

Water and Nutritional Management on the Growth and Chlorophyll *a* Fluorescence of Plants Used in the Revegetation of Remaining Sand and Clay Extraction Areas

André Lucas Reboli Pagoto¹, Robson Bonomo², Adriano Alves Fernandes², Antelmo Ralph Falqueto², Rayane Rosa¹, André Luiz Ribeiro Azeredo², João Vítor Garcia Silva¹ & Adriele dos Santos Jardim¹

¹ Postgraduate Program in Tropical Agriculture, Federal University of Espírito Santo, São Mateus, ES, Brazil

² Federal University of Espírito Santo, São Mateus, ES, Brazil

Correspondence: André Lucas Reboli Pagoto, Postgraduate Program in Tropical Agriculture, Federal University of Espírito Santo, São Mateus, ES, Brazil. E-mail: andrelucasrebolipagoto@gmail.com

Received: December 10, 2021

Accepted: January 31, 2022

Online Published: February 15, 2022

doi:10.5539/jas.v14n3p136

URL: <https://doi.org/10.5539/jas.v14n3p136>

Abstract

The processes of using the environment and natural resources are increasingly necessary and present in human society. These processes can result in environmental degradation. A recovery strategy for an area that has undergone environmental degradation is revegetation. For the successful establishment of a plant species, the environment must have adequate water and nutritional conditions. The objective of this work was to study the effect of water and nutritional management on the survival, growth, and morphophysiological conditions of plants used in the revegetation of remaining sand and clay extraction areas. The experiment was carried out in a sand loan extraction area and a clay loan extraction area, both in the coastal region of the municipality of São Mateus, Espírito Santo, Brazil. The experimental design was a randomized block with three replications in a split-plot scheme, using methods of water management in the plots and doses of fertilization (0.000 kg, 0.072 kg, 0.144 kg, 0.288 kg and 0.576 kg) in the pits in the subplots. In both areas, five different species of native plants were used: Aroeira (*Schinus terebinthifolius* Raddi), Cajá Mirim (*Spondias mombin* L.), Goiaba do Ipiranga (*Psidium cattleianum* Sabine), Ingá Mirim (*Inga laurina* (Sw.) Willd.) and Murta de Restinga (*Mouriri guianensis* Aubl.). The plants used in the experiment were evaluated for growth, survival, leaf attributes, and chlorophyll *a* fluorescence. The water management method and the fertilization of the pit had a significant effect on the development of the species evaluated in both areas, acting on the survival rate, growth, morphology and physiology of the plants.

Keywords: aroeira, chlorophyll *a* fluorescence; coastal tableland; restinga; leaf attributes; recovery of mining-degraded areas

1. Introduction

The preservation of the environment has been continuously increasing in the daily lives of human society. Brazil has become worldwide notorious for its biodiversity and the size of its native reserves. Much of the degradation of the Brazilian environment is the result of the exploitation of natural resources, with fossil fuels being the most important and most exploited by human society, especially oil (dos Santos, 2012)

The processes of environmental degradation affect different environments at different intensities, and each scenario has a particularity that impairs the process of environmental recovery. The degraded area is a concept that refers to anthropogenic alterations caused in a natural environment (Corrêa, 1998). These areas have low nutrient availability, low water retention capacity, and high soil compaction, which are characteristics that make the environment unsuitable for plant development and hamper the natural regeneration process (Felfili et al., 2008).

Water is the most limiting environmental factor for plant development, as it alters plant metabolism, causing losses in production, being the main cause of losses in forest productivity (Flexas et al., 2002). When subjected to conditions of limited water supply, plants change their physiological and morphological processes, influencing their ability to tolerate adverse environmental conditions (Pimentel, 2005). Plant growth and development, whether at the beginning, middle, or end of the cycle, are impaired under the condition of water deficit (Taiz et al. (2017).

Some technologies minimize the effect of damage caused by the lack of water and may contribute to the recovering process of degraded areas. Hydro-retaining polymers or hydrogels are macromolecules with segments of hydrophilic groups that can absorb and retain liquids (Monteiro Neto et al., 2017). When incorporated into the soil, the hydro-retainer improves its physical and chemical properties, especially in aeration, retention, and availability of water and soluble nutrients (El-Asmar et al., 2017). As a result, the hydrogel reduces the effects of water deficit and promotes greater nutrient absorption, thus contributing to better plant growth (Navroski et al., 2014).

Soil fertility is also crucial for the success of revegetation in a degraded area. For the adequate development of the inserted species, it is necessary to correct fertility (fertilization), which is more accentuated in the early stages of development (Almeida et al., 2016). The biological differences between the species used in the revegetation processes provide different nutritional needs, so it is necessary to individually assess the response of each species to the given nutrition (Silva et al., 2017).

The morpho-functional characteristics of plants respond directly to changes in the environment and can be used as parameters to assess establishment and performance in a revegetation area. Photosynthesis is the most important physiological event for a plant and all biological processes depend on it, according to Taiz et al. (2017), the environmental conditions in which a plant is found directly influence the photosynthetic performance of a plant.

In addition to physiological changes, environmental conditions, directly or indirectly, act on the structure of plants, modifying their morphology. These changes can be directly observed by evaluating the structures of the affected plant, or indirectly by evaluating the physiological processes that are affected (Yusuf et al., 2010). Transient chlorophyll *a* fluorescence is a technique widely used in the physiological assessment of plant individuals (Stirbet, 2011), as it provides several parameters and enables the observation of specific points in the photosynthetic electron transport chain.

Another alternative for evaluating the performance of individuals in an area of revegetation is the study of the morphological characteristics of the plants. The leaf tissue of a plant, in most cases, makes up the majority of the individual, so evaluations that use this tissue cause little damage to the plants and allow new evaluations.

The objective of this work was to study the effect of water and nutritional management on the survival, growth, and morphophysiological conditions of plants used in the revegetation of remaining areas of sand and clay extraction.

2. Methodology

2.1 Characterization of the Experimental Areas

The experiment was carried out from April to November 2019. The plants were evaluated in two locations with different soil origins, a sand native area, and a clay native area. The areas provide the raw material for the construction and maintenance of the road system, in addition to the construction of well-bases in the oil exploration areas in the region of São Mateus, Espírito Santo state, Brazil. The region's climate is defined as Aw, according to Koppen's international classification, hot and humid tropical, with two well-defined seasons, a dry season in autumn/winter and rainy in spring/summer, with an average temperature of 24 °C (Alvares et al., 2014).

The clay loan area is located in a coastal tableland, 14.3 kilometers from the coast with a current extraction area of three hectares. The sand loan area is located in the Restinga area, 11.3 kilometers from the coast with a current extraction area of 3.88 hectares. After the extraction of the material of interest, a place denominated the bottom of the pit is formed, which is characterized by being the lowest part of the terrain, and the experiments were implemented in these places. The physicochemical soil attributes of the areas are expressed in tables 1, 2, and 3.

Table 1. Soil physical characteristics in clay and sand loan areas in the 0-20 and 20-40 cm layers

Area	Depth	Coarse sand	Fine sand	Total sand	Silt	Clay	Textural classification
	---- cm ----	----- g kg ⁻¹ -----					
Clay	0-20	282	116	398	122	480	Clayey
	20-40	308	130	438	102	460	Clayey
Sand	0-20	910	46	956	4	40	Clayey
	20-40	774	92	866	74	60	Sandy

Table 2. Soil physical characteristics in clay and sand loan areas in the 0-20 cm layer

Area	pH	O.M.	P	K	Ca	Mg
		g kg ⁻¹	----- mg dm ⁻³ -----		----- cmol _c dm ⁻³ -----	
Clay	4.60	4.73	0.69	8.75	0.26	0.21
Sand	5.48	5.21	34.25	9.00	0.14	0.03
Area	Al	H+Al	SB	T	V	M
			----- cmol _c dm ⁻³ -----		----- % -----	
Clay	0.68	2.20	0.59	2.79	20.45	55.42
Sand	0.10	3.50	0.20	3.70	8.80	21.37

Note. M.O.: organic matter; P: phosphorous content in the soil; K: potassium content in the soil; Ca: calcium content in the soil; Mg: magnesium content in the soil; Al: aluminum content in the soil; H+Al: soil hydrogen and aluminum content; SB: sum of bases; T: cation exchange capacity; V: base saturation; M: aluminum saturation.

Table 3. Soil water characteristics in clay and sand loan areas

Area	Field capacity (cm ³ cm ⁻³)	Permanent wilting point (cm ³ cm ⁻³)
Clay (0-20)	0.6871	0.1953
Clay (20-40)	0.4394	0.1580
Sand	0.1738	0.0502

2.2 Meteorological Data

Meteorological data were obtained from a Davis 6162 Wireless Vantage Pro2 Plus weather station, located in flat terrain at 1400 meters from the clay loan area and 8300 meters from the sand loan experimental area. The information used in this paper corresponds to April to November 2019 (Figures 2, 3, 4, and 5), the period when the experiment was conducted.

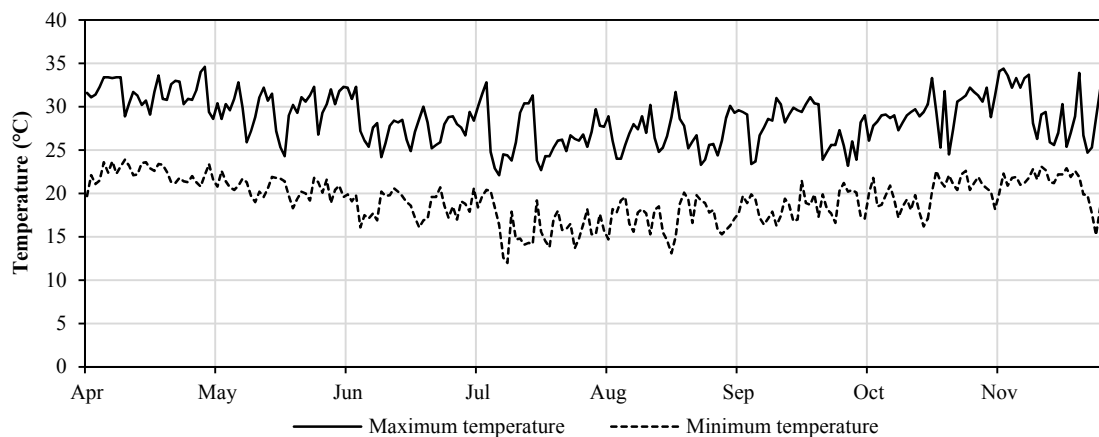


Figure 1. Maximum and minimum daily air temperatures (°C) in clay and sand loan areas

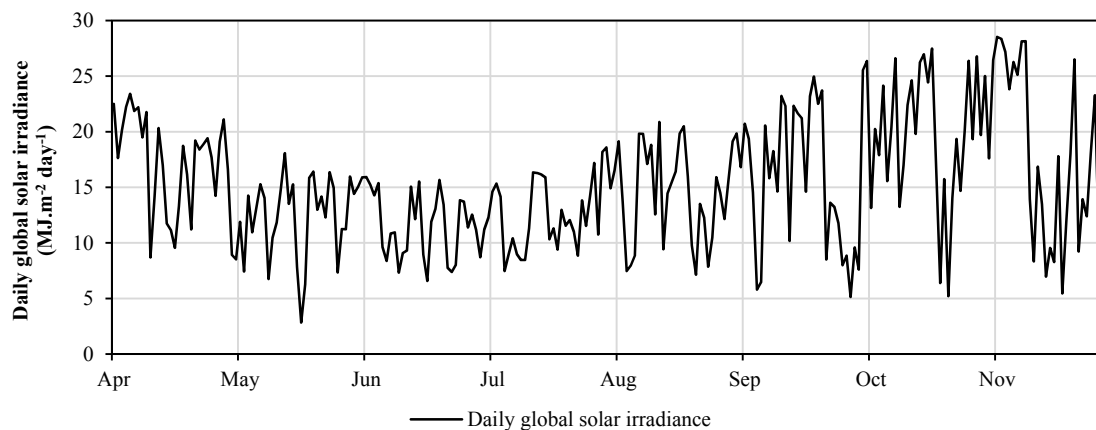


Figure 2. Daily global solar irradiance ($\text{MJ m}^{-2} \text{day}^{-1}$) in clay and sand loan areas

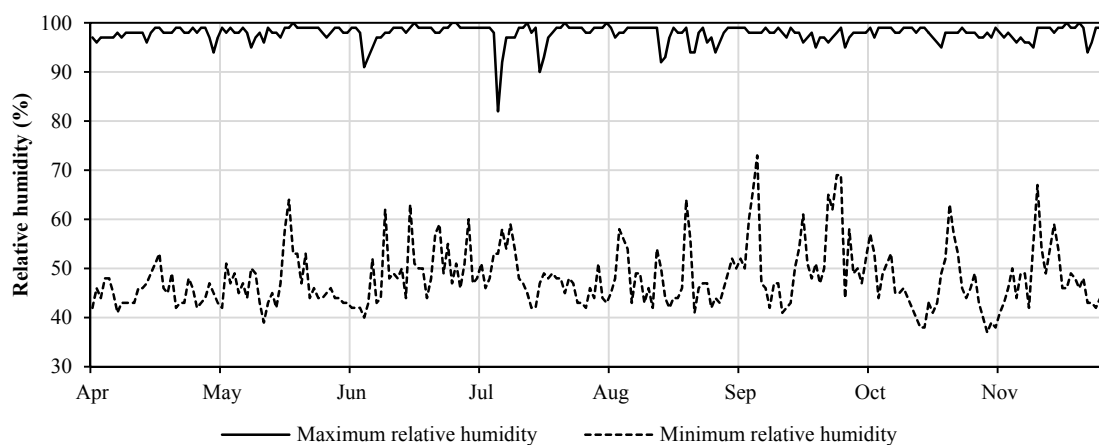


Figure 3. Daily minimum and maximum relative humidity (%) in the clay and sand loan areas

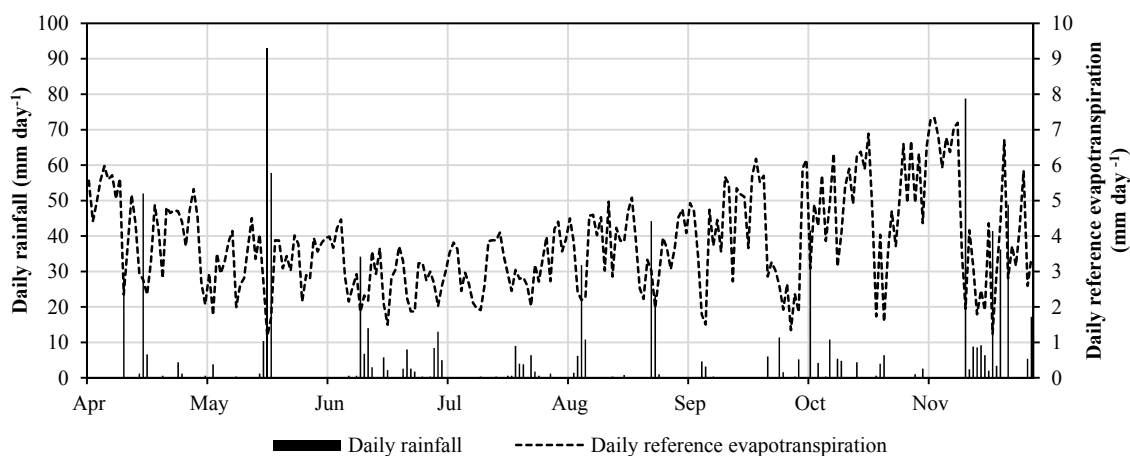


Figure 4. Daily rainfall (mm) and daily reference evapotranspiration (mm day^{-1}) in the clay and sand loan areas

2.3 Experimental Design

2.3.1 Clay Loan Experimental Area (Coastal Tableland)

In the clay loan area, a randomized block design was used as the experimental design with three replications in a 2×5 split-plot scheme. The plot was represented by two water management methods: with a hydro-retainer and without a hydro-retainer. The subplots were represented by the five doses of fertilization in the pit using the NPK

04-14-08 formulated fertilizer of the commercial brand Natufert®, composed of potassium chloride (KCl), carbamide ((NH₂)₂CO), phosphorus pentoxide (P₂O₅), mixed with organic matter. The doses were: 0, 0.072, 0.144, 0.288 and 0.576 kg per pit. Fertilization followed as a basis the recommendation for native essences according to Prezotti et al. (2013).

2.3.2 Sand loan Experimental Area (Restinga)

In the sand loan area, the experimental design adopted was a randomized block design with three replications in a 3 x 5 split-plot scheme, with three methods of water management in the plot: the use of a drip irrigation system, with a hydro-retainer and without water management. In the subplots, the treatments were five doses of fertilization in the pits using the NPK 04-14-08 formulated fertilizer of the commercial brand NATUFERT®, composed of potassium chloride (KCl), carbamide ((NH₂)₂CO), phosphorus pentoxide (P₂O₅) mixed with organic matter. The dosages were: 0.000, 0.072, 0.144, 0.288 and 0.576 kg. Fertilization followed as a basis the recommendation for native essences according to Prezotti et al. (2013).

2.4 Tillage and Planting

2.4.1 Clay loan Experimental Area (Coastal Tableland)

Tillage was carried out by subsoiling the area to an average depth of 60 cm. The pits were marked in a triangular pattern with a distance of 1.2 meters between them. After digging the pits, they were fertilized following the description using the doses corresponding to the treatments. Five species of native plants were used: Aroeira (*Schinus terebinthifolius* Raddi), Yellow mombin (*Spondias mombin* L.), Araçá Vermelho (*Psidium cattleianum* Sabine), Ingá Mirim (*Inga laurina* (Sw.) Willd.) and Murta da Restinga (*Mouriri guianensis* Aubl.), which are defined by their natural presence in the region's ecosystem and by their commercial availability. Planting was carried out on April 11, 2019, with the application of the hydro-retainer solution which was prepared at planting. Thus, 0.5 liter of the solution was applied per pit, at a concentration of 8 g of hydro-retainer agent for each liter of water, corresponding to 4 g of hydro-retainer gel per plant. The product used in the experiment was the Hydroplan® soil conditioning water-retaining gel-EB/HyB. After planting, the seedlings were covered for their protection using a handmade structure composed of wooden (eucalyptus) rods and non-woven fabric (NWF) popularly known as "flags".

At 30 days after planting, the cover of the seedlings was removed and staking was carried out to avoid lodging. As needed, control of invasive plants was carried out in the area through manual weeding. All plants received topdressing fertilization, at a dose of 25 g plant⁻¹ of NPK 20-00-20, from planting, every 60 days and during the complete experimental period.

2.4.2 Sand loan Experimental Area (Restinga)

To establish the transit of heavy machinery during the exploration process in the area, the deposition of a clayey soil layer at the bottom of the pit is the standard protocol. This layer was removed to promote the prevalence of the sand fraction, the predominant soil characteristic in the region. Afterward, the pits were demarcated following a triangular pattern with a distance of 1.2 meters between pits. After digging, fertilization was carried out with the doses proposed for the treatments.

Planting was carried out on April 12, 2019, with the application of the water-retaining solution made at the time of planting. A 0.5-L solution was applied per pit, at a concentration of 8 g of hydro-retainer agent for each liter of water, corresponding to 4 g of hydro-retainer gel per plant. Hydroplan® soil conditioning hydro-retainer gel-EB/HyB was used. After planting, the seedlings were covered for their protection using a handmade structure composed of wooden stalks (eucalyptus) and non-woven fabric (NWF) popularly known as "flags".

The irrigation system was implemented after fertilizing the pits using a drip tape of 1.2 L h⁻¹, at 100 kPa, spaced at 0.2 m. The system was automatic-controlled which enabled the programmed application of the predetermined water depth. Irrigation was performed twice a day with 12-hour intervals between each application, when necessary. The applied water depth was obtained using the daily water balance, considering precipitation and crop evapotranspiration for a unitary crop coefficient, with the estimate of reference evapotranspiration obtained through the Penman-Monteith method. The data used in the experiment were obtained from the weather station set in the oil production unit. The update of the applied water depth was carried out weekly and applied over the experimental period.

At 30 days after planting, the cover of the seedlings was removed and staking was carried out to avoid lodging. As needed, control of invasive plants was carried out in the area through manual weeding. All plants received topdressing fertilization, at a dose of 25 g plant⁻¹ of NPK 20-00-20 since planting, every 60 days and during the complete experimental period.

2.5 Evaluations

2.5.1 Survival and Growth

After 180 years of planting, evaluations were made for the following growth characteristics: plant height (PH), with the aid of a measuring tape, graduated in millimeters; stem diameter (SD), measured at ground level with the aid of a digital caliper; and the total number of leaves (LN), obtained by counting all developed leaves. The survival rate of the plants was also evaluated.

2.5.2 Chlorophyll *a* Fluorescence

At 180 days after planting, chlorophyll *a* fluorescence was evaluated using a portable fluorometer (Handy-PEA, Hansatech, UK). Two plants were used per treatment in each block, chosen at random. A reading was performed on each plant. Chlorophyll *a* fluorescence was induced by red light (650 nm) of approximately $3,000 \mu\text{mol m}^{-2} \text{s}^{-1}$. To make the light-collecting system fully oxidized, complete oxidation of the reaction centers was necessary. This was done using a 30-minute dark adaptation of young and fully developed leaves (third or fourth leaf from the apex), with the aid of leaf clips (Hansatech, UK). Readings were performed from 6:00 a.m. to 10 a.m. With the aid of the Biolyzer software, data were obtained for the interpretation of the parameters of the JIP test, which was performed according to Strasser & Strasser (1995). The parameters obtained from the JIP Test allow the quantification of the absorption efficiency and energy use through the photosynthesis electron transport chain. Besides evaluating the functionality of photosystem II (FSII), it reflects the rate of electron transport within the thylakoid membrane and the subsequent functioning of ferredoxin-NADP oxidoreductase and Calvin cycle (Schansker et al., 2003).

The variables analyzed through chlorophyll *a* fluorescence were the following:

- Minimum fluorescence (F_0), fluorescence intensity at 0.02 ms of OJIP transient;
- Maximum fluorescence (F_m), fluorescence maximum intensity at P point at 300 ms of OJIP transient;
- Primary photochemical maximum quantum yield (ϕ_{p0}), obtained through the equation:

$$\phi_{p0} = 1 - (F_0/F_m) \quad (1)$$

- Quantum efficiency of the transfer of an electron from Q_A to the electron transport chain beyond Q_A (ϕ_{E0}), obtained through the equation:

$$\phi_{E0} = 1 - (F_0/F_m) \times \psi_0 \quad (2)$$

- Photochemical quantum yield for heat dissipation (ϕ_{D0}), obtained through the equation:

$$\phi_{D0} = F_0/F_m \quad (3)$$

- Specific flow of energy absorption per reaction center (ABS/RC), obtained through the equation:

$$\text{ABS/RC} = M_0/V_j/\phi_{p0} \quad (3)$$

- Capture per reaction center (TR_0/RC) obtained through the equation:

$$TR_0/RC = M_0/V_j \quad (5)$$

- Transport per reaction center (ET_0/RC), obtained through the equation:

$$ET_0/RC = TR_0/RC \times (1 - V_j) \quad (6)$$

- Dissipation per reaction center (DI_0/RC), obtained through the equation:

$$DI_0/RC = \text{ABS/RC} - TR_0/RC \quad (7)$$

- Potential performance index (PI_{abs}), obtained through the equation:

$$PI_{\text{abs}} = \text{ABS/RC} \times \phi_{p0}/(1 - \phi_{p0}) \times \phi_{E0}/(1 - \phi_{E0}) \quad (8)$$

- Total performance index (PI_{total}), obtained through the equation:

$$PI_{\text{total}} = PI_{\text{abs}} \times (\delta_{R0}/(1 - \delta_{R0})) \quad (9)$$

2.5.3 Leaf Attributes

At 180 days after planting, the leaf attributes of the plants were also evaluated. With the aid of a metal leaf disc extractor, three leaf discs were extracted from the median region of the leaf blade, with 27.99 mm^2 in diameter. With the aid of a precision digital scale (0.0001 g), the three leaf-discs were weighed to obtain the value of the total fresh mass (FM) of the three discs. Then, the discs were placed in Petri dishes and hydrated with distilled water for 24 hours, and then thickness measurements (mm) of each disc were performed using a digital caliper (Digimess®).

100.174BL 150 mm/6) and mass was measured to obtain the turgid mass (TM) value. Finally, the discs were placed in paper bags and placed in an oven for drying at around 60 °C, until a constant dry mass (DM) was obtained. From the values of fresh, turgid, and dry mass obtained, the following were calculated:

- Leaf succulence (SUC) (g m^{-2}) obtained through the difference between the leaf turgid mass and leaf dry mass divided by the area of the leaf discs (Kluge & Ting, 1978);
- Fresh mass per leaf area (FMA) (g m^{-2}) estimated by the ratio between leaf dry mass and leaf area (Kluge & Ting, 1978);
- Specific Leaf Area (SLA) ($\text{cm}^2 \text{g}^{-1}$) estimated by the ratio between leaf disc area and leaf dry mass (Witkowski & Lamont, 1991);
- Sclerophylly index (SI) (g cm^{-2}) was obtained with half of the ratio between leaf dry mass and leaf disc area (Rizzini, 1976).

2.5.4 Statistical Analysis

The obtained data were subjected to analysis of variance and when their significance was determined, they were subjected to test of the means (Tukey at 5%) for the results corresponding to the use of hydro- retainers and regression analysis in the case of results corresponding to planting fertilization. Statistical analyses were performed with the aid of the SISVAR statistical software (Ferreira, 2011).

3. Results and Discussion

3.1 Clay Extraction Experimental Area (Coastal Tableland)

3.1.1 Survival Rate

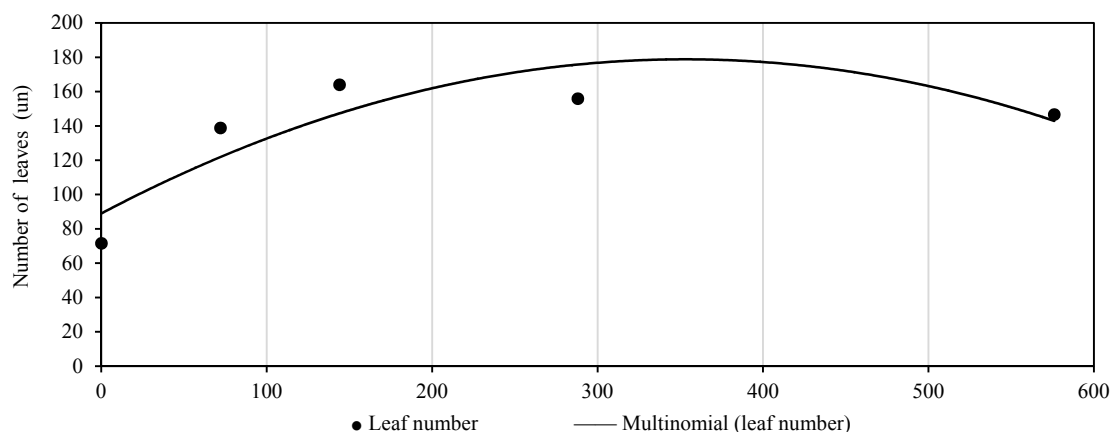
The survival indices found in the clay extraction experimental area were not statistically influenced by the water management factor and the fertilization in the pit of the species *S. terebinthifolius*. This fact is possibly explained by the precipitation that occurred close to the planting date on April 11th. Rainfall was 28 mm and 52 mm on April 10 and 15, 2019, respectively. The level of precipitation associated with the textural class of the soil in the experimental area (Table 1) provided a long period of high soil moisture, which may have harmed the initial effect of the hydro-retainer. Texture determines the contact area between solid particles and water, so the greater the clay fraction, the greater the contact area. The clay content of the soil positively and markedly affected water retention (Beutler et al., 2002).

The *S. terebinthifolius* plants showed average survival rates of 97.77%. The rusticity of the species *S. terebinthifolius* results in the adaptability to unfavorable conditions for plant development, such as soils low in fertility and conditions of water availability. Oliveira et al. (2008), in evaluating the development of *S. terebinthifolius* in oil-contaminated soils, identified 100% survival rates, which corroborates the adaptive capacity of the species. Knapik and Maranhão (2007) when evaluating revegetation in a mining area, recorded survival rates of 100% for *P. cattleianum* and *S. terebinthifolius*.

The nutritional increment resulting from the fertilization of the pit applied in the treatments provided an improvement in soil fertility conditions at lower doses and created unfavorable conditions for some species at higher doses. The clayey soil (Table 1) has a greater capacity for nutritional retention, which exposes the plants to conditions generated by the treatments used for a longer period. This condition can affect either positively in the case of ideal fertilization doses, or negatively in the case of excessive doses. According to Almeida and Sánchez (2005), the 90% survival rate of seedlings is considered as a reference in revegetation projects, a level that was reached by the species.

3.1.2 Plant Growth

The fertilization factor was significant for the three assessed variables. Although the variables PH and SD present a significant effect on the fertilization of the pit, it was not possible to establish a significant regression model for them. For the LN, the quadratic model was adjusted, where the highest number of 181 leaves was obtained with the dose of 363.71 g pit^{-1} of the fertilizer NPK 04-14-08 (Figure 5). Silva et al. (2011) when studying the development of *S. terebinthifolius* in a copper-contaminated environment did not find significant differences in plant growth characteristics even at high doses of the contaminant, indicating high adaptability of the species to inadequate nutritional conditions.



$$LN = -0.0007x^2 + 0.5092x + 88.927 \quad R^2 = 0.7655 \quad (10)$$

Figure 5. Effect of the NPK 04-14-08 doses on the leaf number (LN) of *S. terebinthifolius* in the clay loan area at 180 days after planting

Sousa et al. (2014), in evaluating the effect of different nitrogen doses in revegetation areas, identified a similar behavior, the increase in the nitrogen dose created a point of maximum morphological development followed by a drop in the results.

3.1.3 Chlorophyll *a* Transient Fluorescence

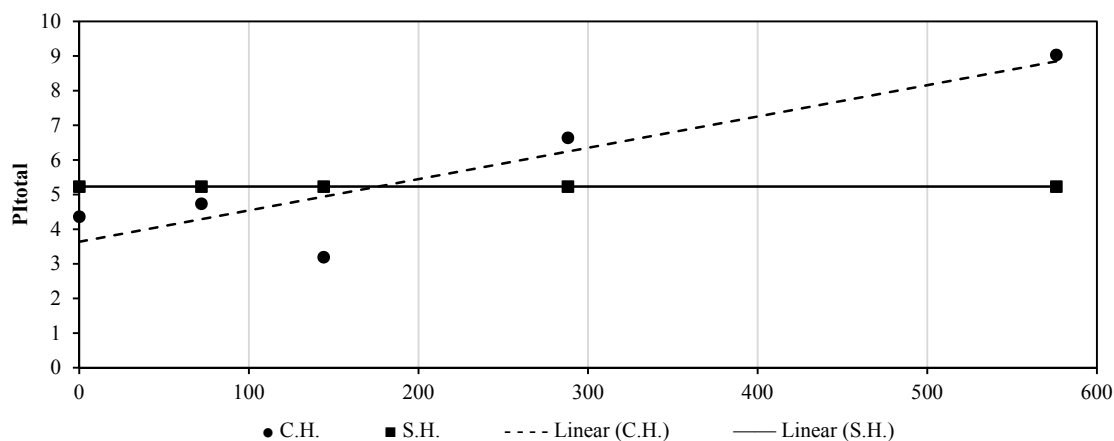
The species Aroeira (*S. terebinthifolius*) showed a significant response only for the $P_{I_{total}}$ parameter, with the interaction between the factors water management and doses of fertilization in the pit. The assessment of the doses of fertilization in the pit within the water management factor (Table 4) showed a significant difference in the dose of 144.00 g pit⁻¹, in the treatment without the hydro-retainer application, where the highest $P_{I_{total}}$ was observed (6.36). The application of the hydro-retainer resulted in the highest $P_{I_{total}}$ (9.03) obtained at a dose of 576.00 g pit⁻¹. It is verified that higher total performance indices are obtained, with the use of hydro-retainer associated with greater fertilization of the pit (Table 4)

Table 4. Total performance index ($P_{I_{total}}$) in Aroeira (*S. terebinthifolius*) plants without hydro-retainer application and with the addition of hydro-retainer at different NPK 04-14-08 doses in the Inhambu experimental site at 180 days after planting.

NPK doses (g pit ⁻¹)	$P_{I_{total}}$	
	Without water-retainer	With water retainer
0	3.09 a	4.36 a
72	5.31 a	4.73 a
144	6.36 a	3.19 b
288	5.40 a	6.63 a
576	5.98 b	9.03 a

Note. Means followed by the same letter in the row are not different from each other by the test of Tukey at 5% of probability.

The assessment of the effect of the water management factor within the pit fertilization doses allowed us to identify that the presence of the hydro-retainer provided an increase in $P_{I_{total}}$ which was proportional to the increase in the pit fertilization doses (Figure 6). The highest $P_{I_{total}}$ was 8.82 at the dose of 576.00 g pit⁻¹. Without the presence of the hydro-retainer, $P_{I_{total}}$ did not present significant differences in relation to the doses of fertilization applied in the pit (Figure 6).



$$\text{S.H. Mean} = 5.2307$$

$$\text{C.H.} = 0.009x + 3.6362 \quad R^2 = 0.8103 \quad (11)$$

Figure 6. Effect of the NPK 04-14-08 doses with no application of the hydro-retainer (S.H.) and with the application of the hydro-retainer (C.H.) on the total performance index (PI_{total}) of Aroeira (*S. terebinthifolius*) in the Inhambu experimental area at 180 days after planting

The increase in PI_{total} may indicate an improvement in the ability to use the energy present in the photosynthetic process. PI_{total} is a very sensitive parameter, especially to water stress (Oliveira et al., 2018). It is related to the performance of the plant as an individual as it indicates the quality of the photosynthetic process and the plant condition in terms of growth or survival under stress conditions (Desotgiu et al., 2012). The results obtained in this work show that the presence of the hydro-retainer increased the value of PI_{total} as the amount of fertilizer in the pit increased (Figure 5). This behavior was not observed in the environment without the presence of the hydro-retainer. The presence of the hydro-retainer created a different behavior of the plant in relation to the fertilization where it reached higher levels of performance, which indicates a better use of the fertilization in the pit.

3.1.4 Plant Leaf Characteristics

Aroeira (*S. terebinthifolius*) plants were affected only by the factor fertilization of the pit in the variable SUC. However, the regression analysis did not allow the establishment of a mathematical model that described the behavior of the variable. Pattison et al. (1998), Mielke et al. (2005), and Silva et al. (2016) classify Aroeira (*S. terebinthifolius*) as a perennial, heliophite, pioneer, and aggressive species. These characteristics are almost always related to plants that have great adaptability to inadequate development conditions, which may have contributed to the preservation of the invariable leaf morphology of the species even under the conditions to which they were submitted in the experiment.

3.2 Sand Loan Experimental Area (Restinga)

3.2.1 Survival Index

An interaction was found between the factors water management and fertilization of the pit for the variable survival index in the species *S. terebinthifolius*. In comparison to the experimental area of the clay loan area and the sand loan area showed an effect of water management on the results. This occurrence can be explained by the difference in the behavior of the soil water retention capacity (Table 3) of the two areas. Soil texture is a factor that determines its water holding capacity. Soils with a greater presence of the sand fraction tend to retain less water over time (C. Klein & V. A. Klein, 2015).

Among the means observed in the three methods of water management (without water-retainer, with water-retainer, and with irrigation), for the survival rate of the species *S. terebinthifolius*, a significant difference was observed only at the dose of 576 g pit⁻¹ of 04-14-08 NPK. At this dose, the highest mean observed was 100% survival with the use of irrigation (Table 5).

Table 5. Survival index in *S. terebinthifolius* and *S. mombin* plants grown in increasing NPK 04-14-08 doses without the addition of hydro-retainer, with the addition of hydro-retainer, and with irrigation in the sand extraction experimental area at 180 days after planting

<i>S. terebinthifolius</i>	NPK doses (g pit ⁻¹)	Survival rate		
		Without hydro-retainer	With hydro-retainer	With irrigation
	0	100 a	77.77 a	100 a
	72	88.88 a	100 a	100 a
	144	100 a	100 a	100 a
	288	88.88 a	100 a	100 a
	576	55.55 b	55.55 b	100 a

Note. Means followed by the same letter in the row are not different from each other at 5% of probability by the test of Tukey.

The nutritional characteristics of the soil in the area offer a small development capacity for plants (Table 2). When subjected to the use of irrigation, the species expressed the highest values of survival rates. Oliveira et al. (2008), in evaluating the development of *S. terebinthifolius* in oil-contaminated soils, identified 100% survival rates, which corroborates the adaptive capacity of the species.

The regression model was adjusted for the survival rate of the species *S. terebinthifolius* in the water management methods (without hydro-retainer, with hydro-retainer, and with irrigation) (Figure 12). The highest survival rate without the use of water retainer was 96.75%, obtained with the dose of 41.75 g pit⁻¹ of NPK 04-14-08 fertilizer. The use of water retainer resulted in 100% at a dose of 236.50 g pit⁻¹. No significant difference was found for the survival rate of *S. terebinthifolius* plants subjected to different fertilization rates combined with irrigation. The average survival was 100%.

The results show that the plants have a range of survival optimization when subjected to increasing doses of fertilization in the pit. According to Malavolta (1980), considering the particularities of each species, the scarcity or excess of nutrients, characterizing deficiencies or toxicity, respectively, are harmful to the development of plants.

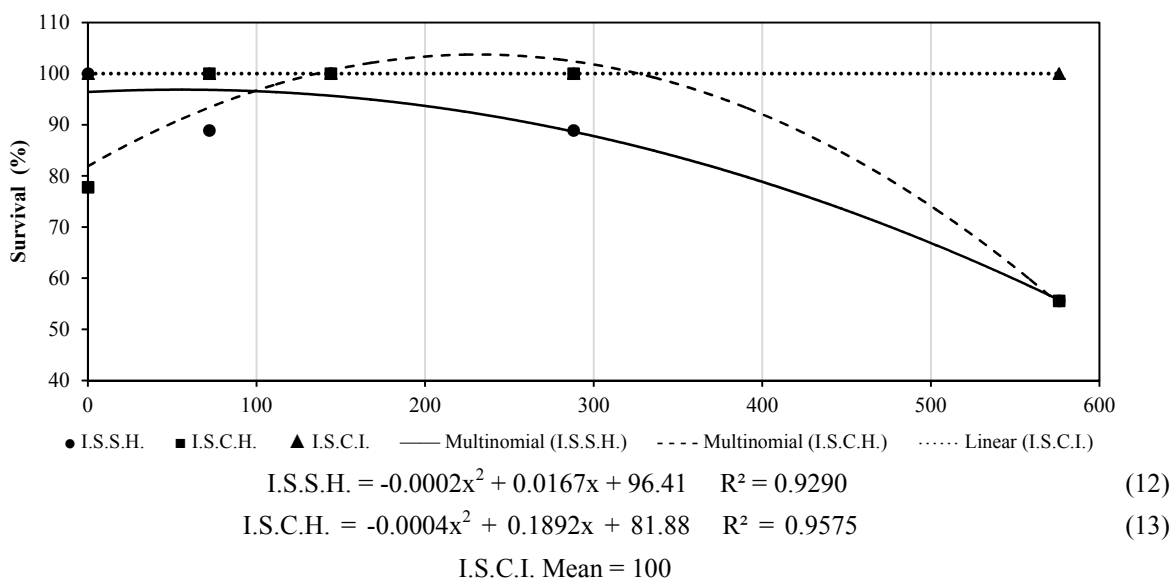


Figure 7. Effect of the NPK 04-14-08 doses on the survival rate of *S. terebinthifolius* without the addition of hydro-retainer (I.S.S.H.), with the addition of hydro-retainer (I.S.C.H.), and with the use of irrigation (I.S.C.I.) in the experimental area of sand extraction at 180 days after planting

3.2.2 Plant Growth

Regarding PH, among the means observed in the three water management methods, a significant difference was observed only in the doses of 288 g pit⁻¹ and 576 g pit⁻¹ of NPK 04-14-08, where the best results were obtained with the use of hydro-retainer and irrigation. (Table 6). For the variable SD, a significant difference was also observed in the higher doses of 288 and 576 g pit⁻¹ of NPK 04-14-08, with the addition of hydro-retainer and with the use of drip irrigation (Table 6). Scheer et al. (2017), when studying the effect of liming and pit fertilization on four species used in revegetation, identified that *S. terebinthifolius* was the species that presented stem diameters and heights considerably higher than the others, even when subjected to high doses of pit fertilization.

Table 6. Plant height (PH) and average stem diameter (SD) in Aroeira (*S. terebinthifolius*) plants subjected to increasing doses of NPK 04-14-08 without the addition of hydro-retainer, with the addition of hydro-retainer and with the use of drip irrigation in the sand loan area at 180 days after planting.

NPK doses (g pit ⁻¹)	Plant height (cm)		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	36.55 a	40.27 a	27.27 a
72	49.16 a	54.05 a	53.77 a
144	62.55 a	62.77 a	69.00 a
288	45.55 b	60.72 ba	70.77 a
576	52.83 b	88.45 a	68.55 ba
NPK doses (g pit ⁻¹)	Stem diameter (mm)		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	4.12 a	5.55 a	5.02 a
72	10.57 a	10.86 a	8.43 a
144	10.28 a	11.42 a	13.56 a
288	8.60 b	12.60 ba	14.47 a
576	8.42 b	15.10 a	15.46 a

Note. Means followed by the same letter in the row are not different from each other by the test of Tukey at 5% probability.

The variable PH showed a linear behavior proportional to the increment in fertilization with NPK in the pit when evaluated within the water management with the application of the hydro-retainer and a quadratic behavior when evaluated within the treatment with water management with the use of drip irrigation (Figure 8). The highest plant height, 86 cm, was obtained with a dose of 421.5 g pit⁻¹ of the 04-14-08 NPK fertilizer. These differences in the growth behavior of the species may be related to nutrient availability and nutritional leaching caused by irrigation.

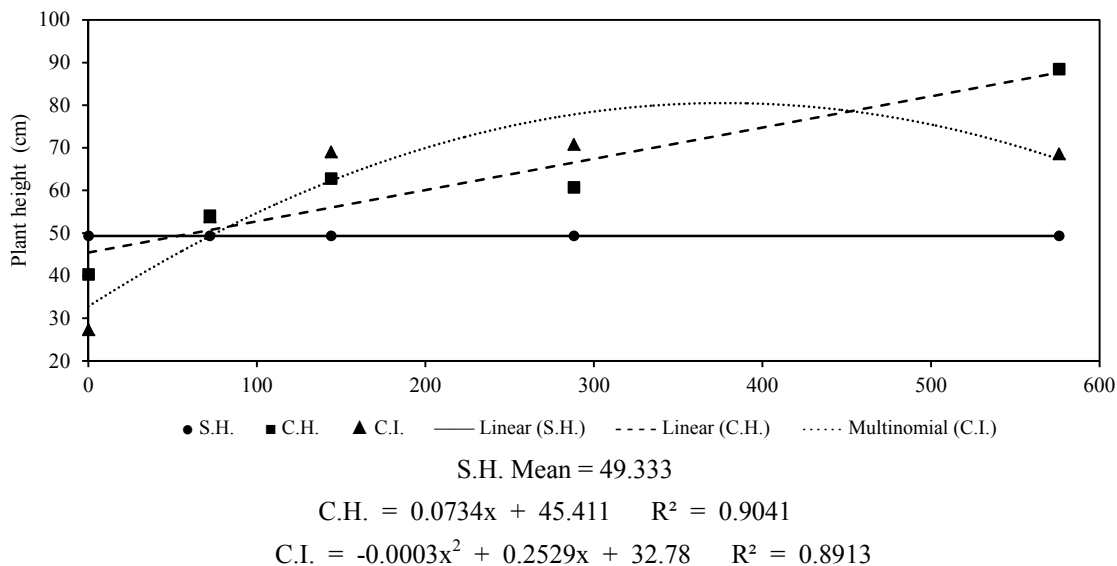


Figure 8. Effect of the NPK 04-14-08 doses without the addition of hydro-retainer (S.H.), with the application of hydro-retainer (C.H.), and with the use of drip irrigation (C.I.) on plant height of Aroeira (*S. terebinthifolius*) plants in the sand loan area at 180 days after planting

In addition to providing a gradual increase in plant height (presence of water retainer) when subjected to increasing doses of fertilization in the pit, the water availability provided an optimization point with the use of irrigation. Xavier et al. (2011) when studying the growth of two eucalyptus hybrids under different levels of water deficit, identified greater growth under greater water availability.

The variable SD showed a quadratic behavior when evaluated in all methods of water management (Figure 9). The largest SD without the use of a hydro-retainer was 10 mm, obtained with a dose of 333.75 g pit⁻¹ of the NPK 04-14-08 fertilizer. The use of a water-retainer resulted in an SD of 16 mm, obtained at a dose of 558.33 g pit⁻¹ of the NPK 04-14-08 fertilizer and, the use of irrigation the result was 17 mm obtained with a dose of 447.50 g pit⁻¹ of the NPK fertilizer 04-14-08.

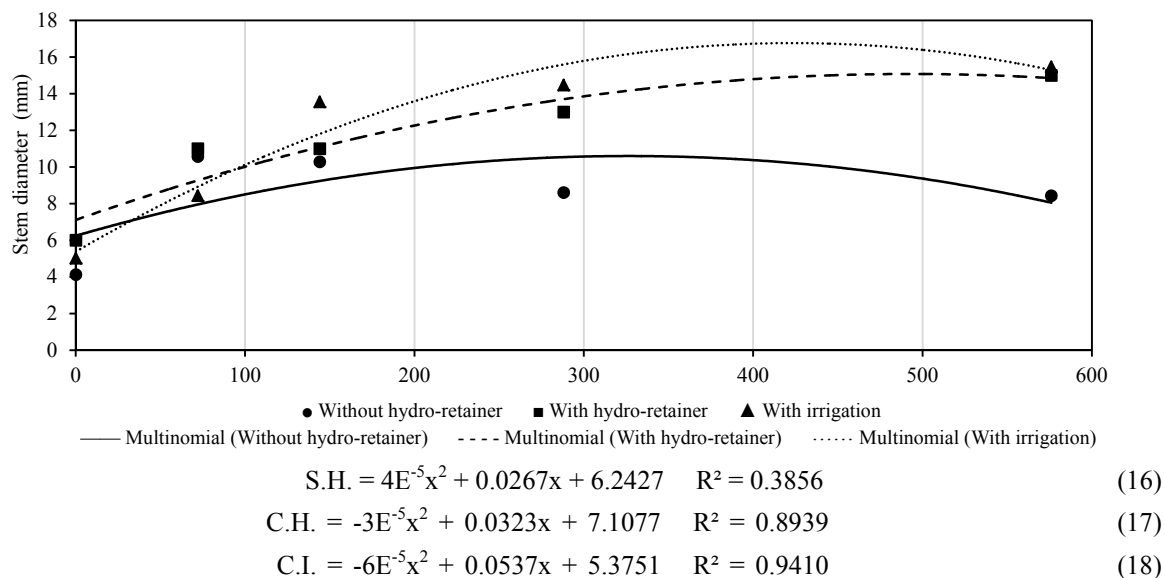


Figure 9. Effect of NPK 04-14-08 doses without the application of hydro-retaining (SH), with the application of hydro-retainer (CH), and with the use of drip irrigation (CI) on the stem diameter of Aroeira (*S. terebinthifolius*) plants in the sand loan area at 180 days after planting

The LN variable showed a quadratic behavior without interaction with the water management methods used in the experiment (Figure 10). The highest LN 124 was obtained with a dose of 463.50 g pit⁻¹ of the 04-14-08 NPK fertilizer.

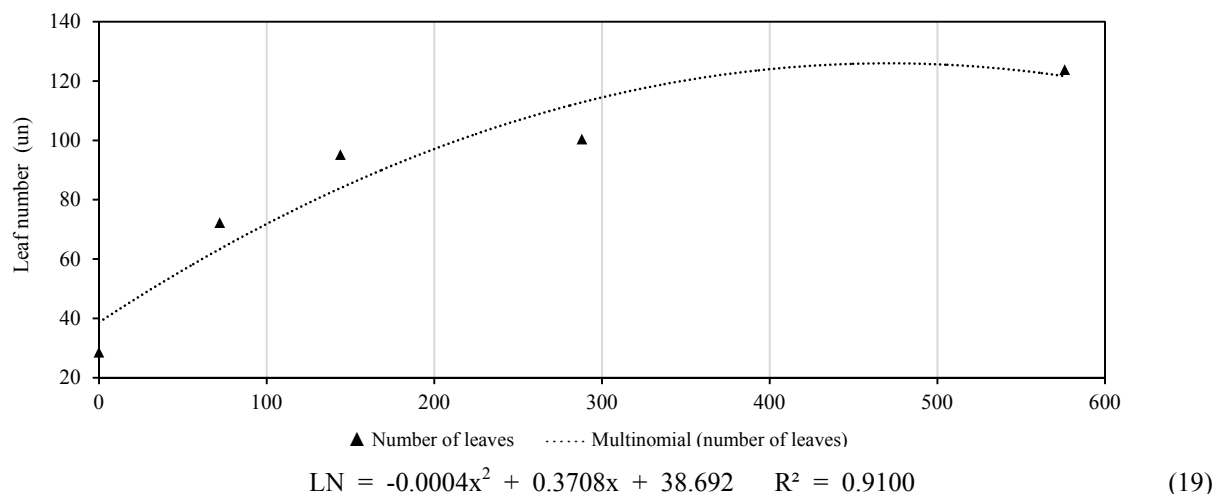


Figure 10. Effect of NPK 04-14-08 doses on the number of leaves (LN) of Aroeira (*S. terebinthifolius*) plants in the sand loan area at 180 days after planting

In a work on the initial development and phenology in restoration nuclei, Silva (2019) identified that *S. terebinthifolius* demonstrated the best performance and the importance of the species in ecological restoration projects in areas of degradation where the species is native.

3.2.3 Chlorophyll *a* Fluorescence Transient

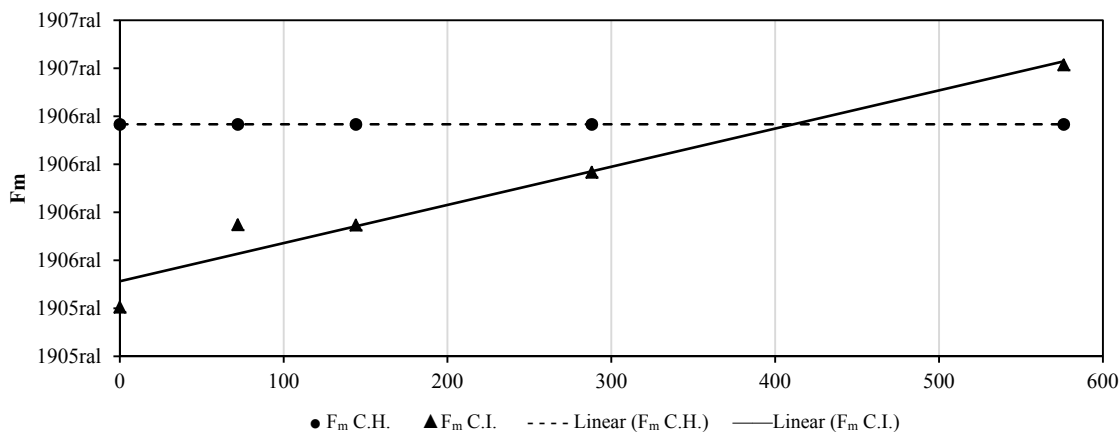
Plants of Aroeira (*S. terebinthifolius*) showed an interaction effect of the two assessed factors only in the variable F_m (Table 7). The assessment of the effect of the fertilizer doses in each water management method identified the difference between the management methods only at the dose 0.00 g pit⁻¹, where the treatment with drip irrigation resulted in the lowest F_m value of 102.66. Again, according to Ecco et al. (2017), favorable conditions raise the F_m . A sandy textured soil (Table 1) tends to suffer more accentuated leaching effects when compared to clayey textured soils, and the irrigation used as a water management method may result in the sandy soil in a nutritional leaching condition. Studying potassium leaching under different irrigation depths, da Silva Albuquerque et al., (2011) identified that the application of 120% of crop evapotranspiration with a dose of 120 kg ha⁻¹ of K₂O causes greater losses of potassium in the form of K₂O.

Table 7. Maximum fluorescence (F_m) in Aroeira (*S. terebinthifolius*) plants, without the addition of hydro-retainer and with the addition of hydro-retainer under different doses of NPK 04-14-08 in the experimental area of Nova Era at 180 days after planting

NPK doses (g pit ⁻¹)	F_m		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	2664.33 a	2526.16 a	2102.66 b
72	2286.83 a	2566.33 a	2274.33 a
144	2384.33 a	2412.66 a	2273.66 a
288	2700.00 a	2440.50 a	2383.50 a
576	2371.33 a	2470.75 a	2607.33 a

Note. Means followed by the same letter in the row are not different from each other by the test of Tukey at 5% probability.

The regression analysis identified the effect of the variation of the fertilizer doses in the pit in the water management method without hydro-retainer. However, it was not possible to determine a regression model to estimate the behavior of the variable in this treatment (Figure 11). The application of the hydro-retainer did not result in statistical differences among the means in the pit fertilization dose, in which a mean of 2483.28 was found (Figure 11). In the drip-irrigation water management method, a linear behavior proportional to the increase in fertilization was identified. The highest F_m mean of 2614.57 was obtained with the pit fertilization dose of 576.00 g pit⁻¹. The result obtained corroborates with da Silva et al. (2015) who, in studying the effect of irrigation depths on chlorophyll a fluorescence in eggplant plants, found an increase in F_m as the irrigation depths were incremented, with no damage to the photosynthetic apparatus. The increase in F_m (Figure 11) may be related to the increase in succulence (SUC) (Figure 12) which indicates a healthier leaf tissue.



$$F_m \text{ C.H. Mean} = 2483.3$$

$$F_m \text{ C.I.} = 0.7951x + 2156.6 \quad R^2 = 0.9519 \quad (20)$$

Figure 11. Effect of NPK 04-14-08 doses without hydro-retainer application (S.H.), with hydro-retainer (C.H.) application and irrigation use (C.I.) on maximum fluorescence (F_m) of Aroeira (*S. terebinthifolius*) plants in the experimental area in Nova Era at 180 days after planting

The variable ϕ_{E0} was significantly affected only by the water management factor (Table 8). The ϕ_{E0} showed the lowest value, 0.3953, in the drip irrigation treatment (Table 8). The drop in this parameter indicates a reduction in the photosynthetic performance of the plant (Silva et al., 2019) indicating that the irrigation treatment did not benefit photosynthesis in Aroeira (*S. terebinthifolius*) plants.

Table 8. Quantum efficiency of the transfer of an electron from Q_A to the electron transport chain beyond Q_A (ϕ_{E0}) and capture per reaction center (TR_0/RC) in Aroeira (*S. terebinthifolius*) plants, without the addition of hydro-retainer, with the addition of a hydro-retainer and the use of irrigation in the Nova Era experimental area at 180 days after planting

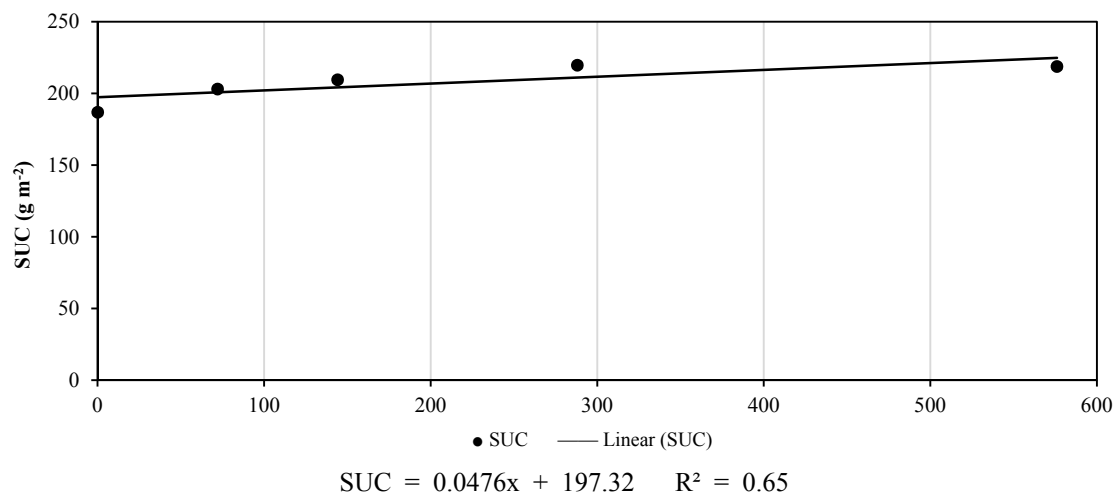
ϕ_{E0}		
Without hydro-retainer	With hydro-retainer	With irrigation
0.4486 a	0.4620 a	0.3953 b

Note. Means followed by the same letter in the row are not different from each other by the test of Tukey at 5% of probability.

3.2.4 Plant Leaf Characteristics

Aroeira (*S. terebinthifolius*) plants were affected by the factor fertilization in the pit on the variable SUC (Figure 12), exhibiting a linear behavior proportional to the increment of the fertilizer dose in the pit. The highest mean found for SUC was 224.73 g m⁻² at the dose of 576.00 g pit⁻¹. The succulence of leaf tissue of a plant is related to the thickness of that tissue. Thicker leaves tend to retain more water (Ferreira de Melo Júnior & Boeger, 2016)

which provides better plant development under these conditions. According to Arruda et al. (2009), the degree of succulence, is related to the water content in the cells, besides being influenced by the water and nutritional availability of the soil. The result of this study indicates that Aroeira (*S. terebinthifolius*) plants adapted better to higher doses of fertilization in the pit.



$$\text{SUC} = 0.0476x + 197.32 \quad R^2 = 0.65 \quad (21)$$

Figure 12. Effect of NPK 04-14-08 doses on succulence (SUC) of Aroeira (*S. terebinthifolius*) plants in the experimental area in Nova Era at 180 days after planting

Aroeira (*S. terebinthifolius*) plants showed an interaction between the assessed factors in the variables FMA, SLA, and SI (Table 9). The FMA showed statistical differences between the water management methods used in the pit fertilization doses of 72.00 and 576.00 g pit⁻¹. At the dose of 72.00 g pit⁻¹, the highest FMA (146.05 g m⁻²) was observed in the treatment without the hydro-retainer and it did not differ statistically from the value of 124.90 g m⁻², which occurred in the hydro-retainer treatment (Table 9). At the dose of 576.00 g pit⁻¹, the highest FMA 136.22 g m⁻² occurred in the treatment with the use of drip irrigation and this did not differ statistically from the value of 132.55 g m⁻² which was found in the treatment with the hydro-retainer application (Table 9). The increase in FMA indicates greater leaf longevity which is extremely relevant in environments with limited resources, and the cost of producing a new leaf is high (Wright et al., 2002).

FMA showed statistical differences between the water management methods at doses of 72.00 and 288.00 g pit⁻¹ fertilization. At the pit fertilization dose of 72.00 g pit⁻¹, the highest value (92.53 cm² g⁻¹) of EFA was found in the water management method with drip irrigation, which did not statistically differ from the value 80.65 cm² g⁻¹, found with the use of the water retainer (Table 9). At the pit fertilization dose of 288.00 g pit⁻¹, an inverse behavior was observed with the highest value (98.67 cm² g⁻¹) of FMA being found in the water management method without the use of a hydro-retainer, which did not differ statistically from the 88.73 cm² g⁻¹ value found with the use of drip irrigation (Table 9).

Specific leaf area (SLA) is a characteristic that indicates the use of resource strategy and plant growth (Wilson et al., 1999). According to Vendramini et al. (2002), plants that grow in an environment with limiting resources, such as water constraints, develop a lower SLA when compared to plants that grow without such limitations.

The SI showed the highest means when the application of the hydro-retainer occurred in the pit fertilization doses of 72.00, 288.00, and 576.00 g pit⁻¹. At the pit fertilization dose of 72.00 g pit⁻¹, the highest value of 51.33 cm² g⁻¹ of the SI was found in the water management method without the use of a hydro-retainer and it did not differ statistically from the value of 44.00 cm² g⁻¹ found with the use of the hydro-retainer (Table 9). At the 288.00 g pit⁻¹ fertilization dose, the highest value of 44.00 cm² g⁻¹ of the SI was found in the water management method with the use of a hydro-retainer and it did not differ statistically from the value of 40.00 cm² g⁻¹, found with the use of drip irrigation (Table 9). The highest SI value of 48.00 cm² g⁻¹ was found in the hydro-retainer management method with the use of drip irrigation at the pit fertilization dose of 576.00 g pit⁻¹, and it did not differ statistically from the value of 46.66 cm² g⁻¹, found with the use of hydro-retainers (Table 9).

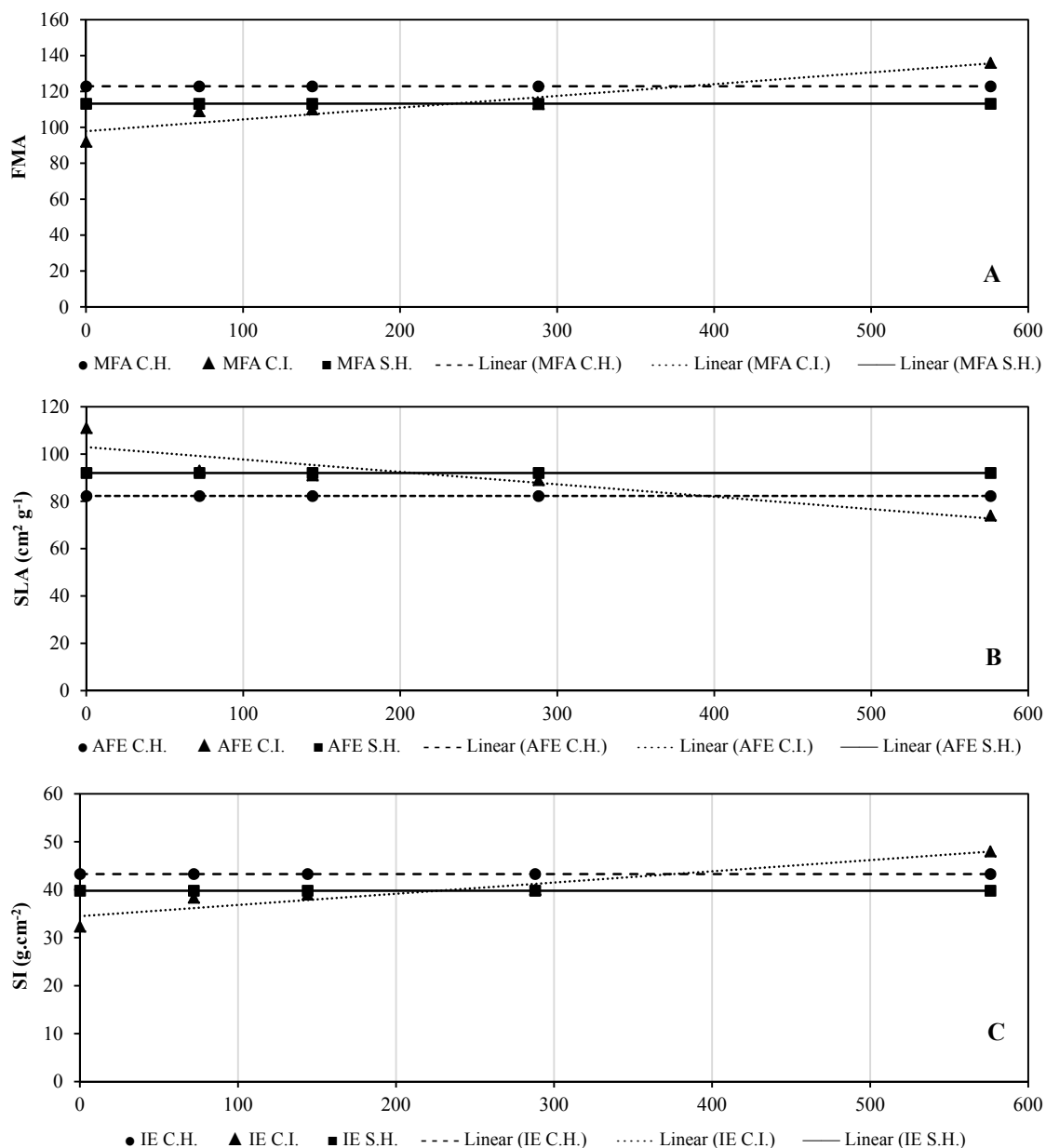
Table 9. Fresh mass per leaf area (FMA), Specific leaf area (SLA) and Sclerophylly index (SI) in Aroeira (*S. terebinthifolius*) plants, without hydro-retainer addition, with hydro-retainer addition and with the use of irrigation under different NPK 04-14-08 doses in the experimental area in Nova Era at 180 days after planting

NPK doses (g pit ⁻¹)	FMA (g m ⁻²)		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	92.34 a	110.41 a	91.94 a
72	146.05 a	124.90 ab	109.02 b
144	114.38 a	122.12 a	110.21 a
288	102.07 a	124.50 a	113.39 a
576	112.19 b	132.55 ab	136.22 a
NPK doses (g pit ⁻¹)	SLA (cm ² g ⁻¹)		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	110.95 a	90.82 b	110.80 a
72	69.63 b	80.65 ab	92.53 a
144	89.27 a	82.49 a	91.14 a
288	98.67 a	81.22 b	88.73 ab
576	90.94 a	76.20 a	74.22 a
NPK doses (g pit ⁻¹)	SI (g cm ⁻²)		
	Without hydro-retainer	With hydro-retainer	With irrigation
0	32.66 a	38.66 a	32.33 a
72	51.33 a	44.00 ab	38.33 b
144	40.00 a	43.00 a	39.00 a
288	35.66 b	44.00 a	40.00 ab
576	39.33b	46.66 ab	48.00 a

Note. Means followed by the same letter in the row do not differ from each other by the test of Tukey at 5% probability.

Under the conditions of the study, the results obtained with the use of drip irrigation did not differ in most from the results obtained with the use of the hydro-retainer, which indicates the feasibility of using it. The incorporation of the hydro-retainer in the soil extends the retention period of rainfall water in the soil (Huttermann et al., 1999). The presence of the hydro-retainer provided better development conditions for the Aroeira (*S. terebinthifolius*) plants.

When evaluated within the water management methods, fertilization showed significant differences between the doses of fertilization in the pit when drip irrigation was used for the variables FMA, SLA, and SI (Figure 13). The means found were 113.20 g m⁻², 92.00 cm² g⁻¹ and 0.39 g cm⁻² respectively in the treatment without hydro-retainer application and 122.90 g m⁻², 82.27 cm² g⁻¹ and 0.43 g cm⁻² respectively in the treatment with the application of hydro-retainer (Figure 13). In drip irrigation conditions, FMA and SI showed a behavior proportional to the increase in the dose of fertilization in the pit with the highest values of 135.61 g m⁻² and 47.96 g cm⁻² respectively obtained with the doses 576.00 g pit⁻¹ (Figure 13). FMA showed a linear behavior inversely proportional to the increase in fertilization, the highest value was 102.93 g cm⁻² obtained at the dose of 0.00 g pit⁻¹ (Figure 13).



$$\text{FMA S.H. Mean} = 113.20$$

$$\text{FMA C.H. Mean} = 122.90$$

$$\text{FMA C.I.} = 0.0656x + 97.825 \quad R^2 = 0.9020 \quad (22)$$

$$\text{SLA S.H. Mean} = 92.00$$

$$\text{SLA C.H. Mean} = 82.27$$

$$\text{SLA C.I.} = -0.0524x + 102.93 \quad R^2 = 0.8199 \quad (23)$$

$$\text{SI S.H. Mean} = 0.39$$

$$\text{SI C.H. Mean} = 0.43$$

$$\text{SI C.I.} = 0.0234x + 34.483 \quad R^2 = 0.9034 \quad (24)$$

Figure 13. Effect of 04-14-08 NPK doses without the hydro-retainer application (SH), with the application of hydro-retainer (CH) and with the use of irrigation (CI) on the fresh mass per leaf area (FMA) (A), specific leaf area (SLA) (B) and sclerophylly index (SI) (C) of Aroeira (*S. terebinthifolius*) plants in the Nova Era experimental area at 180 days after planting

The nutritional leaching process is much accentuated in sandy soils, and irrigation can enhance this process (Ernani, 1999; Bortolini, 2000). During the process in which the leaching takes place, considering that the solution that moves vertically in the soil is a mixture between the soil solution and the added water, the leaching time of the soil nutritional pool is proportional to the initial concentration of the nutrient in the soil solution (Ernani et al., 2003). Thus, even with the possible increase in nutritional leaching caused by drip irrigation, the higher doses of fertilization maintained the levels of nutrients in the soil available for longer.

4. Conclusions

The Aroeira plants did not show significant effects of the assessed factors on the survival rate and reached a value of 98%. For plant growth in the clay loan experimental area, the Aroeira plants showed a significant effect only from pit fertilization. The highest growth rates were found at doses of 364 g pit⁻¹. Aroeira plants showed interaction among the assessed factors on the chlorophyll *a* fluorescence. For Aroeira plants, the best water management method was the use of a hydro-retainer and the best photosynthetic performance was obtained with a pit fertilization rate of 576 g pit⁻¹. In relation to the leaf attributes of Aroeira plants in the clay loan experimental area, no effects of the treatments used were observed.

In the experimental sand loan area, Aroeira plants had their survival influenced by the interaction of the two factors. The difference between the methods of water management occurred only in the pit fertilization of 576 g pit⁻¹. The best management method was the use of drip irrigation which provided 100% survival. All evaluated doses of soil fertilization provided 100% survival when drip irrigation was used. In the use of the hydro-retainer, the dose of 236 g pit⁻¹ provided 100% survival. In the treatment without hydro-retainer, the greatest survival was 97% obtained with the dose of 41.75 g pit⁻¹.

The factors assessed for the variables plant height and stem diameter interacted in the growth of Aroeira plants. Concerning water management, the best results were obtained with the use of hydro-retainers and with drip irrigation. The highest plant height (88 cm) was obtained with the dose of 576 g pit⁻¹ associated with the hydro-retainer. The largest stem diameter was obtained with the dose of 447 g pit⁻¹ combined with drip irrigation. The number of leaves was only affected by the fertilization factor. The greatest number of leaves (124) was obtained with the fertilization dose of 1 463 g pit⁻¹.

Aroeira plants showed an effect of the interaction between the assessed factors on the chlorophyll *a* fluorescence. For Aroeira plants, the best results were obtained with the presence of the hydro-retainer and with the use of drip irrigation. The best photosynthetic performance was achieved at the dose of 576 g pit⁻¹.

Regarding the leaf attributes of the plants in the sand loan experimental area, it was possible to observe that the Aroeira plants affected the interaction of the assessed factors on the leaf attributes. For Aroeira plants, the best water management method was the use of a hydro-retainer. In addition, in this scenario, the fertilization rates did not show statistical differences.

References

- Almeida, A. C., Pereira, I., Silva, M. A., Carlos, L., & Souza, F. (2016). Sobrevivência e crescimento de cinco espécies do cerrado em diferentes adubações na recuperação de uma cascalheira, Diamantina-MG. *Enciclopédia Biosfera*, 13(23). https://doi.org/10.18677/Enciclopedia_Biosfera_2016_108
- Almeida, R. O. P. O., & Sánchez, L. E. (2005). Revegetação de áreas de mineração: critérios de monitoramento e avaliação do desempenho. *Revista Árvore*, 29(1), 47-54. <https://doi.org/10.1590/S0100-67622005000100006>
- Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. D. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6), 711-728. <https://doi.org/10.1127/0941-2948/2013/0507>
- Arruda, R. D. C. D. O., Viglio, N. S. F., & Barros, A. A. M. D. (2009). Anatomia foliar de halófitas e psamófilas reptantes ocorrentes na restinga de Ipitangas, Saquarema, Rio de Janeiro, Brasil. *Rodriguésia*, 60(2), 333-352. <https://doi.org/10.1590/2175-7860200960207>
- Beutler, A. N., Centurion, J. F., Souza, Z. M., Andrioli, I., & Roque, C. G. (2002). Retenção de água em dois tipos de Latossolos sob diferentes usos. *Revista Brasileira de Ciência do Solo*, 26(3), 829-834. <https://doi.org/10.1590/S0100-06832002000300029>
- Bortolini, C. G. (2000). *Eficiência do método de adubação nitrogenada em pré-semeadura do milho implantado em semeadura direta após aveia preta* (p. 48, Doctoral dissertation, Dissertação (Mestrado em Fitotecnia), Universidade Federal do Rio Grande do Sul, Brazil).
- Corrêa, R. S. (1998). *Ecologia e recuperação de áreas degradadas no cerrado* (Paralelo 15).

- da Silva Albuquerque, F., de França, Ê. F., de Souza, A. E. R., & Rolim, M. M. (2011). Lixiviação de potássio em um cultivo de pimentão sob lâminas de irrigação e doses de potássio. *Revista Caatinga*, 24(3), 135-144.
- da Silva Oliveira, L., Bona, C., de Oliveira Santos, G., & Koehler, H. S. (2008). Crescimento de *Schinus terebinthifolius* Raddi (Anacardiaceae) em solo contaminado com petróleo. *Revista Acta Ambiental Catarinense*, 5(1/2), 21-33.
- da Silva, F. G., Dutra, W. F., Dutra, A. F., de Oliveira, I. M., Filgueiras, L., & de Melo, A. S. (2015). Trocas gasosas e fluorescência da clorofila em plantas de berinjela sob lâminas de irrigação. *Revista Brasileira de Engenharia Agrícola e Ambiental-Agriambi*, 19(10). <https://doi.org/10.1590/1807-1929/agriambi.v19n10p946-952>
- da Silva, M. P. K. L., Rovedder, A. P. M., Hummel, R. B., Piaia, B. B., Toso, L. D., Felker, R. M., ... Matiello, J. (2019). Desenvolvimento inicial e fenologia em núcleos de restauração no bioma Mata Atlântica, Sul do Brasil. *Revista Brasileira de Ciências Agrárias*, 14(1), 5612. <https://doi.org/10.5039/agraria.v14i1a5612>
- Desotgiu, R., Pollastrini, M., Cascio, C., Gerosa, G., Marzuoli, R., & Bussotti, F. (2012). Chlorophyll a fluorescence analysis along a vertical gradient of the crown in a poplar (Oxford clone) subjected to ozone and water stress. *Tree Physiology*, 32(8), 976-986. <https://doi.org/10.1093/treephys/tps062>
- dos Santos, P. V. (2012). Impactos ambientais causados pela perfuração em busca do petróleo. *Caderno de Graduação-Ciências Exatas e Tecnológicas-UNIT-SERGIPE*, 1(1), 153-163.
- Ecco, M., Santiago, E. F., Richart, A., Lima, P. R., & Borsoi, A. (2017). Fluorescência da clorofila a em cana-de-açúcar inoculada com fungos micorrízicos arbusculares sob aplicação de fósforo. *Acta Iguazu*, 6(1), 81-95.
- El-Asmar, J., Jaafar, H., Bashour, I., Farran, M. T., & Saoud, I. P. (2017). Hydrogel banding improves plant growth, survival, and water use efficiency in two calcareous soils. *CLEAN—Soil, Air, Water*, 45(7), 1700251. <https://doi.org/10.1002/clen.201700251>
- Ernani, P. (1999). Nutrição e produtividade de espécies vegetais em sistemas de plantio direto e convencional. *Reunião Técnica Catarinense de Milho e Feijão*, 2, 19-30.
- Ernani, P. R., Mantovani, A., Scheidt, F. R., & Nesi, C. (2003). *Mobilidade de nutrientes em solos ácidos decorrentes da aplicação de cloreto de potássio e calcário* (Vol. 29). Congresso Brasileiro de Ciência do Solo.
- Felfili, J. M. (2008). *Conservação da natureza e recuperação de áreas degradadas na Bacia do São Francisco: treinamento e sensibilização*. Centro de Referência em Conservação da Natureza e Recuperação de Áreas Degradadas.
- Ferreira de Melo Junior, J. C., & Torres Boeger, M. R. (2016). Leaf traits and plastic potential of plant species in a light-edaphic gradient from restinga in southern Brazil. *Acta Biológica Colombiana*, 21(1), 51-62. <https://doi.org/10.15446/abc.v21n1.47621>
- Ferreira, D. F. (2011). Sisvar: A computer statistical analysis system. *Ciência e Agrotecnologia*, 35(6), 1039-1042. <https://doi.org/10.1590/S1413-70542011000600001>
- Flexas, J., Bota, J., Escalona, J. M., Sampol, B., & Medrano, H. (2002). Effects of drought on photosynthesis in grapevines under field conditions: An evaluation of stomatal and mesophyll limitations. *Functional Plant Biology*, 29(4), 461-471. <https://doi.org/10.1071/PP01119>
- Hüttermann, A., Zommodi, M., & Reise, K. (1999). Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought. *Soil and Tillage Research*, 50(3-4), 295-304. [https://doi.org/10.1016/S0167-1987\(99\)00023-9](https://doi.org/10.1016/S0167-1987(99)00023-9)
- Klein, C., & Klein, V. A. (2015). Estratégias para potencializar a retenção e disponibilidade de água no solo. *Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental*, 19(1), 21-29.
- Kluge, M., & Ting, I. P. (2012). *Crassulacean acid metabolism: analysis of an ecological adaptation* (Vol. 30). Springer Science & Business Media.
- Knapik, P., & Maranhão, L. T. (2007). Avaliação da revegetação em área de mineração, região de inundação do rio Iguaçú, Araucária, PR. *Revista Brasileira de Biociências*, 5(S1), 507-509.
- Malavolta, E. (1980). *Elementos de nutrição mineral de plantas*. São Paulo: Agronômica Ceres.

- Mielke, M. S., De Almeida, A. A. F., Gomes, F. P., Mangabeira, P. A. O., & Silva, D. D. C. (2005). Effects of soil flooding on leaf gas exchange and growth of two neotropical pioneer tree species. *New Forests*, 29(2), 161-168. <https://doi.org/10.1007/s11056-005-0247-7>
- Navroski, M. C., Araujo, M. M., da Silva Cunha, F., Berghetti, A. L. P., & de oliveira Pereira, M. (2014). Influência do polímero hidrorretentor na sobrevivência de mudas de *Eucalyptus dunnii* sob diferentes manejos hídricos. *Nativa*, 2(2), 108-113. <https://doi.org/10.14583/2318-7670.v02n02a08>
- Neto, J. L. L. M., Araújo, W. F., Chagas, E. A., da Silva Siqueira, R. H., Oliveira, G. A., & Rodriguez, C. A. (2017). Hydrogels in Brazilian agriculture. *Revista Agro@ambiente On-line*, 11(4), 347-360. <https://doi.org/10.18227/1982-8470ragro.v11i4.4130>
- Oliveira, W. J., de Souza, E. R., Santos, H. R. B., de França, Ê. F., Duarte, H. H. F., & de Melo, D. V. M. (2018). Fluorescência da clorofila como indicador de estresse salino em feijão caupi. *Revista Brasileira de Agricultura Irrigada*, 12(3), 2592. <https://doi.org/10.7127/rbai.v12n300700>
- Pattison, R. R., Goldstein, G., & Ares, A. (1998). Growth, biomass allocation and photosynthesis of invasive and native Hawaiian rainforest species. *Oecologia*, 117(4), 449-459. <https://doi.org/10.1007/s004420050680>
- Pimentel, C. (2005). In R. J. M. C. Nogueira, E. de L. Araújo, & L. G. Willadino (Eds.), *Respostas fisiológicas à falta d'água: Limitação difusiva ou metabólica* (pp. 13-21).
- Prezotti, L. C., Oliveira, J. A., Gomes, J. A., & Dadalto, G. G. (2013). *Manual de recomendação de calagem e adubação para o Estado do Espírito Santo* (5ª aproximação).
- Rizzini, C. T. (1979). *Tratado de fitogeografia do Brasil* (Vol. 2). Edusp, Sao Paulo.
- Schansker, G., Srivastava, A., & Strasser, R. J. (2003). Characterization of the 820-nm transmission signal paralleling the chlorophyll a fluorescence rise (OJIP) in pea leaves. *Functional Plant Biology*, 30(7), 785-796. <https://doi.org/10.1071/FP03032>
- Scheer, M. B., Carneiro, C., Bressan, O. A., & dos Santos, K. G. (2017). Crescimento inicial de quatro espécies florestais nativas em área degradada com diferentes níveis de calagem e de adubação. *Floresta*, 47(3). <https://doi.org/10.5380/RF.V47I3.41973>
- Silva A. A., Nogueira, D. W. R., Silva, K. R., Santos, F. H. S., & Lopes, V. M. (2017). Teor de nutrientes e crescimento de mudas de ipê-branco na fase inicial em solução nutritiva. *South American Journal of Basic Education, Technical and Technological*, 4(2), 44-56.
- Silva, D., Carneiro, M., Menezes, L., & Falqueto, A. (2019). *Fisiologia de Acessos de *Jatropha curcas* L.* Cultivados em Solo Contendo Lama do Rio Doce.
- Silva, K. D. A., Martins, S. V., Miranda Neto, A., Demolinari, R. D. A., & Lopes, A. T. (2016). Restauração florestal de uma mina de bauxita: Avaliação do desenvolvimento das espécies arbóreas plantadas. *Floresta e Ambiente*, 23(3), 309-319. <https://doi.org/10.1590/2179-8087.142515>
- Sousa, F. F. de, Venturin, N., Carlos, L., Macedo, R. L. G., & Lima, F. S. (2014). *Efeito de doses de nitrogênio sobre o crescimento inicial e sobrevivência de mudas de baru em campo*. XI Congresso Nacional de Meio Ambiente de Poços de Caldas.
- Stirbet, A., Riznichenko, G. Y., & Rubin, A. B. (2014). Modeling chlorophyll a fluorescence transient: Relation to photosynthesis. *Biochemistry*, 79(4), 291-323. <https://doi.org/10.1134/S0006297914040014>
- Strasser, B. J., & Strasser, R. J. (1995). Measuring fast fluorescence transients to address environmental questions: The JIP test. In P. Mathis (Ed.), *Photosynthesis: From Light to Biosphere* (Vol. V). Proceedings of the Xth International Photosynthesis Congress. Montpellier, France, Kluwer Academic Publishers, Dordrecht. https://doi.org/10.1007/978-94-009-0173-5_1142
- Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2017). *Fisiologia e desenvolvimento vegetal*. Artmed Editora.
- Vendramini, F., Díaz, S., Gurvich, D. E., Wilson, P. J., Thompson, K., & Hodgson, J. G. (2002). Leaf traits as indicators of resource-use strategy in floras with succulent species. *New Phytologist*, 154(1), 147-157. <https://doi.org/10.1046/j.1469-8137.2002.00357.x>
- Wilson, P. J., Thompson, K. E. N., & Hodgson, J. G. (1999). Specific leaf area and leaf dry matter content as alternative predictors of plant strategies. *New Phytologist*, 143(1), 155-162. <https://doi.org/10.1046/j.1469-8137.1999.00427.x>

- Witkowski, E. T. F., & Lamont, B. B. (1991). Leaf specific mass confounds leaf density and thickness. *Oecologia*, 88(4), 486-493. <https://doi.org/10.1007/BF00317710>
- Wright, I. J., Westoby, M., & Reich, P. B. (2002). Convergence towards higher leaf mass per area in dry and nutrient-poor habitats has different consequences for leaf life span. *Journal of Ecology*, 90(3), 534-543. <https://doi.org/10.1046/j.1365-2745.2002.00689.x>
- Xavier, T. M. T., Pezzopane, J. E. M., Penchel, R. M., Caldeira, M. V. W., Klippel, V. H., Toledo, J. V., & Silva, M. R. (2011). *Crescimento do eucalipto sob diferentes níveis de déficit hídrico*. Congresso Brasileiro De Fisiologia, Búzios, RJ.
- Yusuf, M. A., Kumar, D., Rajwanshi, R., Strasser, R. J., Tsimilli-Michael, M., & Sarin, N. B. (2010). Overexpression of γ -tocopherol methyl transferase gene in transgenic *Brassica juncea* plants alleviates abiotic stress: Physiological and chlorophyll a fluorescence measurements. *Biochimica et Biophysica Acta-Bioenergetics*, 1797(8), 1428-1438. <https://doi.org/10.1016/j.bbabi.2010.02.002>

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/4.0/>).