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MORPHOPHYSIOLOGY OF CAETÊ PLANTS UNDER SUN EXPOSURE AND SOIL TEXTURES

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ABSTRACT - Easily found in humid and shady places, *Maranta sobolifera* has spread in agricultural areas. However, the lack of information on the development of the species in different environments makes it difficult to understand its adaptive capacity**.** This paper evaluated the morphophysiological changes of *M. sobolifera* plants to sun exposure and soil textures. In a completely randomized experimental design and split plots, the main plots corresponded to light exposure and the subplots to soil textures. Gas exchange indices, stomatal density, chlorophyll a, b and total contents, macronutrients and dry mass were evaluated. The lower incidence of luminosity increases the photosynthetic rate by an average of 43% and 33% in clayey and sandy soils, respectively. Stomatal density was higher in full sun, while chlorophyll contents a and b were higher in shaded plants. The N and K contents in leaves, stems and roots were higher in shaded plants by up to 37%. The P content in the stem was 69% and 48% higher in plants grown in clayey and sandy soil, respectively. Dry mass was 26% higher in shaded plants compared to plants grown in full sun. In clayey soil, the total dry mass was 42% higher in relation to plants in sandy textured soil. It is concluded that *M. sobolifera* plants show morphophysiological changes (>stomatal density) that help adapt to full sun. However, under the canopy of agricultural crops, this species can compete intensely for nutrients, especially in clayey soils.
Keywords: *Maranta sobolifera*, stomatal density, phosphorus, macronutrients, nitrogen.

MORFOFISIOLOGIA DE PLANTAS DE CAETÊ SOB EXPOSIÇÃO SOLAR E TEXTURAS DE SOLO

RESUMO - Facilmente encontrada em locais úmidos e sombreados, a espécie *Maranta sobolifera* tem se disseminado em áreas agrícolas. Contudo, a falta de informações sobre o desenvolvimento da espécie em diferentes ambientes, dificulta o entendimento sobre sua capacidade adaptativa. Este trabalho avaliou as alterações morfofisiológicas de plantas de *M. sobolifera* à exposição solar e texturas de solo. Em delineamento experimental inteiramente casualizado e parcelas subdivididas, as parcelas principais corresponderam a exposição da luminosidade e as subparcelas a texturas de solo. Foram avaliados os índices de trocas gasosas, densidade estomática, teores de clorofilas *a*, *b* e *totais*, teor de macronutrientes e massa seca. A menor incidência de luminosidade aumenta a taxa fotossintética em média de 43% e 33% em solo de textura argilosa e arenosa, respectivamente. A densidade estomática foi maior a pleno sol, enquanto os teores de clorofilas *a* e *b* foram maiores nas plantas sombreadas. Os teores de N e K nas folhas, caule e raízes foram maiores nas plantas sombreadas em até 37%. O teor de P no caule foi superior em 69% e 48% nas plantas cultivadas em solo de textura argilosa e arenosa, respectivamente. A massa seca foi 26% maior nas plantas sombreadas em relação as plantas cultivadas a pleno sol. Em solo de textura argilosa, a massa seca total foi 42% superior em relação as plantas em solo de textura arenosa. Conclui-se que as plantas de *M. sobolifera* apresentam alterações morfofisiológicas (>densidade estomática) que auxilia na adaptação a pleno sol. Entretanto, sob o dossel das culturas agrícolas, esta espécie pode competir intensamente pelos nutrientes, principalmente em solos de textura argilosa.
Palavras-chave: *Maranta sobolifera*, densidade estomática, fósforo, macronutrientes, nitrogênio.

INTRODUCTION

The *Maranta sobolifera* species, commonly known as Caetê, belongs to the *Marantaceae* family and its distribution extends to Argentina, Paraguay and the South and Southwest of Brazil (VIEIRA et al., 2012). As an herbaceous plant with perennial cycle, vigorous vegetative reproduction and ease of regeneration of fragments, the species grows on the edges of forests, humid areas and under reduced sunlight (COSTA et al., 2008; FORZZA, 2007; ZANOTTI et al., 2018). The aggressiveness of the species in agricultural areas of the western region of Paraná has attracted the attention of producers, especially due to its tolerance to herbicides commonly used in agriculture, (KUHN et al., 2022; SALVALAGGIO et al., 2018).

When estimating the damage of *M. sobolifera* plants in commercial areas of cultivation of off-season corn, Kuhn et al. (2021) reported losses in grain yield up to 303.7 kg plant^{-1} of *M. sobolifera* and the lack of information about the species' biology has hampered the implementation of management strategies.

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The best way to control weeds, especially in large areas, includes biological knowledge about the species in their environment. When exposed lower levels of sunlight, some plant species increase photosynthetic rates by more than 40%, which directly improves their development and growth (MORAIS LIMA et al., 2016).

Under less sunlight, plants strategically reduce their stomatal opening to avoid water loss and ensure survival, thus reducing their photosynthetic rate (SILVA et al., 2010). In addition to light, the soil is another important source for the development of plant communities. Aspects related to soil texture indicate the rate of infiltration and water retention, aeration, nutrition, as well as the adhesion or cohesion strength of soil particles (SOUSA et al., 2018).

Thus, as *M. sobolifera*, which is common in shaded areas, is surviving in regions with greater sunlight intensity, an attempt was made to understand which physiology-related aspects can be considered survival strategies for the species. Therefore, we aimed to evaluate physiological changes in response to changes in sunlight exposure (shading up to 50% and full sun) and different soil textures (clayey and sandy soil).

MATERIAL AND METHODS

The open-air field experiment was installed from July 2019 to January 2020, at the Horticulture and Protected Cultivation experimental station (24°33'40” S latitude, 54°04'12” W longitude and 485 m altitude). A completely randomized experimental design was used, and split plots. The main plots corresponded to sunlight exposure (shading up to 50% and full sun) and the subplots corresponded to the soil textural classes (clayey and sandy soil), with five replications. Each replication corresponded to one plant per pot.

To obtain *M. sobolifera* seedlings (Herbário UNOP from Unioeste - 8719), rhizomes of the species were collected in the municipality of Nova Santa Rosa-PR (24°28'08.4” S and 53°58'26.6” W). Rhizomes with 2 to 4 pairs of visibly viable buds were transplanted into pots (44 cm x 16 cm x 16 cm), containing soil with their respective textural class, according to the design, on the day of collection.

The clay textured soil contained 50.70% clay, 38.95% silt and 10.35% sand. Chemical analysis of the clayey soil showed the following results: pH ($CaCl_2$): 5.81; H+Al: 3.52 $cmol_c\ dm^{-3}$; Al^{+3}: 0.00 $cmol_c\ dm^{-3}$; Ca^{+2}: 3.84 $cmol_c\ dm^{-3}$; Mg^{+2}: 1.89 $cmol_c\ dm^{-3}$; K+: 0.24 $cmol_c\ dm^{-3}$; P: 31.20 mg dm^{-3}; OM: 17.77 g $dm^{-3;}$ CEC: 9.50 cmolc dm^{-3} and V: 62.94%. The sandy textured soil had 52.78% sand, 35.2% clay and 12.01% silt. Chemical analysis of the sandy soil showed the following characteristics: pH ($CaCl_2$): 5.80; H+Al: 2.00 $cmol_c\ dm^{-3}$; Al^{+3}: 0.00 $cmol_c\ dm^{-3}$; Ca^{+2}: 1.47 $cmol_c\ dm^{-3}$; Mg^{+2}: 0.95 $cmol_c\ dm^{-3}$; K+: 0.05 $cmol_c\ dm^{-3}$; P: 3.09 mg dm^{-3}; OM: 3.42 g dm^{-3}; CEC: 4.47 $cmol_c\ dm^{-3}$ and V: 55.25%. Data on average temperature (°C) and average global solar radiation (KJ m^{-2}) and average precipitation (mm) over the experimental period are shown in Figures 1a and 1b.

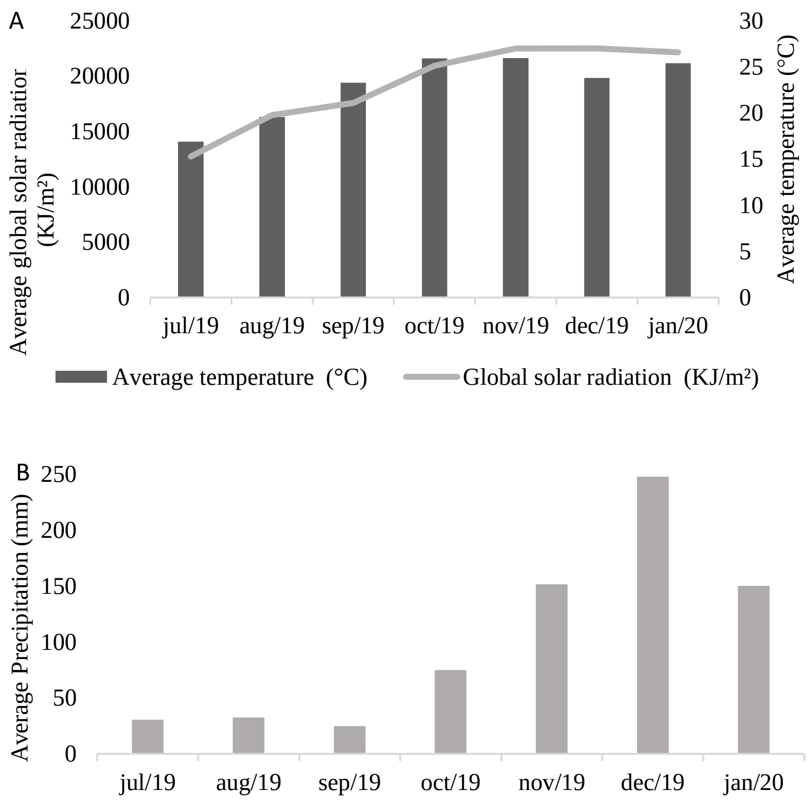


FIGURE 1 - Data on average temperature (°C) and average global solar radiation (KJ m^{-2}) (A), and average precipitation (mm) (B), in the experimental area.

To determine chlorophyll a, b and total, samples of fresh leaf tissue were placed in Falcon tubes covered with aluminum foil and filled with 10 mL of extract solution [80% (v/v) acetone]. The samples were kept at rest in the dark for 48 h, at an average temperature of 25°C and the supernatant was measured on a UV Vis spectrophotometer (Shimadzu, UV1800, Japan), at wavelengths of 645 and 663 nm, with the use of quartz cuvettes. Based on these readings, the concentration (mg cm^{-3}) of chlorophyll a, b and total was determined, using formulas proposed by Arnon (1949).

Nitrogen (N), phosphorus (P) and potassium (K) contents (g kg^{-1}) were determined using leaves dry biomass, stem dry biomass and root dry biomass of *M. sobolifera* plants, previously dried in a forced air circulation oven at 65ºC until a constant mass was obtained and subsequently ground in a Willey-type mill. Macronutrient extraction was performed using the Kjeldahl method of nitrogen determination (N), the colorimetric method (P) and atomic absorption spectrometry (K), adapted by Lana et al. (2016).

The curves obtained on gas exchange indices were adjusted according to a rectangular hyperbola [$y = a*x/(b+x)$], considering a 5% probability of error using the F- test method, where a represents the maximum rate obtained, b represents an adjustment coefficient of the equation and x represents the PPFD. The graphs were plotted in EXCEL Data on adaxial and abaxial stomatal density, chlorophyll a, b and total contents and macronutrient content (N, P, K) were subjected to analysis of variance (ANOVA) and the means were compared by Tukey test, at a 5% probability of error, using the statistical software SISVAR (FERREIRA, 2019).

RESULTS AND DISCUSSION

M. sobolifera plants grown under lower incidence of light showed photosynthetic rates (A) higher than the rates of plants subjected to greater exposure to sunlight (Figure 2). Grown in clayey soil, shaded plants obtained the maximum photosynthetic rate, with values higher than the values of plants grown in full sun and in the same soil texture, on average 43% (Figure 2a). Likewise, in sandy soil, shaded plants also showed the best photosynthetic rates, with the maximum rate obtained being greater than 33% compared to plants grown in full sun. The characteristics observed indicate the presence of C3 metabolism in the monocot, with photosynthetic activity in a range between 12 and 25 μmol m^{-2} s^{-1} (KLUGE et al., 2015).

Regardless of the soil texture, the saturation point of photosynthesis was reached at about 500 μmol m^{-2} s^{-1} of PPFD in plants kept under lower incidence of light, while in plants grown in full sun, the saturation point was reached at about 200 μmol m^{-2} s^{-1}. Plants in less sunlight need a greater amount of light to reach the saturation point; on the other hand, when they are grown in full sun the opposite occurs, as saturation is reached quickly with excess light, and factors such as electron transport reaction, Rubisco activity or triose phosphate metabolism become limiting (HABERMANN et al., 2003).

The results of stomatal conductance (gs) and transpiration (E) data were similar to those obtained for photosynthetic rate data, as can be seen in Figures 2b and 2c. In clayey soil, shaded plants had maximum gs and E values, 60% and 53% higher than those of plants grown in full sun, respectively. When grown in sandy soil, the maximum gs and E values were higher, on average 64% and 54%, respectively, in plants grown in the shade compared to plants entirely exposed to full sun during their growth**.** Morais Lima et al. (2016) reported that the reduction in gs was directly related to the reduction in water availability in the soil. The fact that clayey soils allow greater water retention would explain the higher gs in clayey soil conditions.

The higher gas exchange index rates observed in plants grown in clayey soil compared to sandy texture can also be related to the greater availability of nutrients for the plants. Soil analysis shows that the percentage of base saturation (V%) of the clayey soil was 62.94%. This soil proved to be more fertile than the sandy soil, with V% of 55.25%, as a soil with a percentage of base saturation (V%) greater than 50% can be considered a fertile soil. Therefore, soils with greater fertility allow suitable conditions for the plants to reach maximum growth potential (DIAS et al., 2016).

In the adaxial and abaxial region of *M. sobolifera* leaves, stomatal density was, respectively, 43% and 20% higher in plants exposed to full sun compared to shaded plants. Regarding soil textures, there was a difference in the abaxial region of the leaves, in which plants grown in clayey soil had stomatal density 23% greater than plants grown in sandy soil (Figure 3). Stomatal density is directly related to gas exchange rates, as when there is a high incidence of sunlight, stomatal closure occurs, providing a defense mechanism aimed to reduce water loss (SCHOCK et al., 2014; MORAIS LIMA et al., 2016).

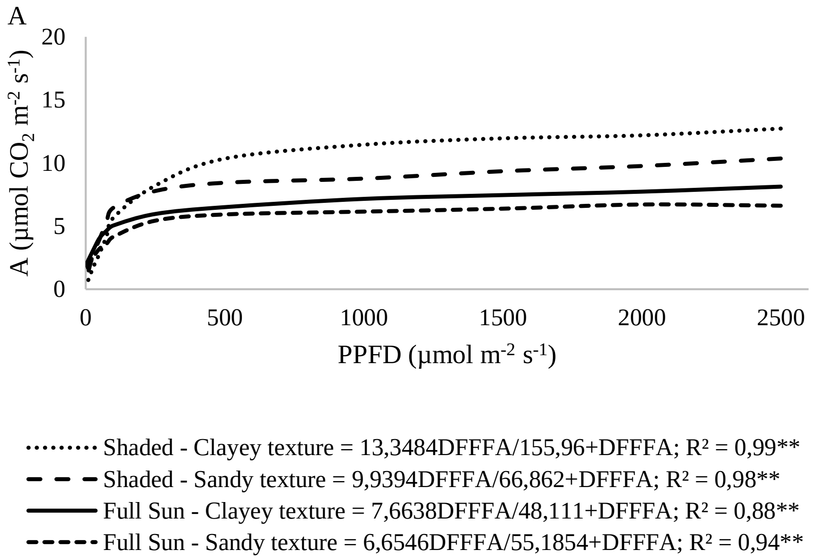
Stomatal closure reduces gas exchange and directly decreases stomatal conductance, transpiration and photosynthetic rates (GOBBI et al., 2011; BALIZA et al., 2012). The increase in stomatal density allows the increase in gas conductance in the plant, and in conditions of high incidence of sunlight, the exchange of gases will be greater than in shaded plants, which are in more favorable conditions to carry out this exchange.

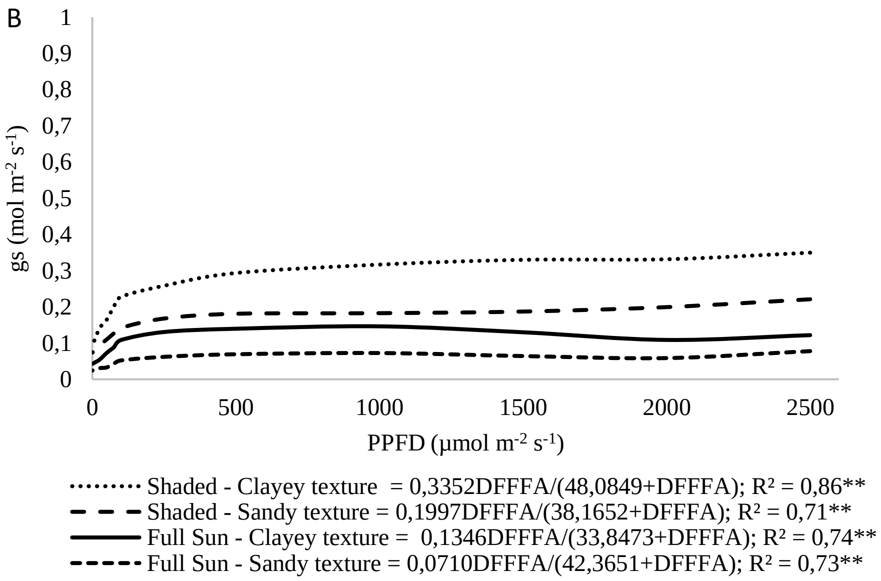
The chlorophyll a content in shaded plants was 32% higher in plants grown in clayey soil and 25% higher in plants grown in sandy textured soil. A difference was also observed in plants kept under shade regarding soil texture, as follows: chlorophyll a content was higher in plants grown in clayey textured soil by 23.04% compared to plants grown in sandy textured soil (Table 1).

Photosynthetic pigments (chlorophylls) are responsible for the absorption of photons, which will begin the photosynthetic process. Under high irradiance, the rate of chlorophyll degradation is greater than that of synthesis, which explains the low values observed in the full sun treatment, compared to the shade treatment (STREIT et al., 2005; LIMA JUNIOR et al., 2005; GONÇALVES et al., 2012).

The lower chlorophyll content in plant leaves reduces the use of photons and, consequently, the subsequent assimilation of CO_2, damaging the photosynthetic process (ZHU et al., 2012). This fact can be confirmed, as chlorophyll *a* and *b* contents tended to be lower in plants grown in full sun compared to shaded plants, with a reduction in the photosynthetic rate and other parameters associated with the gas exchange index (Figure 2). Similarly, this fact occurred with the chlorophyll *b* content for plants grown in clay-textured soil, which was 50.11% lower in plants grown in full sun compared to shaded plants. Furthermore, plants grown in shade and in clayey textured soil had a higher chlorophyll *b* content of 51.95% compared to plants in sandy textured soil.

Regarding the total chlorophyll content, in clayey soil, plants subjected to a higher incidence of light had a total chlorophyll content 35.29% lower compared to shaded plants. Furthermore, in clayey soil, total chlorophyll levels were 27.94% and 14.95% higher compared to plants grown in sandy texture soil.





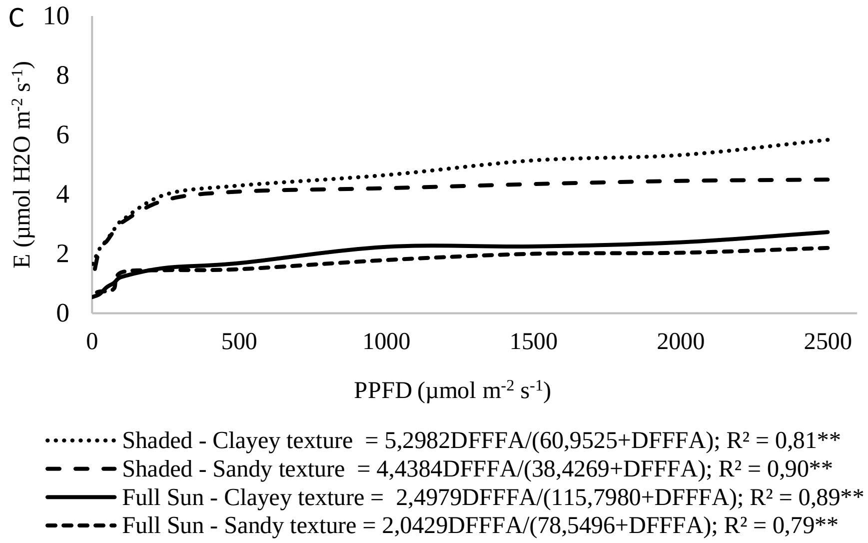


FIGURE 2 - Photosynthetic rates (A), stomatal conductance (gs) (b) and transpiration (E) (c) of *Maranta sobolifera* plants according to photosynthetically active photon flux density (PPFD) subjected to 50% shading and full sun, grown in clayey and sandy soil. **Significant at 5% probability of error.

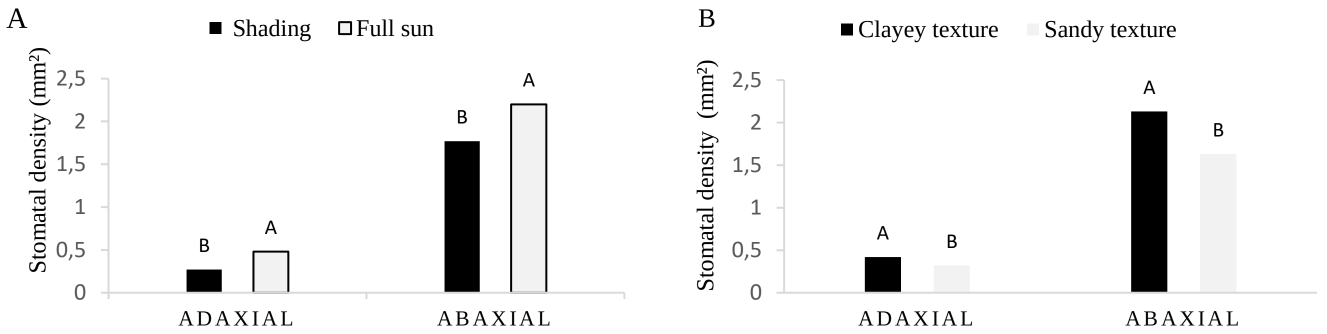


FIGURE 3 - Stomatal density of *Maranta sobolifera* leaves subjected to 50% shading and full sun (a), and grown in clayey and sandy textured soil (b).

TABLE 1 - Average values for chlorophyll *a*, *b* and total contents (*a* + *b*), in *Maranta sobolifera* plants, subjected to 50% shading and full sun, grown in clayey and sandy soil.

Textural class	Chlorophyll *a* content (mg cm^{-3}).	
	Shaded	Full Sun
Clayey texture	21.48 Aa*	14,53 Ab
Sandy texture	16.53 Ba	12,44 Ab
Textural class	Chlorophyll *b* content (mg cm^{-3})	
	Shaded	Full Sun
Clayey texture	4.35 Aa	2.17 Ab
Sandy texture	2.09 Ba	1.76 Aa
Textural class	Chlorophyll *a* + *b* content (mg cm^{-3})	
	Shaded	Full Sun
Clayey texture	25.84 Aa	16.72 Ab
Sandy texture	18.62 Ba	14.22 Ba

*Equal capital letters in the column and lowercase letters in the row do not differ statistically according to Tukey test, at a 5% probability of error.

The results obtained for chlorophyll levels are similar to those obtained in other species, such as *Athyrium pachyphlebium*, *Tapirira guianensis*, *Malus domestica* and *Capsicum anmuum*, with chlorophyll a, b and total levels higher by up to 33% in plants grown under shade (HUANG et al., 2011; AMARANTE et al., 2007). Due to shading, plants need to increase the amount of chlorophyll to ensure greater efficiency in capturing photons (ZHU et al., 2012).

The reduction in the chlorophyll content of plants grown in full sun may also be related to the photooxidation of chlorophyll molecules. In case of excess light, chlorophylls react with O_2 and form unstable molecules known as free radicals, which degrade the structure of chloroplasts and cause irreversible damage to the photosynthetic system (MELO; ALVARENGA, 2009; MORAIS LIMA et al., 2016).

The amount of chlorophyll in the leaves, in addition to having a significant effect on the plant's net photosynthesis, is directly related to nitrogen availability. The greater amount of nitrogen increases the formation of chlorophyll structures (SANTOS; CASTILHO, 2015).

Shaded plants had higher leaf N content than plants grown in full sun, with a difference of 37%. Shaded plants had higher leaf N content than plants grown in full sun, with a difference of 37%. Furthermore, a higher foliar N content was observed in plants grown in clay-textured soil, 19% higher than that of plants grown in sandy-textured soil (Table 2).

TABLE 2 - Average values for the content of nitrogen (N), phosphorus (P) and potassium (K) in the leaves, stem and roots of *Maranta sobolifera* plants subjected to 50% shading and full sun, grown in clayey and sandy soil.

	Nutrient content	Shaded	Full sun
Leaf	N	8.51 A*	5.37 B
	P	1.85 A	1.87 A
	K	15.39 A	13.07 B
Stem	N	5.31 A	3.92 B
	K	18.26 A	13.04 B
Root	N	3.24 A	2.22 B
	K	7.57 A	4.90 B
		Clayey Texture	Sandy Texture
Leaf	N	7.68 A	6.19 B
	P	2.52 A	1.23 B
	K	14.72 A	13.75 A
Stem	N	4.79 A	4.43 A
	K	20.79 A	15.65 B
Root	N	3.06 A	2.39 B
	K	6.76 A	5.71 A

*Capital letters that are the same on the line do not differ statistically according to the Tukey test, at a 5% probability of error.

In many species, high gas exchange rates are associated with high concentrations of foliar nitrogen (LIMA JUNIOR et al., 2005), which is consistent with the results obtained in this study, in which *M. sobolifera* plants grown in the shade and also those grown in clayey soil, showed higher values in gas exchange indices. N content in the stem was 26% higher in shaded plants compared to plants grown in full sun. Shaded plants had N content in the roots 31% higher than plants grown in full sun. As for soil textures, plants grown in clayey soil had N content 22% higher than that of plants grown in sandy soil.

A result similar to that obtained in this study was found by Silva and Marenco (2001), who reported that the highest levels of foliar nitrogen of the weed *Ischaemum rugosum* (1.32%) were obtained in shaded plants. The same authors also did not observe changes in the N content in the roots, regardless of the level of shading, as in the present study. Leaf P content differed between soil textures, so that P content in plants grown in clayey soil was 52% higher than that of plants grown in sandy soil.

Plants grown in the shade had 69% higher P content in the stem when grown in clayey soil and 48% higher when grown in sandy soil compared to plants grown in full sun in the respective soil textures in which they were grown (Table 3). Considering soil textures, P content in the stem differed only for shaded plants, which when grown in clayey soil had a content of this nutrient 53% higher than that of plants grown in sandy soil, under the same light conditions.

Phosphorus (P) is an important nutrient, as it is part of the composition of membrane proteins and lipids, and acts in the formation of nucleic acids (DNA and RNA), in addition to participating in the storage and transfer of energy (ATP and ADP), photosynthesis, respiration and metabolic reactions with energy expenditure (GRANT et al., 2001). Each type of soil, depending on its texture and degree of weathering, has a variable capacity for P adsorption in the soil. Clayey textured soils have greater nutrient availability compared to soils with a sandy texture (MACHADO; SOUZA, 2012).

There was a statistically significant difference in the potassium (K) content in the leaves, stem and roots of *M. sobolifera*. In the leaves, there was an influence of sunlight on leaf K content, with plants grown in shade having a 15.07% higher leaf K content. Regarding the K content in the stem of *M. sobolifera*, plants grown in the shade also had a higher K content in the stem, around 28% higher than the content observed in plants grown in full sun. In addition, plants grown in clay-textured soil had a K content 25% higher than that of plants grown in sandy-textured soil.

In the roots, shaded plants had a K content 35% higher than *M. sobolifera* plants grown in full sun. The results obtained are greater in clayey soils as the nutrient contents are partly explained by the higher V% and organic matter observed in the soil analysis carried out.

TABLE 3 - Average values for phosphorus (P) content in the stem of *Maranta sobolifera* plants subjected to 50% shading and full sun, grown in clayey and sandy soil.

	P content in the stem (g Kg^{-1})	
	Soil texture	
Light	Clayey	Sandy
Shaded	1.72 Aa*	0.81 Ab
Full sun	0.54 Ba	0.42 Ba

*Means followed by the same letter in the column do not differ statistically from each other using the Tukey test, at a 5% probability of error.

The dry mass contents of the aerial part and the belowground system (roots+rhizomes) of *M. sobolifera* plants were 23% and 28% higher in shaded plants compared to plants grown in full sun, respectively (Table 4). Consequently, the total dry mass was 26% higher in shaded plants compared to plants grown in full sun. Under intense sunlight conditions, the species *Solanum americanum* also had a 13% reduction in total dry mass compared to shaded plants (AUMONDE et al., 2013).

The distribution of dry mass has been shown to be directly related to the photosynthetic rate, as the production of dry mass is directly related to the efficiency with which a plant converts radiant energy into chemical energy, through the process of photosynthesis (CARON et al., 2014). For the soil textural classes, the difference observed was 50% and 36% in the dry mass of the aerial part and the root system, respectively, with emphasis on plants in clayey textured soil, which accumulated a total dry mass 42% higher compared to plants in sandy textured soil.

Dipteryx alata seedlings also had 50% higher root dry mass when grown in clay textured soil compared to sandy textured soil, possibly due to the occurrence of a greater number of micropores in soils with a higher clay content texture, which increases the plant capacity to emit more roots for better use of water and nutrients (AJALLA et al., 2012). No major changes in the proportion of dry mass allocation in different environments were observed in this study, despite physiological and anatomical changes in plants of the *M. sobolifera* species. However, the greater accumulation of dry mass in the root becomes greater than that in the aerial part, the organ that represents its main route of dispersion and survival**.**

TABLE 4 - Dry mass in the aerial part, in the root system and in the total dry mass of *Maranta sobolifera* plants subjected to 50% shading and full sun and in clayey and sandy soil textures.

Light	Dry mass (g plant^{-1})		
	Aerial part	Belowground system	Total
Shaded	25.35 A*	34.93 A	60.28 A
Full sun	19.40 B	25.01 B	44.42 B
Soil texture			
Clayey texture	29.92 A	36.50 A	66.43 A
Sandy texture	14.82 B	23.44 B	38.26 B

*Means followed by the same letter in the column do not differ statistically from each other using the Tukey test, at a 5% probability of error.

Strategies such as smaller crop spacing, or fast-growing cultivars (MOREIRA et al., 2013; COSTA et al., 2018) may present low effectiveness for managing the species under study, since they are adapted to shaded environments. For example, in corn, the growth of *M. sobolifera* may be favored, especially at the end of the cultivation cycle, when there is greater shading between the crop rows. Likewise, management with the application of herbicides is also ineffective, as even after application, the species has shown regrowth, with full development and accumulation of dry mass (SALVALAGGIO et al., 2018). Therefore, prevention is the main management method for controlling *M. sobolifera*, chiefly by carrying out appropriate hygiene and cleaning measures of materials, PPE and equipment, in addition to constant monitoring of the area, in order to identify possible outbreaks for rapid eradication of the species.

CONCLUSIONS

M. sobolifera plants undergo physiological changes in the face of changes in exposure to sunlight and soil textures. This fact may explain the occurrence and adaptation of this species in agricultural areas (full sun) and the possibility of it becoming an important competitor with soybean and corn crops, since, even under the crop canopy (shaded environment) *M. sobolifera* plants can compete intensely for soil nutrients, especially in clayey textures.

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