also, it was important to understand the factors that interfere in the accuracy of obtaining the readings and application of the phenotyping techniques in the characterization of native grasses for use on green roofs.

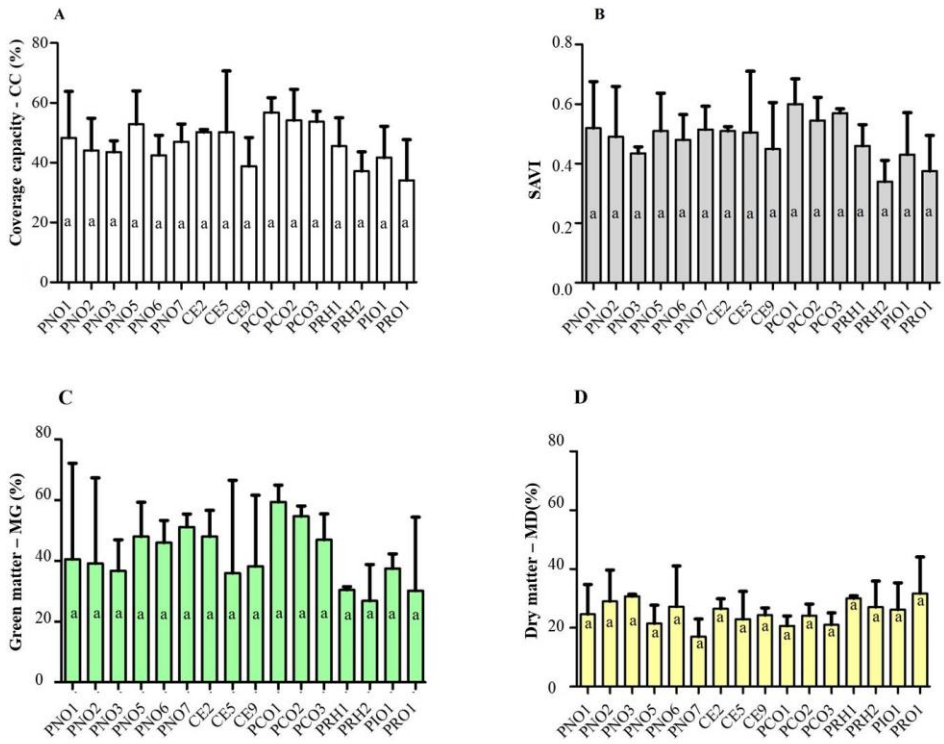

Figure 2. Variables observed for SAVI vegetation index in accessions of *Paspalum* spp A - coverage capacity (CC, %); B - vegetation index adjusted to correct soil effects (SAVI); C - green matter (MG, %) and D - dry matter (MD, %). Vertical bars represent the standard average deviations. Averages followed by the same letter do not differ statistically from each other by Tukey test at 5% probability.

There were significant differences between the assessments for all the variables analyzed when comparing the evaluations performed at 350 and 365 DAP. It was observed that at 350 DAP, the highest percentages occurred with mean CC (52.6%); SAVI (0.55) MG (50.6%) and minors of MD (19.6%) and at 365 DAP. This behavior was reversed with CC (39.9%); SAVI (0.41); MG (33.1%) and MD (31.5%) (Figure 3), as observed, for example, in the CE5 accession (Figure 4). Thus, the dense vegetation cover has a greater absorption capacity, less reflection, and less transmission of photosynthetically active radiation, configuring a greater use of this resource for green mass production when compared to the lower levels of plant density (Fernandes et al., 2021).

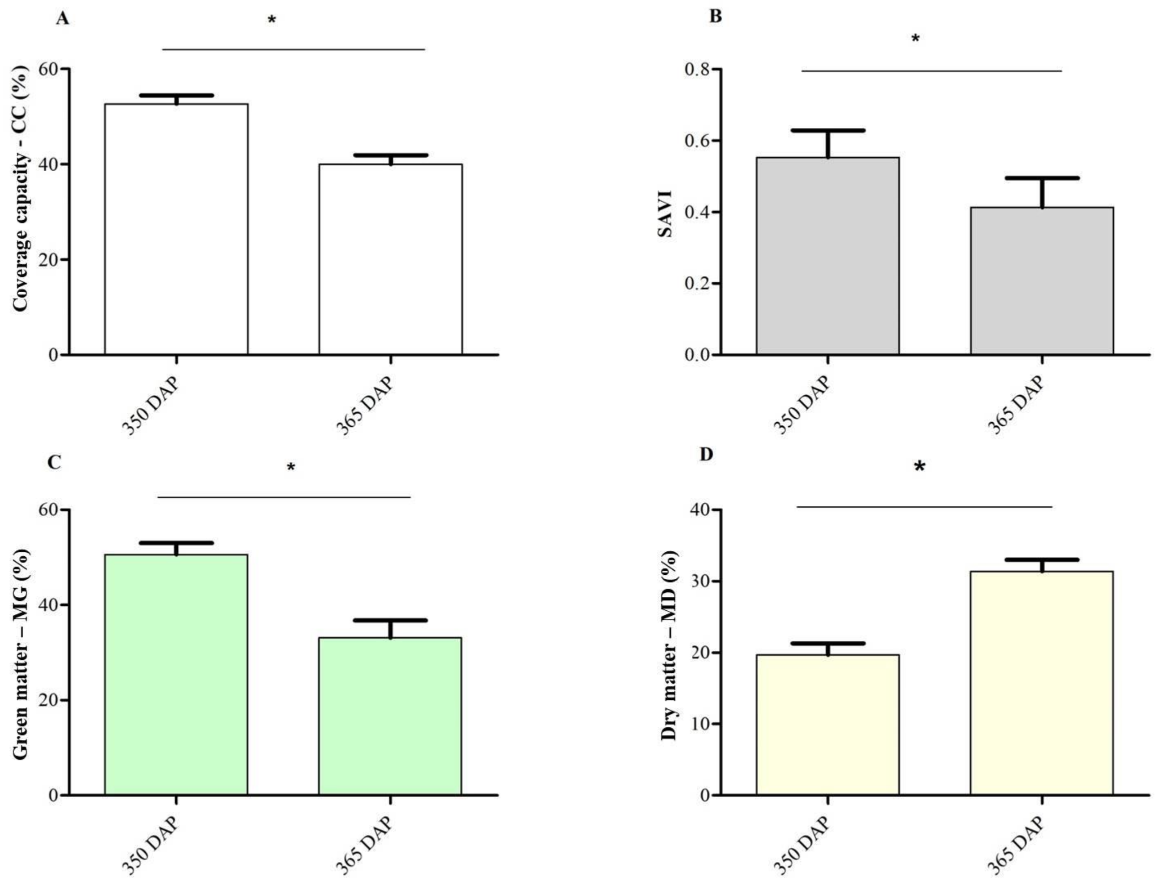

Figure 3. Means at 350 and 365 days after plantation (DAP) of the variables observed for SAVI vegetation index in accessions of *Paspalum* spp.: A - Coverage capacity (CC, %); B - vegetation index adjusted to correct soil effects (SAVI); C - green matter (MG, %) and D - dry matter (MD, %). Significance at 5% between evaluations. Vertical bars represent the standard average deviations.

DAP	Multispectral image	Bynary image CC (%)	Image of SAVI MG e MD (%)
350			
365			

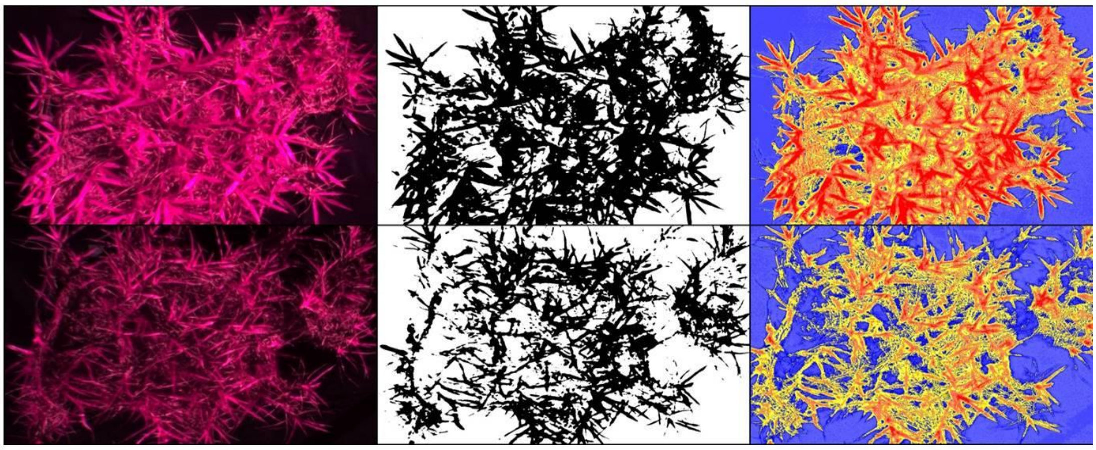

Figure 4**.** *Paspalum* spp. CE5 accession green matter (MG) and dry matter (MD) vegetation index (SAVI) at 350 and 365 DAP according to the image color of red to green vegetation, yellow to dry vegetation, and blue to exposed soil.

This behavior may have been influenced by the rainfall that occurred in 15 days before the first and second evaluations (May 23 and June 6, 2019). It was possible to observe that the rainfall of 116.70 mm was well distributed before the first data collection, while before the second collection, occurred 218.70 mm and a higher concentration of rainfall, mainly at May 29, 2019 (Figure 5). It was observed that in the days of intense rainfall the trays were flooded for some time, showing a drainage deficiency, possibly due to the clayey soil, and by the time that remained in the field, it was compacted. The rainiest period in the city of Recife, eastern part of the Brazilian Northeast, occurs from April to July, when it is associated with a greater circulation of the breeze in addition to the influence of the eastern waves from May to August (Hounsou-Gbo et al., 2016; Marengo et al., 2018; Bezerra et al., 2021).

After this period, the plants presented some yellow leaves that later became senescent producing dry matter, reduced the soil cover, as well as the SAVI values (Figure 3). According to Pesck (2017), this can happen, as rainfall period can cause leaf fall and reduction of photosynthetic activity, influencing the SAVI and soil cover values. According to Wachowicz and Carvalho (2002), when plants are subjected to water stress (flooding of the tray affecting the aeration of the soil), some physiological disturbances can occur, triggering survival mechanisms, to reduce energy expenditure and accumulate reserves for the vital processes of the plant, considering that the photosynthetic rates were affected, possibly, by the absence of adequate aeration, then chlorosis, yellowing, breakdown of chlorophyll molecules. According to Souza et al. (2016), in lawns, soil cover can also be conditioned by occasional stresses.

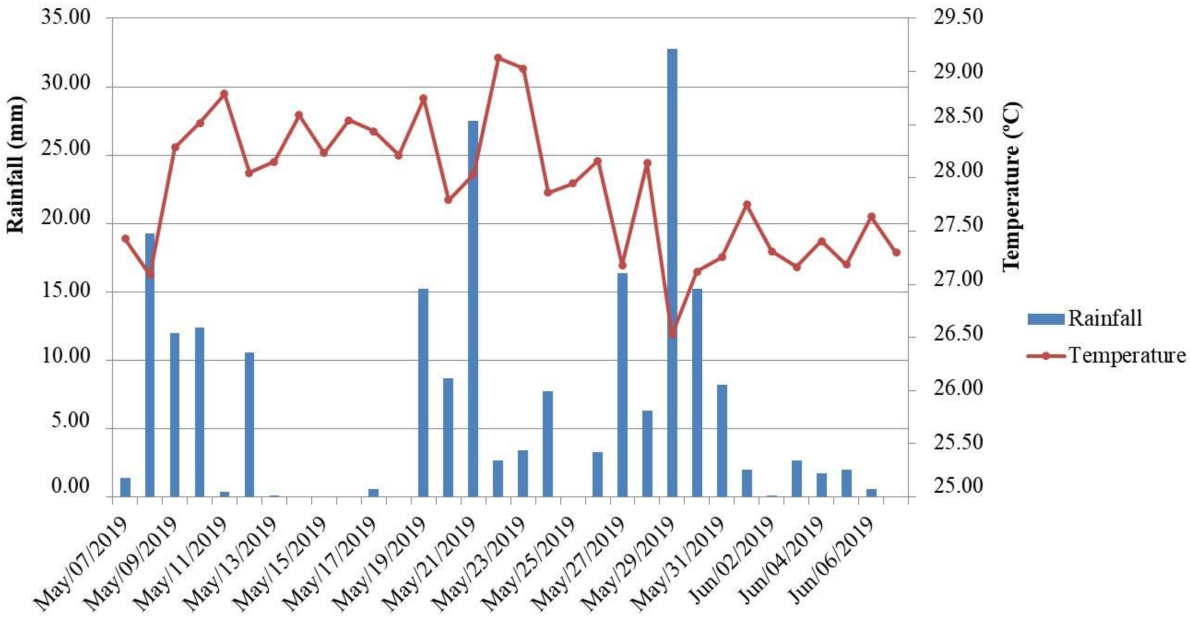

Figure 5. Rainfall and temperature climatology from 7th May to 7th June, 2019 (Recife, Pernambuco, Brazil (Irrigated Agriculture Station Department of Agricultural Engineering- UFRPE).

The SAVI vegetation index showed a high relationship with the coverage (R^2 = 0.84), demonstrating that the higher the percentage of SAVI, the higher were CC, expressing a direct relationship between these two variables (Figure 6). Gameiro et al (2016) when estimating the coverage area using the SAVI index, reports that the fact that this index eliminates the effects of the soil makes us have a more realistic view of the situation of the studied area, being suitable for evaluating the vegetal cover. Covering capacity is a highly relevant characteristic to be evaluated in the selection of grasses for green roofs, as it corresponds to the protective covering capacity of the soil. It is influenced by climatic factors as well as by conditions of the soil, and directly influences the thermal balance of vegetation cover, the main function that a lawn should play (Souza et al., 2016; Ferrante et al., 2016; Suárez-Cáceres et al., 2022).

The high relationship between MG and SAVI, was observed (R^2 = 0.73) (Figure 6) demonstrates that there is a direct correlation between the characteristics and that the SAVI can be used to estimate green coverage, and allows inferences about the photosynthetic activity. According to Sousa et al. (2015), this is possible due to the relationship of this index with chlorophyll, therefore, higher percentages of MG, resulting from higher levels of chlorophylls and, consequently, greater photosynthetic activity. The chlorophyll in a sweaty plant absorbs most of the visible red light, and the plant structure reflects more near infrared light. This means that the high photosynthetic activity, commonly associated with denser vegetation, will have lower reflectance in the red range and higher reflectance in the near infrared range, thus expressing the plant's response to adverse environmental conditions (EOS, 2019). Lower values of SAVI were related to higher values of MD (R^2 = 0.56) (Figure 6). High percentages of dry matter imply less chlorophyll, therefore lower SAVI values, due to the absence or reduction of pigments, with high reflectance in the visible region. In the selection of plants for use on green roofs, it is more interesting to select species with reduce production of dry matter. It entails lower maintenance costs, better ornamental quality and general appearance (Souza et al., 2016) and reduce the risk of canopy flammability.

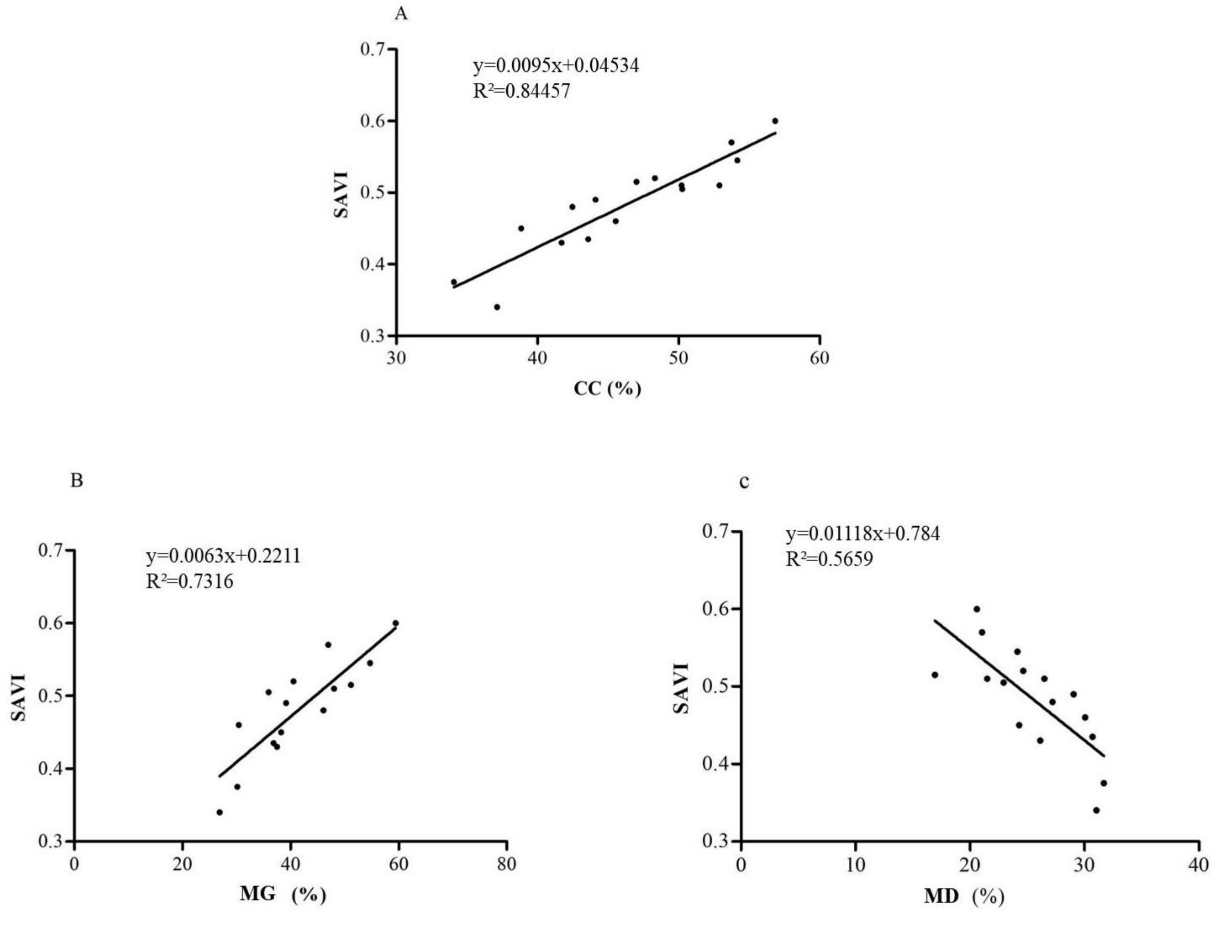

Figure 6. Linear regression analysis of vegetation index adjusted to correct soil effects (SAVI) with CC is the coverage capacity (A), MG is the green matter (B) and MD is the dry matter (C) of *Paspalum* spp.

Thermometry and leaf and canopy thermography

The results of the characterization of meteorological conditions (Figure 7) based on the day June 7 of the analysis show that the minimum air temperature was 21.44 °C, at 06:00 am (9 UTC), while the maximum was 32.64 °C, at around 03:00 pm (18 UTC), contrasting with the relative humidity values, which varied between 92% and 56% (Figure 6A).

The conditions of Tair and RH resulted in a deficit of vapor pressure (VPD) increasing from the beginning of the morning until reaching the maximum value of 2.08 kPa around 11 am (14 UTC) (Figure 7B), contributing to the air become drier and, resulting in the closing of plant stomata (Lopes et al., 2013).

Wind speed can also be a water stress factor for the plant during times or days with low wind. In Figure 7C, a wind speed of less than 1.0 m/s was observed throughout the day. On this day the availability of solar radiation (Figure 7D), with a maximum value around 513 W/m², occurring close to the local noon or occurring around midday local time.

These values possibly influenced leaf and canopy temperatures, considering that most of the analyzes were performed in periods of higher air temperature, radiation, deficit in vapor pressure and wind speed, and lower relative humidity. Those are periods of greater stress for the plant and, according to Yu et al (2015), these factors influence the leaf temperature.

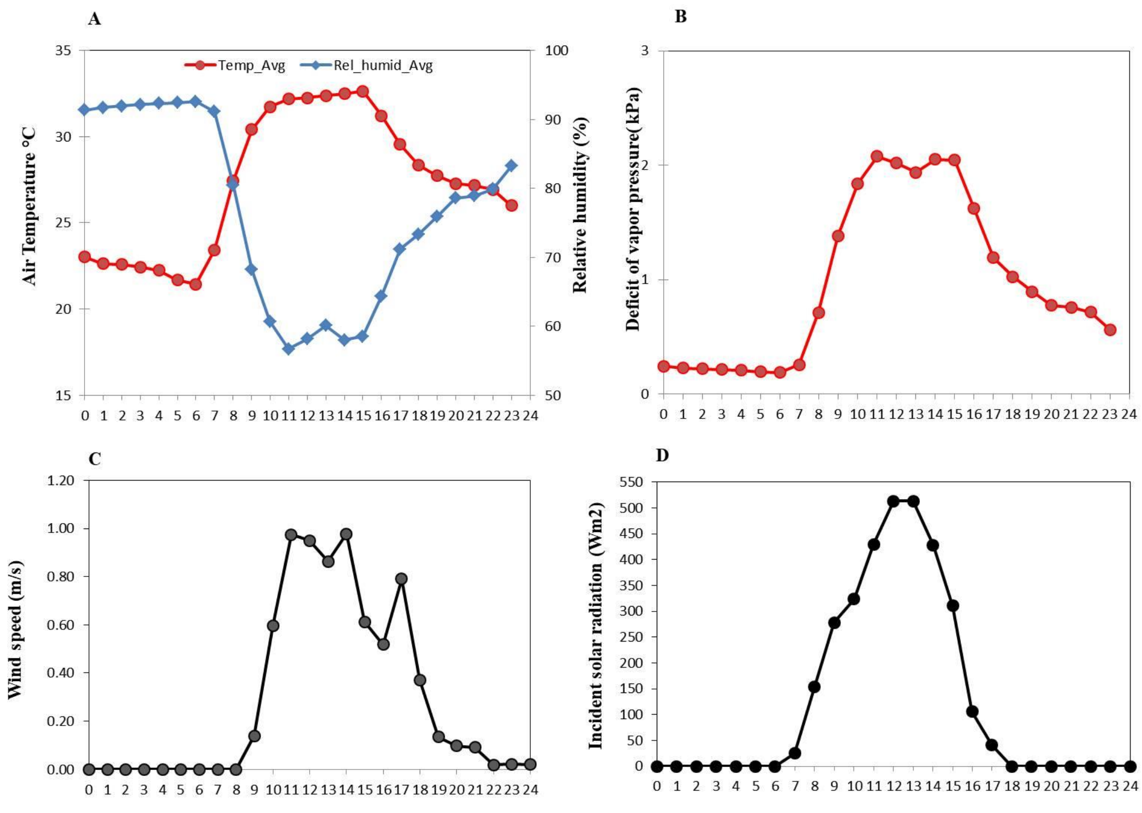

Figure 7. Meteorological characterization of the study area in Recife, Pernambuco, Brazil at June 7th, 2019, 365 days after plantation (DAP): temperature and relative humidity (A); deficit of vapor pressure (B); wind speed (C) and incident solar radiation (D) (Irrigated Agriculture Station Department of Agricultural Engineering - UFRPE).

According to the analysis of variance, there was no significant difference between accessions for leaf temperature comparing both techniques. In leaf thermometry (TML) the averages ranged from 30.38 to 36.01°C. In leaf thermography (TGL) the averages ranged from 31.44 to 35.57 °C (Figure 8). The air temperature ranged from 22.44 °C to 32.64 °C. In general, air temperature is always lower than leaf temperature. However, the high incidence of solar radiation, low relative humidity and low wind speed associated with the high deficit in vapor pressure can lead the plant to water stress. Leaf temperature is the plant's first defense mechanism in reducing water loss, by controlling stomatal opening and closing, indicating the influence of water deficit on the process of thermal dissipation by transpiration (Sousa et al., 2014; 2015). However, these results demonstrate that leaf temperatures in ranges higher than air temperature indicate that accessions were tolerant to water deficit. Leaf temperature can be considered an index of drought tolerance (Yu et al., 2015).

For the canopy thermometry, there was no significant difference between the accessions of *Paspalum*, where the canopy averages varied from 31.43°C to 35.56°C. However, for canopy thermography, a significant difference was observed between the accessions of *Paspalum*, where the prostrate growth accessions presented higher canopy temperature (34.75°C to 38.3°C) than the upright growth accessions (31.4°C to 33.5°C) (Figure 8). The height of the plant and the density of the canopy can be indicators of the ecosystem services of a green roof, for example the height of the plant is positively related to the capture of rainwater. This characteristic, as well as the density of the canopy, contribute to reducing the incidence of solar radiation on the roof cover. In addition, there is the substrate layer of the tray, softening the internal temperatures of the environments (Lundholm et al., 2015). In this way, accesses of *Paspalum* with vertical growth present greater height and greater density, contributing more to ecosystem services, including reducing the incidence of direct solar radiation on the roof cover and, consequently, minimizing temperatures in indoor environments.

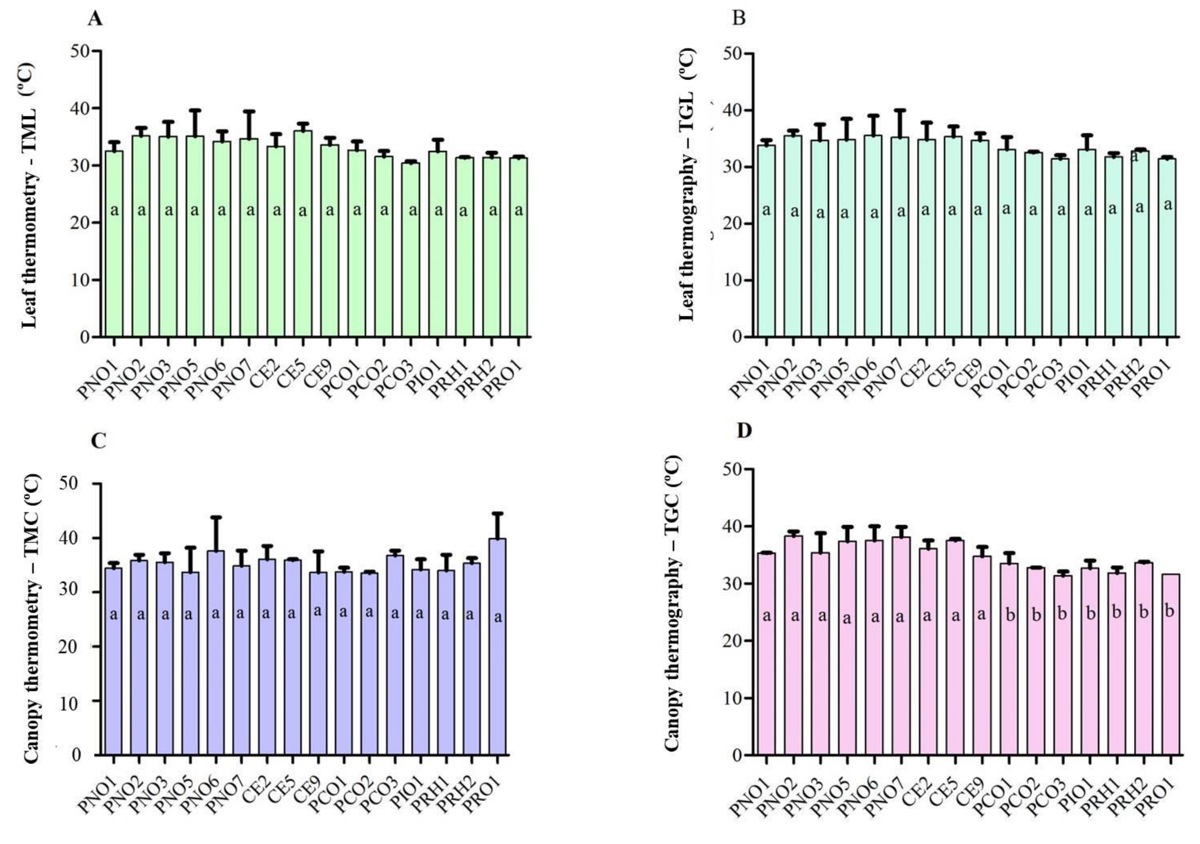

Figure 8. Leaf thermometry - TML (A); Leaf thermography – TGL (B); Canopy thermometry – TMC (C); Canopy thermography - TGC (D) in accessions of *Paspalum* spp 365 days after plantation (DAP). Vertical bars represent the standard average deviations. Averages followed by the same letter do not differ statistically from each other by Tukey test at 5% probability.

The regression analysis showed high determination coefficients ($R^2 = 0.85$) between the techniques for measuring leaf temperature and for measuring canopy temperature ($R^2 = 0.91$) (Figure 9). These results demonstrate that both the infrared thermometer and the thermographic camera can be used for these research purposes. However, it is worth mentioning that thermometry is more viable, due to the ease of acquisition and the lower cost of the infrared thermometer. Thermography has a higher cost, however, it allows the image to be stored for later analysis, being able to be evaluated when and as many times as the researcher wishes, with less need for manpower to carry out the readings. These results corroborate with Hackl et al. (2012) who performed a comparison between thermography techniques and infrared thermometry found that both are compatible, quick, and easy to apply, whether in the field or greenhouse condition. The evaluated techniques are configured as non-destructive, for preserving the material, besides, they provide faster results, factors of extreme importance in the characterization of plants for the genetic improvement of plants.

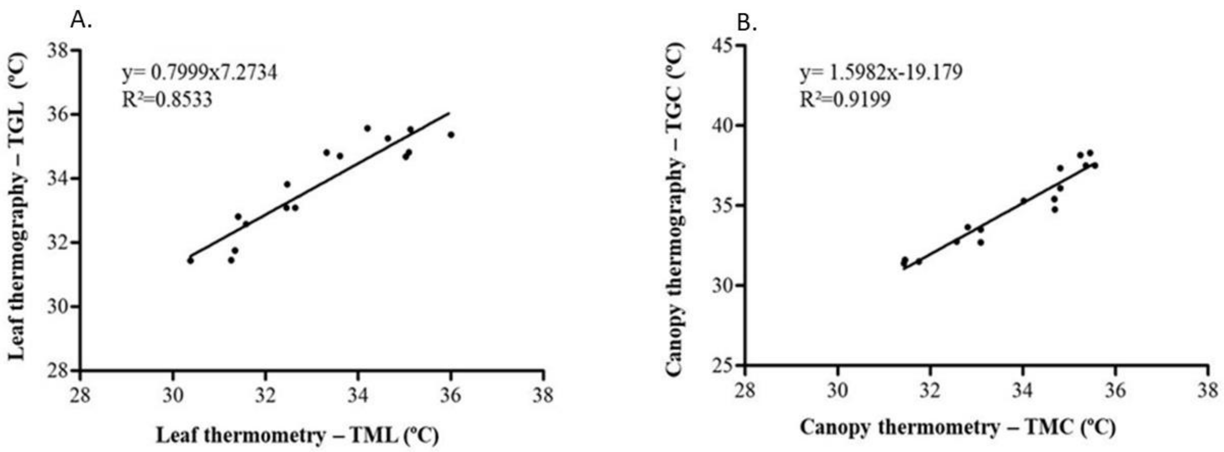

Figure 9. Regression analysis relating thermometry techniques and leaf (A) and canopy thermography (B).

The degree of daily stress demonstrated by leaf thermometry (Figure 10) indicated that accessions of Paspalum were more stressed in the morning from 8am (11 UTC) to 11am (14 UTC). Local meteorological conditions favored an increase in leaf and air temperature differences, leaving the plant more stressed, indicating greater stomatal control and possibly greater tolerance to water deficit. In the afternoon from 1 pm (16 UTC) to 4 pm (19 UTC), the leaf and air temperature difference was the opposite, except for accesses PNO5 and PNO7 (Figure 10). Pires et al (2015) observed that the plants were also more stressed in the morning than in the afternoon.

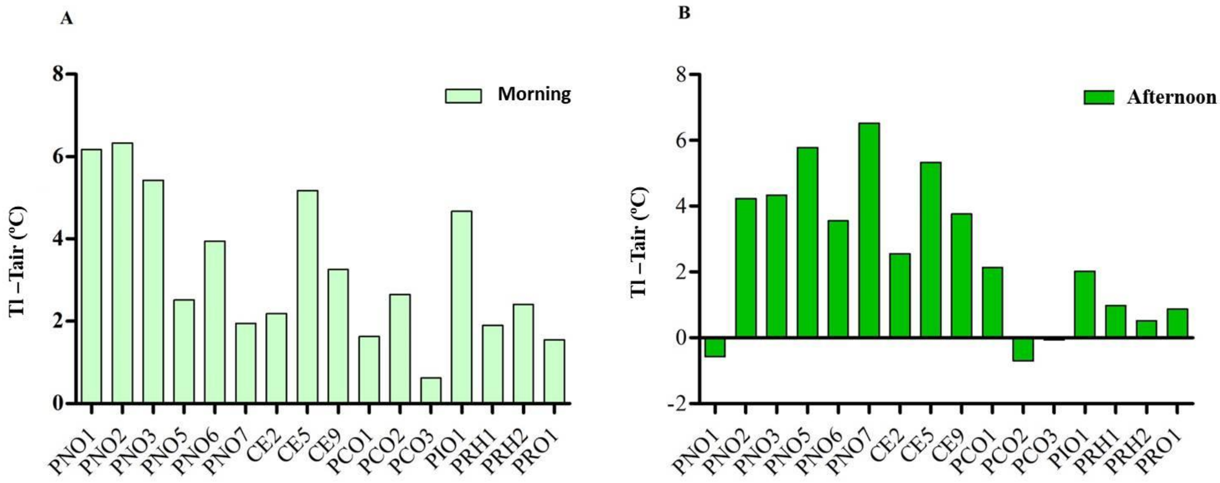

Figure 10. The temperature difference between the leaf and the air (Tl-Tair) in the morning (A) and afternoon (B) (8:00 am to 11:00 am and from 1:00 pm to 4:00 pm) in accessions of *Paspalum* spp in Recife, Pernambuco, Brazil at June 7th, 2019.

The accessions with an erect growth (Figure 11J to 11P) showed lower canopy temperatures, possibly due to their higher canopy density. Dense canopies tend to give a more effective shading effect on the substrate layer, making an air-impeding layer above the warmer canopy, therefore providing a better cooling effect bellow it (Krebs et al., 2017). Therefore, in an extensive green roof condition, planting these accesses would lead to places with milder temperatures, possibly offering greater thermal comfort. It is worth highlighting the importance of vegetation coverage, as it is possible to observe in Figure 11, according to the color scale of temperature observed in the thermal image.

The regions of exposed soil with yellow and lilac coloration, as well as the cobblestone coating with yellow coloration, presented higher temperatures (between 33.7 and 54.9 °C), indicating warmer regions. This type of evaluation using thermographic images has been used to evaluate the thermal performance of extensive green roofs, indicating regions of milder temperatures in vegetated areas, evidencing the contribution of green roofs in urban areas (Liz et al., 2018).

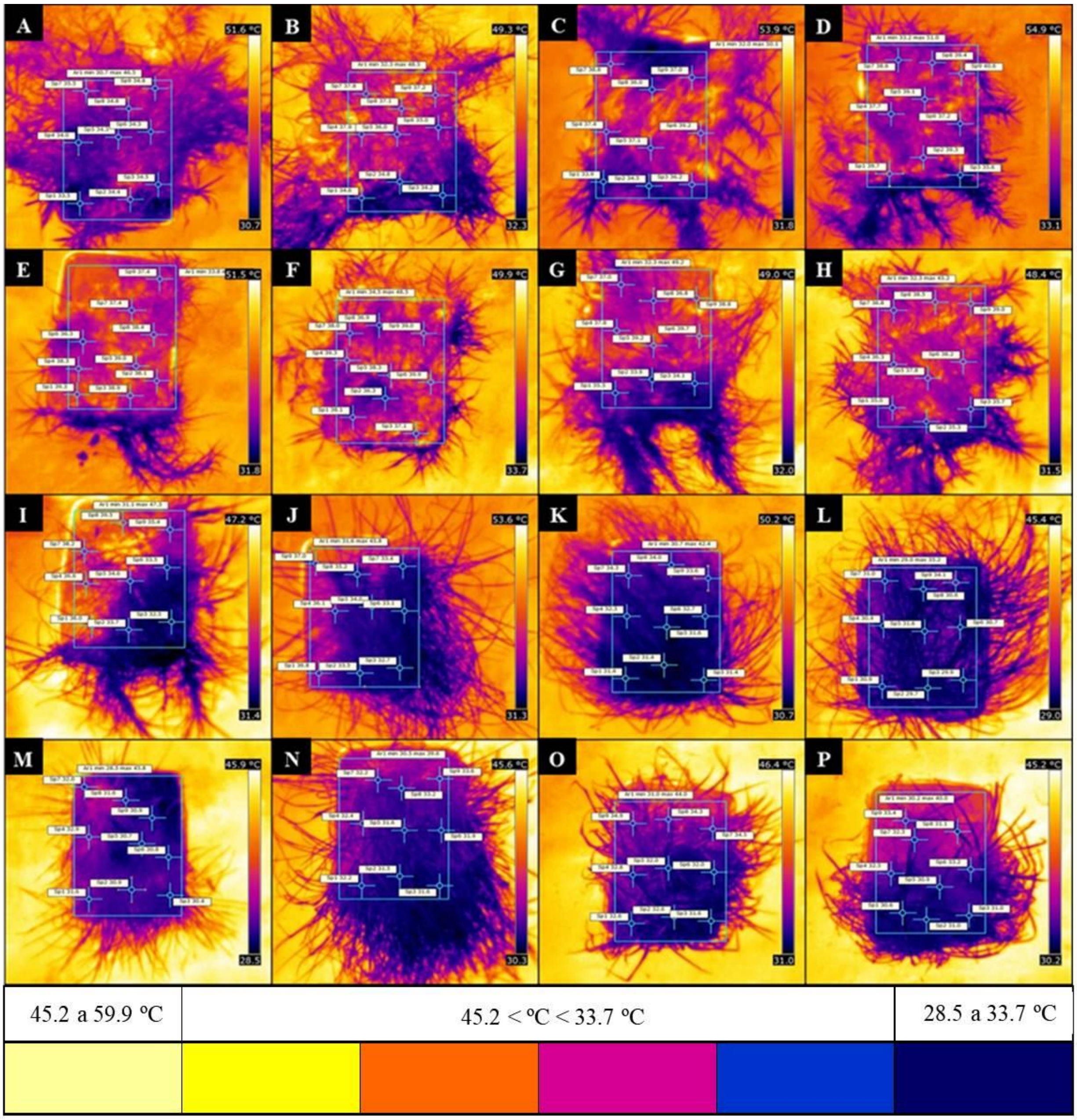

Figure 11. Thermal image and color scale referring to the canopy temperatures of the 16 accessions of *Paspalum spp.* held on June 7th, 2019, from 1 pm to 4 pm: PNO1 (A); PNO2 (B); PNO3 (C); PNO5 (D); PNO6 (E); PNO7 (F); CE2 (G); CE5 (H); CE9 (I); PCO1 (J); PCO2 (K); PCO3 (L); PIO1 (M); PRH1 (N); PRH2 (O); PRO1 (P).

Conclusion

The phenotypic techniques adopted to characterize *Paspalum* accessions demonstrate useful to evaluate their use on simulated green roofs. The accessions of upright growth habit provide the better results and potential to be use in green roofs for thermal comfort

The SAVI index can be used to estimate the coverage capacity (CC), and to identifying how much of this coverage is the green matter (MG%) and dry matter (MD%), characteristics of great relevance in the selection of lawns for green roofs, associated with aspects of establishment, persistence, resilience, and resistance.

Leaf and canopy temperatures can be used as an indication of water deficit in *Paspalum* accessions, using both the infrared thermometer, whose equipment is more accessible, and the thermographic camera.

Canopy temperatures can also be used to evaluate the plant functionality to reduce the temperature on the roof, minimizing the temperature of the environments. Higher plants present lower canopy temperatures as observed in accessions of Paspalum with upright growth habit.

We recommend that further studies to select *Paspalum* accessions for use on green roofs be carried with different soil and climatic conditions.

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