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GROWTH OF *Mimosa caesalpiniifolia* Benth., UNDER SHADE IN THE NORTHEAST SEMI-ARID REGION OF BRAZIL[1]

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ABSTRACT - Seedling production for reforestation aims to achieve the best plant growth in a minimal amount of time, to provide good survival and growth levels after transplantation. During cultivation, it is necessary to know the shading levels that lead to the best growth. The objective of this study was to assess the growth of young *Mimosa caesalpiniifolia* Benth. plants provided with various amounts of shade in the northeast semi-arid region of Brazil. Four types of shade cloth were tested (0, 30, 50 and 70%). Shoot length, stem diameter, stem dry matter, leaf dry matter, total dry matter and leaf area were assessed. Leaf area ratio, specific leaf area, absolute growth rate, relative growth rate and net assimilation rate were also calculated. The different shading levels affected *M. caesalpinifolia* growth, with the best growth indicators observed in plants grown under 50% shade, with increases in plant height, leaf area and total dry matter observed compared to the full sun condition.

Keywords: Caatinga. Seedling production. Shade cloth.

CRESCIMENTO DE *Mimosa caesalpiniifolia* Benth., SOB SOMBREAMENTO NO SEMIÁRIDO NORDESTINO

RESUMO - A técnica de produção de mudas para revegetação visa propiciar o melhor crescimento em um tempo mínimo, de forma a permitir bons níveis de sobrevivência e crescimento após o transplantio para o ambiente definitivo. Dentre as condições de cultivo, há o interesse em se obter os níveis de sombreamento que propiciem o melhor crescimento. Este trabalho teve por objetivo analisar o crescimento de plantas jovens de *Mimosa caesalpiniifolia* Benth. (sabiá) submetidas a sombreamento, no semiárido nordestino. Foram testados quatro tipos de tela de sombreamento (0, 30, 50 e 70%). Foi avaliado o comprimento da parte aérea, o diâmetro do coleto, a massa seca do caule, das folhas, da planta, e a área foliar. Foi calculada a razão de área foliar, a área foliar específica, a taxa de crescimento absoluto, a taxa de crescimento relativo e a taxa assimilatória líquida. Os níveis de sombreamento afetaram o crescimento *M. caesalpinifolia*, com os melhores indicadores de crescimento observados nas mudas mantidas em ambiente sob sombrite 50%, o que proporcionou aumento em altura, área foliar e massa seca das plantas, quando comparado ao tratamento a pleno sol.

Palavras-chave: Caatinga. Produção de mudas. Tela sombrite.

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INTRODUCTION

Seedling production is a technique used to speed up plant production by enabling the early stages of seedling development, in which plants are more sensitive but also more responsive, to be conducted under controlled conditions. It is necessary to understand the main aspects of seedling production in nurseries in order to know which conditions are most favourable for the propagation of a species (SANTELICES; ESPINOZA; CABRERA, 2015). In general, this technique aims to provide conditions that promote maximum growth, allowing good quality seedlings to be obtained in a minimal amount of time.

It is assumed that plants native to the Caatinga biome are highly adapted to intense light, high temperatures and water restriction, but there is little published information (CARVALHO et al., 2006). Light response is an important factor (SILVA et al., 2007; SANTELICES; ESPINOZA; CABRERA, 2015) as there is a collection of interconnected factors that are associated with reduced light. The same environmental factors that cause light reduction can also decrease temperature and wind speed, affecting the microclimate of the plants and their growth in a complex way (CANTU et al., 2013).

Mimosa caesalpiniifolia Benth., widely known in Brazil as sabiá, cebiá, unha-de-gato or sansão-do-campo, is a tree species commonly found in the Caatinga biome. It produces a heavy, hard and compact wood, which is used to make fence posts, stakes, lampposts, firewood and charcoal. During the dry season, its foliage is a valuable fodder for livestock in the semi-arid region (LORENZI, 2008). It is a fast growing species, tolerant to direct light, which makes it ideal for reforestation programs aiming to restore degraded areas (LORENZI, 2008; MAIA, 2004).

The light requirement of a species can be assessed using artificial shading, which, according to Portela, Silva and Piña-Rodrigues (2001), provides uniformity of illumination and allows the effect of light to be isolated and quantified. Several authors make use of shade clothes during shading simulations in order to determine the light requirements of various species during their early stages of development (LENHARD et al., 2013).

Growth analysis is often used to assess the tolerance of different species to changes in the amount of radiation they receive by making use of various parameters to analyse the responses of seedlings to light intensity (BENINCASA, 2003). Thus, plant growth analysis is an important technique for integrating morphophysiological information and inferring the possible responses of plants to environmental changes. In addition, some components of biological fitness, such as survival, competitive ability and reproductive performance, are related to plant size and growth (OLIVEIRA; PEREZ, 2012).

Tree species respond differently to shade. Some grow best under full sun, for example *Tabebuia aurea* (OLIVEIRA; PEREZ, 2012), whereas others cannot tolerate high light levels, for example *Goupia glabra* (DANIEL; OHASHI; SANTOS, 1994). Yet, others are adapted to different light conditions, such as *Caesalpinia pyramidalis* (DANTAS et al., 2009) and *Hymenaea stigonocarpa* (COSTA et al., 2011). However, some nuances are observed in this distribution, with different species growing best at different levels of shade, for example 30% for *Cryptocaria aschersoniana* (ALMEIDA et al., 2004); 50% for *Copaifera langsdorffii* (DUTRA et al., 2012), *Dipteryx alata* (MOTA; SCALON; HEINZ, 2012), *Hymenaea parvifolia* (SILVA et al., 2007) and *Caesalpinia férrea* (LENHARD et al., 2013); or even 80% for *Erythrina velutina* (MELO; CUNHA, 2008).

Therefore, the objective of this study was to assess the initial growth and development of young *M. caesalpiniifolia* plants provided with different levels of shade in the northeast semi-arid region of Brazil.

MATERIAL AND METHODS

The experiment was conducted from May to November 2013 in the Horta Didática II at the Department of Plant Sciences at the Universidade Federal Rural do Semi-Árido (UFERSA) located in Mossoró, Rio Grande do Norte (5º 11' S, 37º 20' W, altitude 18 m). The area is situated in the northeast semi-arid region of Brazil and is characterised by a hot and dry climate with an average annual temperature of around 27.5 ºC, relative humidity of 68.9%, average annual cloudiness of 4.4 tenths and an average annual rainfall of 673.9 mm (CARMO FILHO; ESPÍNOLA SOBRINHO; MAIA NETO, 1991).

Seeds were collected from healthy adult plants near the Museu Vivo do Semiárido (MUVISA), located in the East campus of the UFERSA. The seeds were treated, selected, mechanically cut to overcome dormancy and sown in low density polystyrene trays consisting of 128 cells, using coconut fibre as a substrate. The trays were kept in a seedling nursery in 50% shade for 15 days. After this period, 384 uniform seedlings were selected and transplanted to 1.9 l plastic bags filled with soil from the region. A chemical analysis of the soil is presented in Table 1. The seedlings were placed inside wooden structures covered with knitted shade cloths that provided 0, 30, 50 or 70% shade. The structures were 4.5 by 2.5 by 2.0 m high, with all sides covered with the shade cloth (QUEIROZ; FIRMINO, 2014). Each repetition consisted of one structure completely separate from the others.

Table 1. Chemical analysis (macro and micronutrients) of the soil from the Caatinga area used for production of *M. caesalpiniifolia* seedlings under different levels of shade.

N	OM	EC	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}
----g kg^{-1}----		ds m^{-1}	(H_2O)	------mg dm^{-3}------			-----$cmol_c$ dm^3-----		
0.35	11.36	0.13	8.28	25.8	98.8	95	3.20	0.48	0

(H+Al)	SB	ECEC	CEC	V	m	ESP	Cu	Fe	Mn	Zn
---------$cmol_c$ dm^3----------				--------%--------			---------mg dm^{-3}----------			
0	4.35	4.35	4.35	100	0	10	0.06	2.2	11.3	3.63

The temperature, relative humidity and light in each structure were measured between 8:00 and 10:00 a.m. using a photosynthesis meter (LICOR 6400). During the experiment, manual weeding and daily irrigation were performed in order to control weed germination and maintain the field capacity of the substrate.

The seedlings were arranged in completely randomised blocks in a split-plot design with four replications. The plots represented the four shade levels (0, 30, 50 and 70%), whereas the subplots consisted of eight sampling periods at 21-day intervals after seedling transplantation (0, 21, 42, 63, 84, 105, 126 and 147 days after transplantation, DAT).

At the time of transplanting, and every 21 days, four plants per treatment were harvested for assessment of shoot length (CPA), measured from the apical bud to the soil using a graduated ruler; stem diameter (DC), measured using a pair of digital callipers and leaf area (AF), which was determined using the leaf disk method (SOUZA et al., 2012). The plants were divided into leaves, stem and roots and packed in paper bags before being placed into a dry oven at 65±1ºC, where they were dried until they reached a constant mass for the assessment of leaf dry matter (MSF) and total dry matter (MST). Based on AF and dry matter, the leaf area ratio (RAF), specific leaf area (AFE), absolute growth rate (TCA), relative growth rate (TCR) and net assimilation rate (TAL) were all determined as recommended by Benincasa (2003).

The results were subjected to analysis of variance and F-tests using the SISVAR statistical software, version 5.3 (FERREIRA, 2011). As comparisons of the four shade levels using tests of means could go against the basic assumption of independence, it was decided to compare only the two most contrasting treatments: full sun (sun) and 50% shading (shade), defined as the absence or presence of a factor (the shade cloth), which characterises an acceptable level of independence of treatments. These treatments were compared using a Tukey's test at 5 and 1% probability. To represent plant development over time, regression curves chosen from classic models were generated when representative. The evolution of dry matter, and other parameters associated with biomass (CPA and DC), were modelled using the Verhulst logistic function (1938) and TCA by its first derivative (POMMERENING; MUSZTA, 2015). For the other factors evaluated here, curves were chosen based on the adequacy of their regression coefficients.

RESULTS AND DISCUSSION

CPA, DC, MSF and MST are shown in Figure 1.

Little difference was observed in CPA among the types of shade cloth 21 days after transplantation. However, after 21 days the differences increased and plants under shade showed CPA around 100% greater than that observed among plants under full sun. Shoot height is a useful parameter for evaluating the plant's response to shading, as species show different response patterns depending on their capacity to adapt to variations in light intensity (MUROYA; VARELA; CAMPOS, 1997). According to Moraes Neto et al. (2000), the ability of a species to grow quickly when shaded is an important mechanism for plant acclimation to conditions of low light intensity. This phenomenon is known as shade avoidance, where plants invest their resources into height growth at the expense of growth in other parts, such as stem diameter, in order to outgrow whatever is shading them. Under these conditions there is generally a rapid allocation of assimilates to the shoot, which allows plants to outgrow the nearby vegetation and more favourably expose their photosynthetic surface to light (QUEIROZ; FIRMINO, 2014). However, when height growth is accompanied by a proportional increase in dry matter this is not shade avoidance but rather growth itself.

Results obtained by Câmara and Endres (2008) also show that 60 days after seedling emergence *M. caesalpiniifolia* plants under 50 and 70% shade were taller than plants grown under full sun.

For DC, seedlings without shade showed higher values at 21 days, but this effect was reversed in the other sampling periods. DC growth is usually well correlated with increases in dry biomass. In the case of shade avoidance, a CPA increase is expected at the expense of DC. We did not observe this during this experiment, again indicating that shade conditions favour greater growth in *M. caesalpiniifolia* and not just shade avoidance.

At 63 DAT, DC values of 1.3, 2.5, 2.3 and 2.4 mm were observed for plants under 0, 30, 50 and 70% shade respectively, whereas Câmara and Endres (2008) observed average values of 3.2, 3.6, 2.6 and 2.0 mm for stem diameter in *M. caesalpiniifolia* seedlings under 0, 50, 70 and 92% shade 62 days after emergence. This may be due to the fact that this experiment was conducted at Maceió, Alagoas, under different climate conditions, i.e. lower temperatures and higher relative humidity.

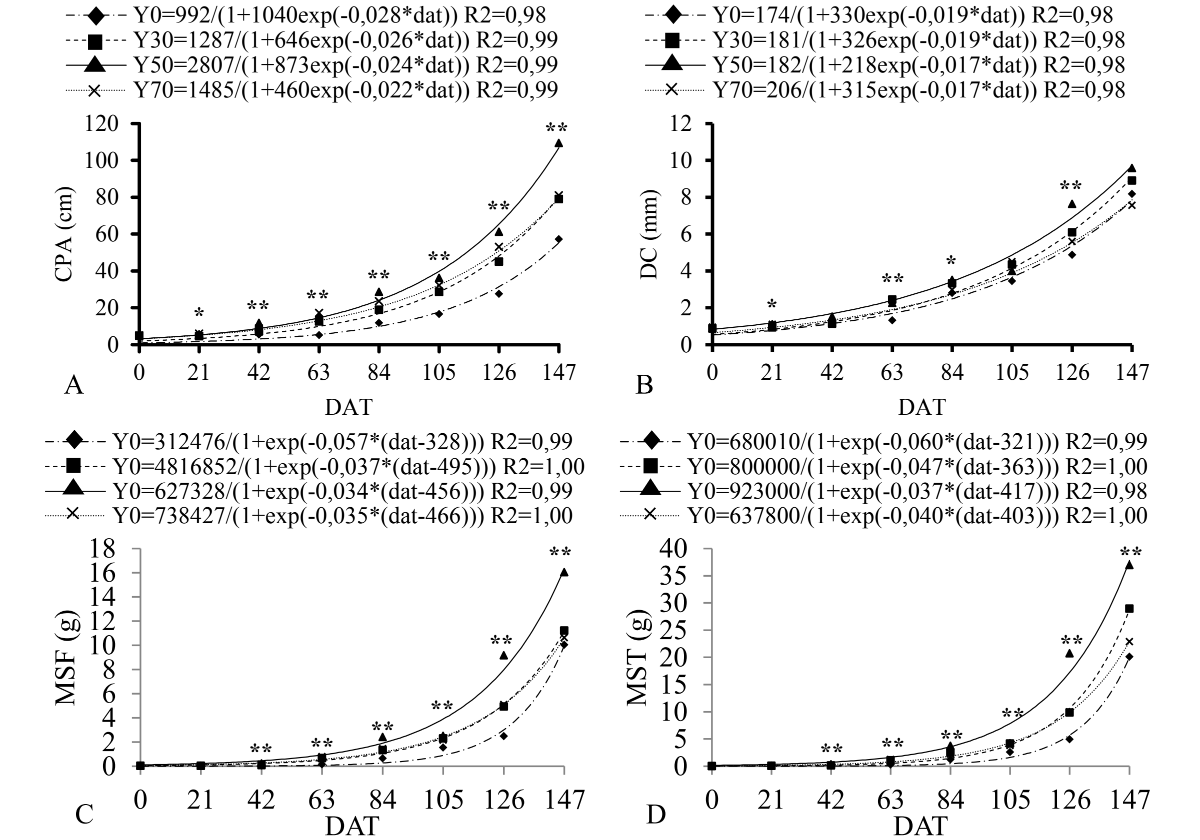

Figure 1. Shoot length–CPA (A), stem diameter–DC (B), leaf dry matter–MSF (C) and total dry matter–MST (D) of *M. caesalpiniifolia* seedlings under shade (● 0%, ◆ 30%, ▲ 50% and ■ 70%); Mossoró, Rio Grande do Norte. Asterisks represent significant differences between treatments of 0 and 50% on each assessment date at a level of 5% (*) and 1% (**).

Gonçalves, Santarelli and Moraes Neto (2000) recommend that a good quality seedling must have a stem diameter ranging from 5 to 10 mm. Thus, acceptable values were found at 126 DAT for *M. caesalpiniifolia* seedlings grown under 30, 50 and 70% shade and at 147 DAT when plants were grown without shade, indicating that plants produced under shade are ready to be transplanted sooner than plants produced without shade.

MSF showed exponential growth under all light intensities, with little leaf mass production up to 63 DAT but increases after 84 DAT (Figure 1C). At 147 DAT, the MSF of plants under 50% shade was 55% greater than that observed for plants grown without shade. Increased investment in leaf production, at the expense of growth in other plant organs, is also an indicator of shade avoidance. At 70% shade, there was a decreasing trend in MSF in relation to 50% shade, indicating the inability of the plants to maintain the levels of investment needed to produce of photosynthetic tissue, i.e. the production of new leaves.

According to Almeida et al. (2004), greater accumulation of leaf dry matter may be a means of compensating for the lower amount of radiation available. These results corroborate those reported by Câmara and Endres (2008), who observed greater accumulation of leaf dry matter in *M. caesalpiniifolia* seedlings grown under 50% shade compared to plants grown under 0, 70 and 92%. However, in the 50% shade condition it was observed that there was an increase in the growth of plants as a whole and not just an increase in the allocation of assimilates to the leaves, indicating higher photosynthetic efficiency under shade.

MST was greater in plants under shade from 42 to 147 DAT, with MST increasing by 55%. This raises an important point. Although the species is native to the Caatinga biome, which is commonly characterised by open vegetation, it grows better in shade. Under 70% shade, the biomass values were similar to those obtained under 30%, indicating that this particular shade level is excessive.

The better growth under 50% shade could be explained in two possible ways. First, under shaded conditions, in addition to an attenuation of light intensity, there could also be changes in other atmospheric conditions such as temperature and relative humidity. The second possibility is that there may be loss of photosynthetic efficiency under high light conditions due to photoinhibition. Table 2 shows the values measured for air temperature and relative humidity under each condition. It was observed that even in the mid-morning there was a significant difference in air temperature and relative humidity between the structures built for the different treatments. Lower air temperatures and higher relative humidity favours stomatal opening, improving CO_2 uptake (LARCHER, 2004). Lower temperatures also favour CO_2 uptake by facilitating the solubilisation of CO_2 in the aqueous phase of the leaf (ANGELOCCI, 2002) and reducing photorespiration (TAIZ; ZEIGER, 2009).

Table 2. Measured values for air temperature, relative humidity and photosynthetic active radiation (PAR) in the plots containing *M. caesalpiniifolia* seedlings. The values were measured around 09:30 a.m.

Shading	Air temperature (ºC)	Relative humidity (%)	Light (µmol PAR m^{-2} s^{-1})
0%	36.7 b	34.2 a	1277
30%	35.0 a	36.8 b	701
50%	34.1 a	38.0 b	518
70%	34.1 a	41.1 c	317
CV (%)	2.76	3.11	33.59

Câmara and Endres (2008) also observed greater shoot dry matter in *M. caesalpiniifolia* seedlings provided with 50% shade compared to plants under 0, 70 and 92% shade 62 days after emergence.

AF showed an exponential trend under all the light levels studied, with higher values obtained under shade and a maximum value of 4709 cm^2 recorded at 147 DAT (Figure 2A).

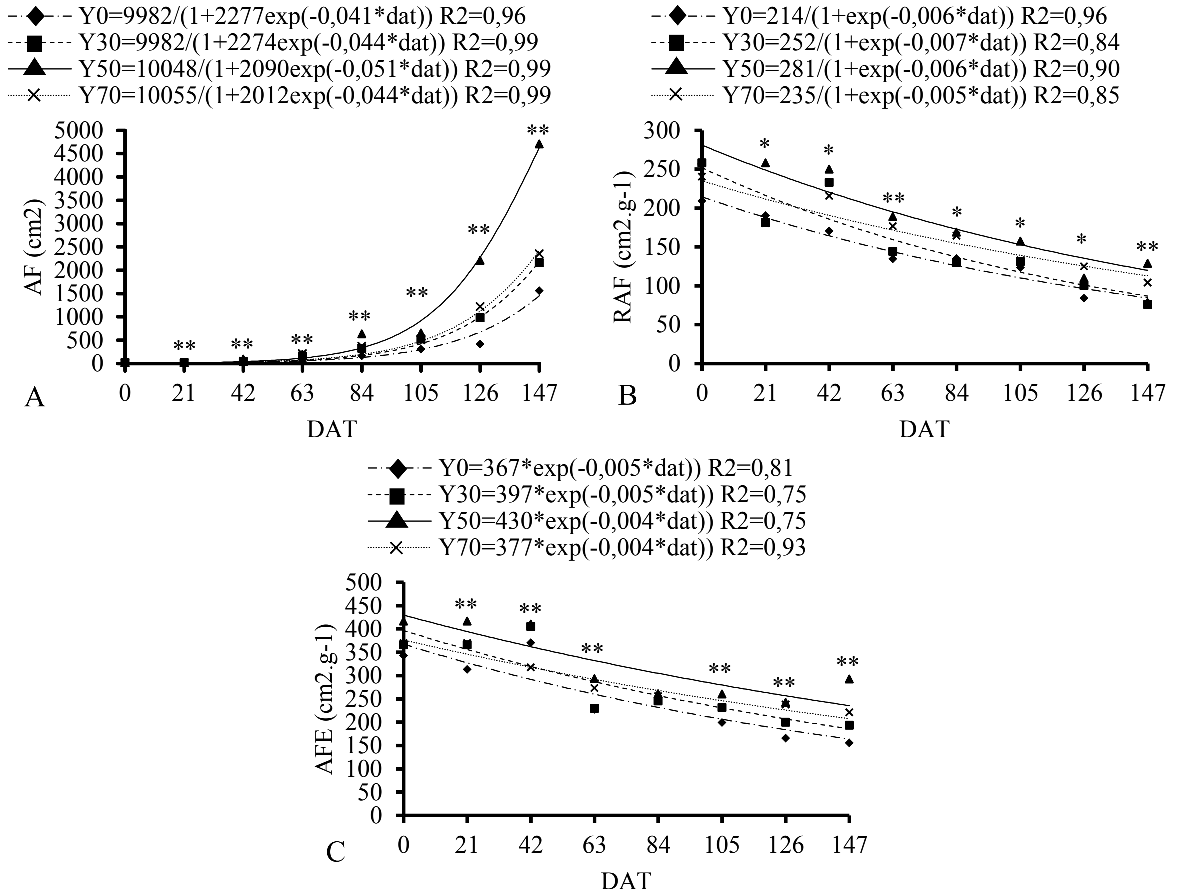

Figure 2. Leaf area – AF (A), leaf area ratio – RAF (B) and specific leaf area – AFE (C) of *M. caesalpiniifolia* seedlings under shading (● 0%, ◆ 30%, ▲ 50% and ■ 70%), Mossoró, Rio Grande do Norte. Asterisks represent significant differences between treatments of 0 and 50%, on each assessment date, at levels of 5% (*) and 1% (**).

From 21 to 147 DAT a greater AF was observed in plants under shade. At 147 DAT their AF was nearly 201% higher in comparison with plants exposed to full sun.

With increasing shade we also observed an increasing trend in AF, with the maximum value obtained at 50% shade, followed by 70% (Figure 2A). The increase in AF could be due to two factors. If the increase is associated with the maintenance or reduction of the total dry matter it would indicate shade avoidance, with investment in leaf area compensating for the loss of photosynthetic efficiency (lower TAL). When seedlings are kept under low light conditions, they increase leaf surface in order to receive greater amounts of sunlight, as sunlight is a limiting factor for growth and photosynthesis (TEIXEIRA et al., 2013). However, an increase in biomass production was also observed (Figure 1D), indicating increased growth under shaded conditions. Under 70% shade, AF showed a decreasing trend, which indicates that the plant has a reduced ability to grow or allocate part of its resources to the maintenance of leaf area. In this situation the shade intensity is considered to be excessive. This hypothesis is supported by the lower total dry matter value at this shade level.

Caesalpinia ferrea seedlings also showed greater AF and MST when provided with shade, compared with the full sun condition, indicating that the first condition was best for growth (LENHARD et al., 2013). In *Caesalpinia pyramidalis* and *Euterpe edulis* provided with 50% shade AF was greater, whereas MST did not change, indicating light compensation (DANTAS et al., 2009; NAKAZONO et al., 2001).

RAF and AFE decreased over time (Figure 2B and 2C respectively). RAF expresses the functional leaf area for photosynthesis, consisting of a ratio between the leaf area responsible for the interception of light energy and CO_2 and the total dry matter resulting from photosynthesis, i.e. the leaf area needed to produce 1 g of dry matter (BENINCASA, 2003). Thus, the results show that functional AF reduced over time in all the light conditions tested here. The decrease in RAF over time occurs as a result of an increased amount of "dead" tissue in the stem and roots.

When the shade and full sun treatments were compared, it was observed that there was a greater proportion of investment in leaf production under shade. If plants invest a larger fraction of their resources in the leaf area it is because they need to absorb more light, which means that the light level in this situation is not ideal, demanding compensation through increased AF production. It is noteworthy that, despite the light limitation assumed here, these plants showed better growth.

In *Hymenaea parvifolia*, the highest RAF was observed in seedlings grown under natural shade, followed by seedlings grown under 70% shade and then seedlings grown under 50% shade and full sun, which were statistically similar (SILVA et al., 2007). In *Caesalpinia ferrea*, RAF was also higher in plants grown under low light intensities, with values of 52 to 24 cm^2 g^{-1} recorded for 70 and 0% shade respectively (LENHARD et al., 2013).

At 147 DAT, AFE was statistically different at 1% probability, with an increase of 88% for plants provided with 50% shade.

According to Benincasa (2003), leaf area is a morphophysiological component of a plant species, while mass is an anatomical component as it is related to the internal structure (number and size) of mesophyll cells. Therefore, it can be inferred that AFE is inversely related to leaf thickness, i.e. the higher the AFE of a given species, the smaller the thickness of its leaves. AFE is an important shade indicator, as a compensatory increase in AF often occurs without a proportional increase in leaf biomass, due to the limitation of photosynthesis, resulting in lower AFE.

In *Caesalpinia pyramidalis*, greater AFE was also observed among seedlings grown under a 50% light condition (DANTAS et al., 2009).

After 126 days, plants provided with 50% shade showed an increase of 606% in TCA compared to plants subjected to full sun. However, at 147 DAT no significant differences were observed (Figure 3A).

TCA can be used to get an idea of the average growth rate over an observation period (BENINCASA, 2003). There were no differences in the TCA of *Hymenaea parvifolia* plants exposed to full sun or 50% shade, while higher shade levels led to a reduction in this variable (SILVA et al., 2007). From 60 to 100 days after emergence, Dantas et al. (2009) found statistical differences in the TCA of *Caesalpinia pyramidalis* plants grown under different light conditions, with a decreasing trend linked to increased shade.

The TCR of seedlings grown under 50 and 70% shade showed an increasing trend up to 63 DAT that reversed thereafter. As for seedlings grown under 0 and 30% shade, the TCR showed an increasing trend up to 84 DAT that decreased thereafter. This may be due to the fact that plants show greater vigour in the early stages of growth before becoming less vigorous over time. From 42 DAT, TCR was higher in plants provided with shade than in plants subjected to full sun, with an increase of 69% after 147 days (Figure 3B). Relative growth rate is a measure of the speed with which a plant grows compared with its initial size (Benincasa, 2003). TCR values recorded during this study support the hypothesis that there was higher plant growth under shade.

While studying *Caesalpinia pyramidalis*, Dantas et al. (2009) found that between 30 and 60 days after emergence seedlings responded differently to light intensities, with those subjected to 30% shade showing higher TCR than those provided with the highest level of shade (75%).

Hymenaea parvifolia plants subjected to full sun and 50 and 70% shade had TCR values that were not statistically different from each other. However, there was a significant difference between these plants and plants grown under natural shade (closed forest canopy) (SILVA et al., 2007).

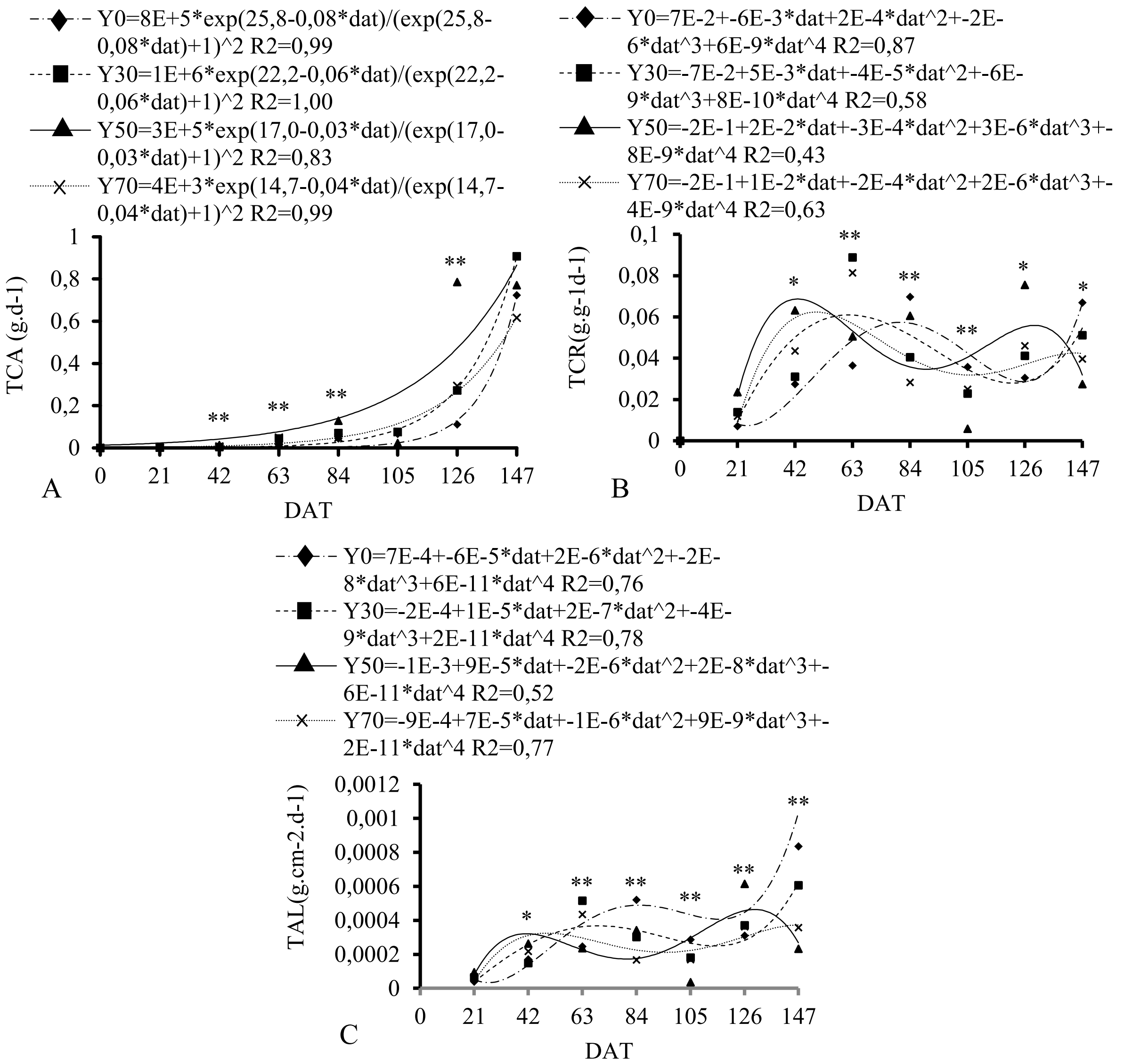

Figure 3. Absolute growth rate–TCA (A), relative growth rate–TCR (B) and net assimilation rate–TAL (C) of *M. caesalpiniifolia* seedlings under shade (● 0%, ◆ 30%, ▲ 50% and ■ 70%), Mossoró, Rio Grande do Norte. Asterisks represent significant differences between treatments of 0 and 50% on each assessment date at levels of 5% (*) and 1% (**).

For TAL, there was a significant effect from 42 DAT, with an increase of 64% in plants provided with shade. TAL expresses the photosynthetic efficiency of the plant in terms of the dry matter produced per unit leaf area, per unit of time (BENINCASA, 2003); therefore, this demonstrates again that the plants ability to grow in shade is greater than under full sunlight.

There were no differences in the TAL of Caesalpinia pyramidalis seedlings under conditions of 0, 30, 50 and 75% shade (DANTAS et al., 2009). In Hymenaea parvifolia, the TAL obtained under 70% shade was lower than that obtained under full sun and 50% shade, but there were no differences in growth rates due to compensation through increased RAF (SILVA et al., 2007).

TAL, TCA, TCR, AF and RAF were greater in plants provided with shade, leading to greater biomass production (MST) and suggesting that this is the most favourable condition for the production of these plants.

CONCLUSIONS

M. caesalpiniifolia shows higher leaf area, height and dry matter values in a shaded environment compared to full sun.

The higher height and leaf area values from the shaded environment are not signs of shade avoidance, suggesting that M. caesalpiniifolia shows better growth when grown in a shaded environment.

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