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The inoculation with arbuscular mycorrhizal fungi improved ecophysiological and growth parameters of *Schinus terebinthifolius* and *Caesalpinia ferrea* in degraded mining sites

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ABSTRACT

The mining activity in Brazil generates several degraded areas. The use of heliophyte forest species inoculated with arbuscular mycorrhizal fungi can be an alternative in active restoration projects of degraded areas. The aim of this study was to evaluate the ecophysiology, growth, and survival rate of *Schinus terebinthifolius* and *Caesalpinia ferrea* seedlings, with and without inoculation with *Rhizophagus clarus*, an arbuscular mycorrhizal fungus (AMF), in a degraded mining area in the municipality of Itaporanga D'Ajuda, SE, Brazil. The experiment was conducted with plants of the two species grown with spacing of 3 × 3 m in an area degraded by sand and gravel mining. The treatments consisted of forest species without AMF and with AMF. Ecophysiological parameters were evaluated using a non-modulated fluorimeter. The plants of each treatment were evaluated for plant height, stem base diameter, and survival rate, at 12 months after planting. The inoculation of AMF in *Caesalpinia ferrea* allowed better efficiency in photosynthesis, promoting a survival greater than 90%, greater diameter (1.04 cm) and height (81.68 cm). Although the inoculation of AMF in *Schinus terebinthifolius* improved the fluorescence parameters, there was an increase only in the survival rate, being more than 90%. It is recommended that other native forest species inoculated with AMF be tested in areas degraded by mining.

1. Introduction

Microbial biomass is made up of arbuscular mycorrhizal fungi and performs important processes at the soil-plant interface (Rodrigues et al. 2018). The inoculation with arbuscular mycorrhizal fungi in forest seedlings increases the content of potassium and sulfur, providing greater growth of the aerial part and roots of plants, increasing the efficiency of the use of nutrients, especially phosphorus, which provides greater growth making it more resistant to biotic and abiotic factors (Rodrigues et al., 2018).

Arbuscular mycorrhizal fungi, classified in the Phylum Glomeromycota, are mandatory symbionts that are established in the root system of plants and promote growth, nutrient absorption and biomass production under natural and stress conditions, for example hidric and saline (Laurindo et al., 2020).

The maintenance of plant ecosystem functions through ecosystem regulation mechanisms, such as facilitating the cycling and absorption of nutrients by host plants, physical and chemical changes to maintain soil structure and regulation of plant competition, suggest that fungi

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arbuscular mycorrhizal can be important facilitators in environments arid stressful, such as mining areas (Hovland et al., 2021). Plant interactions, especially heliophiles with arbuscular mycorrhizal fungi, can accelerate ecological succession, with increased resilience of the native plant community to water stress, overgrazing, fire and resistance to invasion by exotic plants (Hovland et al., 2021). The success of the initial establishment of tree seedlings is related to the plants capture and use of primary resources, such as light and nutrients. The selection of heliophile arboreal species with high carbon assimilation potential and efficient use of nutrients and light facilitates the revegetation of degraded areas, mainly in locations with high solar irradiance and low soil nutrient availability (Santos et al., 2006). Initial restoration and reforestation processes are carried out using heliophile, pioneer species that present fast growth when intercropped with slow growth species that present high soil cover; the first assists in the control and decrease of soil erosive and the latter are effective to maintain the soil physical characteristics (Machado et al., 2014).

The use of arbuscular mycorrhizal fungi (AMF) in mining affected soils provides better plant root and shoot development and favors the plant's survival, resistance, and mineral nutrition for arboreal species. In addition, AMF affect the plant growth and contribute to increasing of carbon fixation and improvement of soil structure (Braguirolli et al., 2012). Some forest species heliophylous such as *Caesalpinia ferrea* Mart. ex Tul. var. ferrea (Fabaceae, Caesalpinioideae) showed good results when inoculated with arbuscular mycorrhizal fungi, as observed by (Dantas et al. (2015), with high survival and growth in areas degraded by sand and gravel mining in the Northeast region of Brazil. However, there is no information about how the inoculation of AMF in Caesalpinia ferrea can favor the ecophysiology of this species planted in a degraded area. Another heliophylous forest species with great potential for revegetation of areas degraded by mining in Brazil is *Schinus terebinthifolius* Raddi (Anacardiaceae) due to its characteristics as a heliophilous species, competitive aggressiveness, hygromorphic tolerance, good biotic interaction, high colonization plasticity, where establishes in different environments (Chiamolera et al., 2011; Marcuzzo et al., 2015; Paula et al., 2021; Resende et al., 2015; Silva et al., 2016). Studies show that *S. terebinthifolius* seedlings in the nursery and field, inoculated with arbuscular mycorrhizal fungi, have the potential to recover degraded areas in Brazil (Dantas et al., 2015; Schoen et al., 2016; Souza et al., 2009).

However, the photosynthetic process is sensitive to abiotic stresses, decreasing the biomass production. The intensity of this response is dependent on the stress duration, type, and intensity (Mathur et al., 2019). Changes related to damages to the plants' photosystems caused by stresses can be evaluated by the chlorophyll a fluorescence technique, which is a fast-non-destructive method that assists in the search for alternatives that minimize environmental effects on plants (Kalaji et al., 2016; Mathur and Jajoo, 2020). However, there are no studies in Brazil that assess ecophysiological aspects of the forest species *C. ferrea* and *S. terebinthifolius* inoculated with arbuscular mycorrhizal fungi and planted in an area degraded by mining.

The main mining activity in the state of Sergipe is the extraction of potassium, being the largest producer of this mineral in Brazil. The exploration of sand and gravel is the second largest mining activity in the State of Sergipe, with a production of 5,769,790 tons (Silva et al., 2020). These activities generate countless degraded areas in the State, and it is mandatory under Brazilian law to recover the area by the mining company (Silva et al., 2020). However, there is little information regarding the use of heliophylous species inoculated with mycorrhizal fungi for the recovery of mining areas in the state of Sergipe and in Brazil, requiring studies that prove their efficiency.

In this context, the objective of this study was to evaluate the ecophysiology, growth, and survival rate of *S. terebinthifolius* and *C. ferrea* plants, inoculated or not with arbuscular mycorrhizal fungi (*Rhizophagus clarus*), in a mining degraded area in the municipality of Itaporanga D'Ajuda, SE, Brazil. It is expected that the results obtained in this study demonstrate the feasibility of inoculation with mycorrhizal fungi in heliophilic forest species, for the restoration of deactivated mining areas or degraded areas.

2. Material and methods

2.1. Study area

The experiment was conducted in a degraded mining area located in the Itália Farm, in the municipality of Itaporanga d'Ajuda, Sergipe, Brazil (11°05′58.8"S and 37°15′57.7"W). The climate of the region is tropical humid, according to the Köppen classification, with a mean annual temperature of 25 °C and mean annual rainfall precipitation of 1,200 mm concentrated in April to August, with low rainfall depths from December to March.

The mining area was degraded for the removal of sand and gravel until the year of 2007, when mining activity ended. The area presented flat topography, no vegetation, and soils with no upper horizons, presenting only a C horizon (subsoil) with sandy texture. The chemical analysis of the C horizon presented the following characteristics: pH (in water) = 5.19; P and K = 1.40 and 3.10 mg dm^{-3}, respectively; Ca + Mg and Al = 0.38 and 0.31 $cmol_c$ dm^{-3}, respectively; and 2.02 g dm^{-3} of organic matter content.

2.2. Biological material

Two heliophile forest species commonly used for restoration of degraded areas were chosen: *S. terebinthifolius* (aroeira) and *C. ferrea* (pau-ferro), with and without inoculation with the arbuscular mycorrhizal fungi (AMF) *Rhizophagus clarus* (Schussler and Walker, 2010), *S. terebinthifolius* and *C. ferrea* seedlings were produced in a nursery of the Department of Forest Sciences of the Federal University of Sergipe. Three-month-old seedlings were transplanted in September 2018. The AMF was acquired from CNPAB5 access from the Glomales Germplasm bank of the Brazilian Agricultural Research Corporation (EMBRAPA Agrobiologia).

S. terebinthifolius is an evergreen, heliophyte and pioneer plant, common in riverbanks, streams and humid floodplains of secondary formations; however, it grows on dry and poor soil. It is widely spread by birds, which explains its good natural regeneration. Its dispersion is wide, ranging from the restinga to the and semideciduous forests (Lorenzi, 2016). The species C. ferrea is a semideciduous evergreen, heliophyte or shaded plant, characteristic of the Atlantic rainforest. Prefers slopes and hilltops where drainage is fast. Despite being a plant from the primary forest, it is often found in more developed secondary formations. Annually produces a large amount of viable seeds (Lorenzi, 2016).

The substrate used for the production of seedlings was composed of soil from horizon C, sand and bovine manure, in the proportion 3: 1: 1, which were packed in polyethylene bags of 800 cm^3. In each plastic bag, 3 seeds were placed and after the emergence of the seedlings, thinning was carried out, leaving only one seedling per bag. Then, the seedlings were inoculated with AMF using 5 g of the inoculum on the seedling substrate. No inoculation of nitrogen fixing bacteria was carried out in *C. ferrea*.

The seedlings were kept in a nursery under a 50% shade screen for three months and then transferred to an area in full sun to stimulate their rustification. Irrigation was performed by manual irrigation twice a day for the entire period and no fertilization or use of nutrient solution was carried out.

After scarification the soil of the area to be planted, pits of 40 × 40 cm were manually opened using an excavator, with 3 × 3 m spacing. Cutter ants were controlled at two months before planting, after planting, and in the following 12 months by applying granulated lures.

2.3. Experimental design

The field experiment was conducted in a randomized block design with four blocks per treatment and 15 repetitions in each block, totaling 60 plants per treatment. Each plant is 3 meters apart. The treatments consisted of *S. terebinthifolius* without FMA (MUWF) and *S. terebinthifolius* with AMF (MUF) and *C. ferrea* without AMF (CFWF) and *C. ferrea* with AMF (CFF).

2.4. Ecophysiologial and growth parameters

The transient chlorophyll *a* fluorescence was analyzed between 8:00h and 12:00h, in fully expanded leaves previously adapted to the dark for 30 minutes, using a non-modulated fluorimeter (OS-30P; Opti-Sciences Inc., Hudson, USA). Five randomly plants of each treatment were selected and evaluated at 12 months after planting (MAP).

The transient states of chlorophyll *a* was obtained under a maximum illumination of 3.000 μmol (photons) m^{-2} s^{-1} by an actinic light (λ=660 nm) for 1 second; this illumination was applied homogeneously to the leaf (Dinis et al., 2016). The fast fluorescence kinetic, which is the passage of initial fluorescence (F0) to the maximum fluorescence (Fm), was measured by emissions described in the OJIP curve, in which O≅ F0 (50μs), J (2ms), I (30ms), and P≅ Fm (maximum fluorescence intensity); the time for the maximum fluorescence emission and the area above the OJIP curve were also evaluated (Chen et al., 2016; Stirbet et al., 2018; Strasser et al., 2010). The parameters obtained and calculated by the non-modulated fluorimeter are dimensionless.

The seedlings were evaluated in the field for plant height, stem base diameter, and survival rate, at 12 MAP. The morphological parameters measured were: total plant height from the stem base to the apical bud (cm), using a measuring tape; and stem base diameter (mm), using a digital caliper (Delarmelina et al., 2014). The survival rate of the plants was determined by comparing the initial total number of plants to the number of alive plants at 12 MAP, with the following formula: Mortality rate = (number of individuals killed / number of individuals planted) * 100.

2.5. Statistical analysis

The fluorescence data, measured at 12 MAP, were subjected to analysis of variance and the significant means were compared by the Tukey's test at 5% significance level, using the R program (R CORE TEAM, 2017). The plant height and stem base diameter data measured at 12 MAP were subjected to analysis of variance and the significant means were compared by the Tukey's test at 5% significance level, using the R program (R CORE TEAM, 2017).

3. Results

The inoculation of plants of both forest species (*S. terebinthifolius* and *C. ferrea*) with the arbuscular mycorrhizal fungi (AMF) *Rhizophagus clarus* significantly affected (p < 0.05) the transient chlorophyll a fluorescence (OJIP), being the initial fluorescence intensity, J value (fluorescence within 2 milliseconds), *I* value (fluorescence within 30 milliseconds) higher in the treatments MUF (157) and CFF (159) than in the MUWF (129) and CFWF (146) treatments (Fig. 1). The *P* value (maximum fluorescence) was affected (p <0.05) by the inoculation with AMF the treatment MUF and CFF had higher mean *P* value in comparison MUWF and CFWF (Fig.1).

The fluorescence transientes parameters of chlorophyll a were influenced (p≤0.05) by the inoculation of the fungus *Rhizophagus clarus* in the plants of *Schinus terebinthifolius* and *Caesalpinia ferrea*. The results demonstrate that the MUF treatment promoted an increase in the parameters of TR0/ABS, ET0/ABS, ET0/RC, ABS/CS0, TR0/CS0, ET0/CS0 and RE0/CS0, which consequently increased the PIcs values, comparatively MUWF treatment (Table 1). Regarding the CFF treatment, it was observed that the parameters TR0/ABS, ABS/RC, ET0/RC, ABS/CS0, ET0/CS0, TR0/CS0 and RE0/CS0 were higher when compared to the CFWF treatment. As with the MUF treatment, the CFF treatment promoted an increase in the performance index per cross section (PIcs). It was also observed that the failure to use *Rhizophagus clarus* for both *Schinus terebinthifolius* and *Caesalpinia ferrea* caused an increase in energy dissipation (DI0) (Table 1).

The mean plant height of the forest species planted in the area degraded by mining evaluated at 12 months after planting (MAP) was significantly higher in the treatment CFF, with a mean of 81.58 cm compared to CFWF. The treatment MUF reached 37.8 cm at 12 MAP, and was similar to the treatment MUWF (Table 2).

The mean stem base diameters of plants in the treatments MUWF and MUF which were similar to each other. CFWF had a significant lower mean than the CFF (Table 2). The mean survival rates of the seedlings in the treatments MUF and CFF were higher than 90% at 12

Table 1
Parameters of the OJIP test for forest species (*Schinus terebinthifolius* and *Caesalpinia ferrea*), with and without inoculation with arbuscular mycorrhizal fungi (*Rhizophagus clarus*), after 12 months of growing in the mining degraded area.

Parameters	MUWF	MUF	CFWF	CFF
TR0/ABS	66.00 ± 0.01b	73.02±0.02a	65.82 ± 0.01b	69.95 ± 0.01a
ET0/ABS	30.39 ± 0.02b	39.99 ± 0.04a	37.75 ± 0.02a	29.12 ± 0.02b
DI0/ABS	33.99 ± 0.01a	26.97 ± 0.01b	28.86 ± 0.01a	27.91±0.02b
PI abs	14,18 ± 0.05b	48.12 ± 0.05a	23.36 ± 0.01a	16.87±0.05b
ABS/RC	23.47 ± 0.05a	20.30±0.05b	20.19 ± 0.05b	21.03±0.05a
ET0/RC	71.33 ± 0.05b	76.24±0.05a	61.52±0.05b	63.32±0.05a
RE0/RC	68.21 ± 0.05a	53.63±0.05b	41.85±0.05b	56.83±0.05a
DI0/RC	82.69 ± 0.05a	62.33±0.05b	96.08±0.05a	63.08±0.05b
ABS/CS0	25.80±0.05b	31.40±0.05a	29.13±0.05b	31.80±0.05a
TR0/CS0	42.57±0.05b	57.43±0.05a	37.49±0.05b	55.51±0.05a
ET0/CS0	39.19±0.05b	73.33±0.05a	54.57±0.05a	46.25±0.05b
RE0/CS0	37.51±0.05b	44.26±0.05a	34.82±0.05b	40.83±0.05a
PI cs	18.29 ± 0.05b	76.02 ± 0.05a	27.72 ± 0.05b	28.56 ± 0.05a

* Means followed by the same lowercase letters on the line do not differ statistically by the Tukey test (α = 0.05). The values were standardized in a 0 to 100 scale. TR0/ABS, The maximum quantum yield of the primary photochemistry of PSII; ET0/ABS; The quantum yield of electron transport from QA to PQ; RE0/ABS; The quantum yield of electron transport from QA- to final PSI acceptors; DI0/ABS; The quantum yield of energy dissipated in the PSII antenna, related to non-photochemical processes (heat); ABS/RC, Determination of the average of the photon fluxes absorbed (ABS) the total of PSII reaction centers (RC), also related to the measurement of the apparent size of the PSII antenna (ABS/RC); TR0/RC, The maximum flow of excited electrons trapped by the reaction centers active in the PSII; ET0/RC; Flow or transport of electrons (ET) transferred from QA- to PQ by activity of PSII reaction centers; DI0/RC, Flow of energy dissipated in other non-photochemical processes by the reaction centers active in the PSII; ABS/CS0, Absorbed photon flow (ABS) by excited cross section of PSII (CS) from the initial fluorescence; TR0/CS0, Maximum flow of energized electrons trapped by PSII cross section at initial fluorescence; ET0/CS0, Electron flow from QA- to PQ by PSII cross section in the initial fluorescence; RE0/CS0, Electron transport flow to PSI acceptors per cross section; DI0/CS0, Non-photochemical energy dissipation in all PSII by cross section; PIcs, Performance index on the base cross section; PIabs, Performance index on base absorption.

Table 2
Mean plant height, diameter and survival rate of forest species (*Schinus terebinthifolius* and *Caesalpinia ferrea*) with and without inoculation with arbuscular mycorrhizal fungi (*Rhizophagus clarus*), after 12 months of growing in the mining degraded area. Means followed by the same letter are not different by the Tukey's test (p ≤ 0.05).

Treatments	Height (cm)	Diameter (cm)	Survival rate (%)
MUWF	41.27 ± 0.02c	1.06 ± 0.01c	71.6
MUF	37.80 ± 0.01c	1.17 ± 0.01c	93.3
CFWF	45.1 ± 0.04b	0,75 ± 0.02b	73.3
CFF	81.68 ± 0.05a	1.04 ± 0.01a	93.3

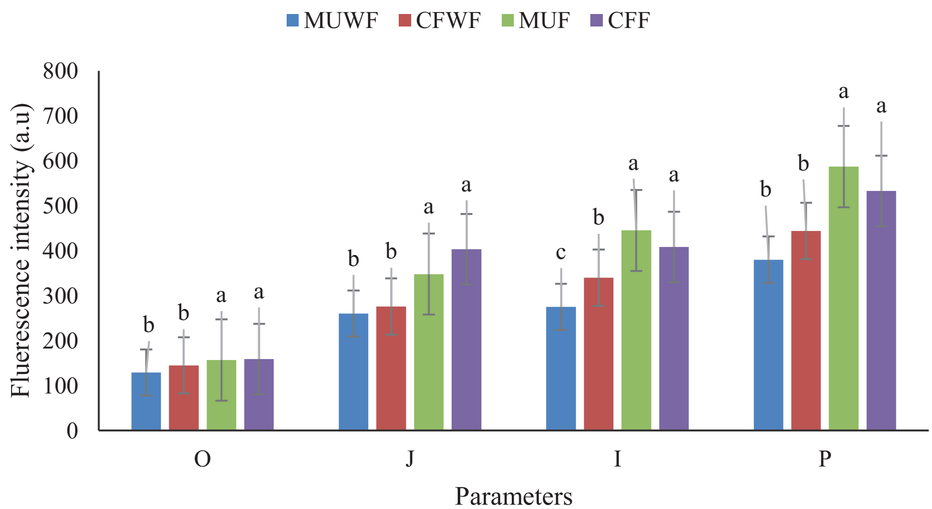

Fig. 1. Transient chlorophyll *a* fluorescence in forest species (*Schinus terebinthifolius* and *Caesalpinia ferrea*), with and without inoculation with arbuscular mycorrhizal fungi (*Rhizophagus clarus*), after 12 months of growing in the mining degraded area. Means followed be the same letter are not different by the Tukey's test ($p \leq 0.05$).

MAP in the area degraded by mining. The survival rates in treatments without inoculation with AMF were 71.1% (MUWF) and 73.3% (CFWF) (Table 2).

4. Discussion

The transient chlorophyll *a* fluorescence is an important parameter to evaluate the plant photosynthetic apparatus, mainly the functioning of the photosystem II, under abiotic stresses conditions (Kalaji et al., 2016). The inoculation of *S. terebinthifolius* and *C. ferrea* plants with arbuscular mycorrhizal fungi (AMF) affected the kinetic of the OJIP curve (Fig. 1). The values of the steps O and J of inoculated plants were higher than those of non-inoculated plants (Fig. 1). The O and J values are directly related to the closure of reaction centers, due to decreases in Qa, because these stages are dependent on light and are correlated with the antenna size and connectivity of the PSII (Mathur et al., 2019). Thus, non-inoculated plants presented lower O and J values, indicating that the reaction centers were closed later, thus decreasing the electron capture and slowing the decrease of secondary electrons (Mathur and Jajoo, 2020).

The J-P stage, termed thermal stage, is correlated to the complete reduction of the electron transport chain (Kalaji et al., 2014). Changes in the OJIP curve due to the use of AMF on *S. terebinthifolius* and *C. ferrea* plants were observed in the O-P and J-P stages. Non-inoculated *S. terebinthifolius* and *C. ferrea* plants had lower values in the I-P stage than inoculated plants (Fig. 1). According to Zivcak et al. (2014) this stage is related to the quantity of reactions centers of PSI, confirming that the use of AMF increases the efficiency of photosystems and prevents their functioning from being compromised.

Inoculated *S. terebinthifolius* and *C. ferrea* plants presented in general, improvements in the photosynthetic apparatus (Fig. 1 and Table 1). Plants in the treatments MUF and CFF had improvements in parameters related to absorption, capture, and flow of electrons to the final acceptor, and to the efficiency of the photosynthetic apparatus. These improvements were confirmed by increases in the parameters de absorption and trapping by cross section (ABS/CS0 and TR0/CS0) in plants of the treatments MUF and CFF (Table 1). Decreases in the parameters ABS/CS0 and TR0/CS0 were related to the deactivation of reactions centers of PSII, which resulted in decreases in the rates of exciton captured in the reaction centers (Chen et al., 2016).

The quantum yield of the energy dissipated in the antenna of PSII (DI0/ABS) is related to the size of the antenna complex (LCHII) and proportions of PSI and PSII (Cascio et al., 2010; Silva et al., 2019). Therefore, the use of AMF decreased losses of energy as heat preventing the inactivation of reaction centers of the photosystem and assisting to increase the PIABS, mainly in *S. terebinthifolius* plants. (Ferreira et al. (2018) evaluated *Mucuba cinereum* plants and found increases in maximum quantum yield, electron transport rate, and effective quantum efficiency of PSII, resulting in higher photochemical dissipation, which was related to increases in soil P levels and to the inoculation with AMF.

C. ferrea (Fabaceae) plants can fix atmospheric nitrogen favored the absorption of N by these plants, resulting in higher plant heights than the other treatments. Nitrogen is required for chlorophyll synthesis and is involved in the photosynthesis process. Thus, increases in N in the plant result in higher quantity of chlorophyll, increasing the interception of solar radiation for energy, nutrient absorption, and carbohydrate production. In a meta-analysis carried out by Neuenkamp et al. (2019), observed that most studies in the world indicated that forest species of the Fabaceae family when inoculated with AMF in degraded areas increase N and P in the plant, allowing greater growth.

Although there was no significant difference in height between the treatments of *S. terebinthifolius* plants they showed a good development for the average height. This species presents good growth in height in degraded areas due to its high capacity to overcome weed competition, thus, it is recommended for a fast soil covering (Marcuzzo et al., 2015). Resende et al. (2015) evaluated the development of 11 arboreal species grown in a degraded area and found that *S. terebinthifolius* plants have larger diameter and higher height and survival rate allowing those species to be recommended for projects of recovery of degraded areas.

The inoculation with AMF resulted in significant relative increases in mean stem base diameter of *C. ferrea* seedlings: from 0.75 cm in those of the treatment CFWF to 1.04 in those of CFF. A higher stem base diameter indicates a higher quantity of photoassimilates requested by the plant's aerial part (higher partitioning of photoassimilates of the aerial part) (Sabbi et al., 2010; Scalon et al., 2003). In this sense, among the species studied, *C. ferrea* showed the best performance when inoculated with AMF in relation to diameter and height.

The demand and use efficiency of nutrients and soil P concentration are the main predictors of responses in plant height and stem base diameter to inoculation with AMF. The soil of the area evaluated in the present work had 1.40 mg dm^{-3} of P which is very low and lower than that found by Costa and Zocche (2009) (5.98 mg dm^{-3}) which is also low for areas degraded by mining in Brazil. Plants inoculated with AMF and grown in soils with low *P* contents are highly dependent on symbiosis, even though AMF use significant part of the fixed carbon however it results in a higher nutrient absorption that promotes a higher photosynthetic rate and better plant growth (Smith and Read, 2008).

The inoculation of plants of *S. terebinthifolius* and *C. ferrea* with FMA resulted in greater survival compared to these species without inoculation. The survival of *S. terebinthifolius* seedlings with AMF was superior to that observed in other experiments with this species without AMF in degraded areas in Brazil (Dantas et al., 2015; Resende et al., 2015). The greater survival observed in plants with AMF may have been due to the fact that AMF has improved the absorption, capture and flow of electrons to the final acceptor, and in the efficiency of the photosynthetic apparatus allowing a better performance in an environment with poor soil in nutrients, high solar radiation and water deficit.

The photosynthetic process starts in the electron capture (photochemical phase) and, later these electrons are transferred between photosystems II and I until they reach the final NADP acceptors, forming NADPH and ATP. When these components are formed, the chemical phase of photosynthesis begins. This is responsible for several physiological phenomena, such as plant growth and development.

Any changes that compromise the absorption of electrons, consequently will compromised the development of the plant. These changes can be caused by several factors, such as high solar radiation, water deficit, mineral deficiency, high temperatures, etc.

In this work, the application of mycorrhizal fungi allows plants to absorb the nutrients available in the soil that are essential for maintaining photosynthesis. In turn, nutritional balance provides the proper functioning of plant photosystems, considering that the absorption of nutrients such as N, Mg and K, for example, are essential for the structure of chlorophylls (responsible for the absorption of light) and for the various biochemicas reactions.

It is worth mentioning that the fluorescence parameters confirm that the photosystems are in good working order and, therefore, the plants were able to perform photosynthesis with greater efficiency, had a higher survival rate, greater diameter and height.

5. Conclusions

In this work, it was evaluated whether inoculation of forest species with AMF planted in an area degraded by mining could improve growth, survival and ecophysiological parameters. In this sense, the species *Schinus terebinthifolius* and *Caesalpinia ferrea* inoculated with AMF can be used in forest plantations to restore areas degraded by mining in environments with high irradiance and soils poor in nutrients.

The inoculation of AMF in *Caesalpinia ferrea* allowed better efficiency in photosynthesis, promoting a survival greater than 90%, greater diameter (1.04 cm) and height (81.68 cm). Although the inoculation of AMF in *Schinus terebinthifolius* improved the fluorescence parameters, there was an increase only in the survival rate, being more than 90%. It is recommended that other native forest species inoculated with AMF be tested in areas degraded by mining.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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