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ORIGINAL ARTICLE

Survival and carbon stock of forest species in mixed plantation at 8 years of age

Sobrevivência e estoque de carbono de espécies florestais em plantio misto aos 8 anos de idade

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Abstract

Forest plantations that aim to neutralize carbon contribute to climate change mitigation by removing carbon dioxide from the atmosphere and fixing it in its biomass. Climate change mitigation via forest restoration is still a practice that needs scientific advances. Thus, the objective of this work was to evaluate the survival and carbon stock of forest species in carbon offset plantation at eight years. The planting took place in December 2010 to neutralize greenhouse gas emissions related to an event at the Federal University of Viçosa in Viçosa-MG. Two hundred and eleven planted seedlings of sixteen Atlantic Forest species had their survival and carbon stock assessed at eight years, aiming to understand the species' carbon removal. The inventory was carried out annually from 2011 (12 months of age) to 2018 (96 months). Diameter at ground height (DAS in mm) and total height (H in m) data were collected. Survival at the end of the eighth year was 52.30% (180 individuals). The evaluated species, *Albizia niopoides*, *Stryphnodendron polyphyllum*, *Senna multijuga* and *Enterolobium contortisiliquum* did not show mortality rates. *Stryphnodendron polyphyllum*, *Anadenanthera colubrina*, *Ateleia glazioveana* and *Citharexylum myrianthum* stood out as species with the highest carbon stock at 8 years of age. The pioneer species obtained the highest carbon stock and survival, while the species with the lowest stock were the non-pioneer species. Thus, species that have the greatest carbon stock and potential for the implementation of restoration and carbon neutralization projects are *S. multijuga*, *S. polyphyllum, A. glazioveana* e *A. colubrina,* due to the high survival and carbon storage of these species.

Keywords: Climate change; Greenhouse gases; Neutralization; Restoration; Forest species.

Resumo

Os plantios florestais que objetivam a neutralização de carbono contribuem para mitigação das mudanças climáticas por removerem dióxido de carbono da atmosfera e o fixarem em sua biomassa. A mitigação das mudanças climáticas via restauração florestal ainda é uma prática que necessita de avanços científicos. Desta forma, o objetivo do trabalho foi avaliar a sobrevivência e estoque de carbono de espécies florestais em plantio de neutralização de carbono aos oito anos. O plantio ocorreu em dezembro de 2010 para neutralizar as emissões de gases de efeito estufa referentes à realização de um evento da Universidade Federal de Viçosa em Viçosa-MG. Duzentas e onze mudas plantadas de dezesseis espécies da Mata Atlântica tiveram sua sobrevivência e estoque de carbono avaliados aos oito anos, visando compreender a remoção de carbono pelas espécies. O inventário foi realizado anualmente no período de 2011 (12 meses de idade) a 2018 (96 meses). Dados de diâmetro à altura do solo (DAS em mm) e altura total (H em m) foram coletados. A sobrevivência ao final do oitavo ano foi de 52,30% (180 indivíduos). As espécies avaliadas *Albizia niopoides,*

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Stryphnodendron polyphyllum, Senna multijuga e *Enterolobium contortisiliquum* não apresentaram mortalidade. *Stryphnodendron polyphyllum, Anadenanthera colubrina, Ateleia glazioveana* e *Citharexylum myrianthum* se destacaram como espécies de maior estoque de carbono aos 8 anos de idade. As espécies pioneiras obtiveram maior estoque de carbono e sobrevivência, já as espécies com menor estoque foram as não pioneiras. Assim, espécies que têm maior potencial para implantação de projetos de restauração e neutralização de carbono são *S. multijuga*, *S. polyphyllum, A. glazioveana* e *A. colubrina,* devido à alta sobrevivência e estocagem de carbono destas espécies.

Palavras-chave: Gases de efeito estufa; Mudanças climáticas; Neutralização; Restauração; Espécies florestais.

1. INTRODUCTION

Brazil in its Nationally Determined Contribution (NDC) proposed to reduce greenhouse gas emissions by 37% of the emission value of the year 2005 by 2025 and 43% of the emission value by 2030 (Brasil, 2015). One of the ways to achieve this goal is to restore 12 million hectares with native tree species by 2030 (Brasil, 2015). The commitment to restore areas in the country is expanded through Federal Law 12,651 / 2012 of the Forest Code, which identified that Brazil has a deficit of 19 million hectares of native forest in legal reserve areas (Guidotti et al., 2017).

Forest restauration is an activity that initiates or accelerates the recovery process of a given area that has suffered some degradation, damage or transformation through human actions (Society for Ecological Restoration, 2004). It is complex and challenging, especially in degraded environments inserted in tropical landscapes with high biodiversity (Souza & Batista, 2004; Silva et al., 2017a; Bustamante et al., 2019).

Restoration projects, through the planting of forest species seedlings, are costly for implementation and monitoring (Brancalion et al., 2021). However, in advanced stages of degradation, planting seedlings is a recommended alternative because, associated with silvicultural techniques, it will provide greater growth of planted species and accelerate the restoration of the area (Holl & Aide, 2011; Brancalion et al., 2016; Bustamante et al., 2019).

Forest restoration can be allied to carbon neutralization (Morais Junior et al., 2020). Tree planting is one of the most common techniques for carbon neutralization, and it is used by companies and institutions to combat climate change (Miranda et al., 2021; Hassan, 2009).

The process of forest restoration and carbon neutralization still needs technical and scientific advances at the species level, so that it can have greater effectiveness in transforming a degraded area into a balanced forest (Brancalion et al., 2010).

The use of native forest species should be a priority in restoration programs in order to preserve the biodiversity of human-dominated landscapes (Janishevski et al., 2015; Possingham et al., 2015). Therefore, studies that allow us to know the potential of native forest species are important (BenDor et al., 2015). In this sense, the present work aimed to evaluate the carbon stock of forest species in restoration and carbon neutralization mixed plantations at eight years of age.

2. MATERIAL AND METHODS.

2.1 Characterization of the Area

The study area is located in the Open Events Space of the Federal University of Viçosa (UFV) in Viçosa, Minas Gerais, Brazil (20° 25' 35.73'' S, 42°52'30.84'' W). The study area has as characteristics: altitude of 708 m; Atlantic Forest biome; regional vegetation classified as Seasonal Semi-deciduous Montana (Martins & Cavararo, 2012). The climate is classified as Cwa (Köppen) with cold, dry winters and hot, rainy summers. The average accumulated rainfall from November to March for the region is 366.3 mm, with water deficit for the remaining months. The average annual precipitation is 1314.0 mm with an average annual temperature of 21.8 °C (Silva et al., 2016).

The topography of the region is characterized by flat hill tops with a predominance of dystrophic latosols with a high presence of aluminum (Table 1), the colluvial slopes present shallow and cambial latosols with a predominance of nutrient-rich cambisols in the grottoes

(Ferreira Júnior et al., 2012). In the study area, at the depth of 0-0.20 m and 0-0.40 m, fifteen simple samples were collected (walking in zig zag), homogenized, to form a composite sample, for which a chemical analysis of the soil was performed.

Table 1 - Chemical analysis of soil in the study area.

Depth	pH	pH	pH	P	K	Mg^{2+}	Al^{3+}	H + Al	SB	t	T	V	m
	H_2O	KCl	$CaCl_2$	mg/dm³	mg/dm³	cmolc/dm³	cmolc/dm³	cmolc/dm³	cmolc/dm³	cmolc/dm³	cmolc/dm³	%	%
0-20 cm	4.41	-	-	0.90	18.00	0.13	1.24	7.10	0.73	1.97	7.83	9.30	62.90
0-40 cm	4.35	-	-	0.70	11.00	0.08	1.14	6.90	0.56	1.70	7.46	7.50	67.10

pH in water, KCl and CaCl - Relation 1:2,5 pH in water, KCL and CaCl - Relation 1:2,5 P - Na - K - Fe - Zn -Mn - Cu -Cd - Pb - Ni - Cr – Extractor Mehlich-1 Ca^{2+} - Mg^{2+} - Al^{3+} - Extractor: KCl - 1 mol/L H + Al - Extractor Calcium acetate 0,5 mol/L - pH 7,0; SB = Sum of Exchangeable Bases; t – Effective Cation Exchange Capability; T – Cation Exchange Capacity at pH 7,0; V = Base Saturation; Index m = Aluminum Saturation Index.

2.2 Implementation of the trial

Planting was carried out in December 2010 with the purpose of neutralizing greenhouse gas emissions (GHG) related to the event "Farmer's Week" held that same year by the Federal University of Viçosa (UFV). The Zero Carbon Program of the UFV Forestry Department is responsible for quantifying the GHG's during the Farmer's Week. The conversion of gases into a number of trees to be planted is carried out with software developed by program members (Alves, 2018), so that the event is neutralized.

The planting area was covered by brachiaria (*Urochloa decumbens*) on bare soil. The brachiaria and leaf-cutting ants were controlled by manual weeding and the use of glyphosate (Roundup Original, 36% m/v; Monsanto do Brasil Ltda, Brasil) and formicide baits (AttaMex-s, 0,3% m/m sulfluramid; Unibrás Agroquímica Ltda Brazil), respectively. The pits, with dimensions of 30 cm x 30 cm x 30 cm, were manually opened using a hoe.

Phosphate fertilizer (18% P_2O_5) was incorporated into the pits twenty days before planting, at a dosage of 120 grams per pit. Two surface fertilizations with NPK 4-14-8 were carried out at a dosage of 120 grams per pit and 100 grams of potassium chloride (60% K_2O) per pit was also applied sixty and ninety days after planting.

The planting area is 1588 m² at 2 m x 2 m spacing and rows oriented in the direction parallel to the slope gradient (Figure 1). The planting was carried out with seedlings produced in plastic bags with a total of three hundred and ninety-seven individuals planted from twenty-nine Atlantic Forest species (Table 2).

After the time the planting was established, two re-plantings were carried out in the area, to meet the demand for carbon neutralization. However, it was decided to use only the species established on the initial planting date, with a minimum number of three individuals per species for survival and carbon analysis. Thus, the scope of the study includes 21 species with 396 individuals from the initial planting for survival and 17 species with 211 surviving individuals for carbon stock (Table 2). Information of the scientific name's species and its respective ecological groups were identified through Lorenzi (2009) and Barbosa et al. (2017).

	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	Line 9	Line 10	Line 11	Line 12	Line 13	Line 14	Line 15	Line 16	Line 17	Line 18	Line 19	Line 20
Plant 21	27		17	29	21		17	12			19									
Plant 20	2	12	3	24	12	19	6	17		12	19								12	12
Plant 19	17	23	12	26	26	3	26	29		19	22	3	18	22	12	29			11	12
Plant 18	18	12	12	3	2	18	17	26	26	12	26	24	20	3	12	6	2	24	12	12
Plant 17	12	27	26	29	29	26	26	29	26	8	5	3	24	29	29	8	8	3	3	26
Plant 16	12	12	24	2	27	25	8	3	27	4	29	26	29	29	3	14	8	1	3	3
Plant 15	22	12	27	20	29	12	12	19	26	19	27	9	2	3	12	20	22	3	12	12
Plant 14	12	12	27	27	18	18	22	2	26	26	23	26	3	12	22	22	8	3	22	24
Plant 13	5	10	23	17	3	21	26	12	29	19	3	29	3	20	23	24	22	12	18	12
Plant 12	18	28	5	18	14	12	3	26	29	18	27	29	26	8	12	26	27	22	23	12
Plant 11	28	27	5	22	18	27	14	27	29	12	18	22	20	3	29	19	18	13	29	12
Plant 10	3	18	29	29	10	17	24	27	22	27	29	8	18	29	8	12	20	22	24	29
Plant 9	19	27	12	29	3	25	27	27	12	18	29	26	27	12	29	22	26	8	8	15
Plant 8	3	12	22	26	18	18	26	27	12	10	19	12	12	24	2	12	6	26	18	3
Plant 7	29	18	22	3	29	17	27	12	23	18	14	26	12	22	12	29	26	26	7	18
Plant 6	19	26	12	23	3	17	2	19	23	10	5	6	11	26	23	14	22	18	1	18
Plant 5	12	18	26	22	2	18	23	7	12	2	16	7	3	27	8	29	18	18	7	26
Plant 4	2	18	23	26	27	2	27	22	19	12	12	26	26	18	3	3	22	18	19	23
Plant 3	16	27	12	23	6	19	19	26	19	14	15	27	23	26	7	27	11	1	1	24
Plant 2	3	12	19	7	22	19	12	19	12	26	15	12	12	23	8	24	17	23	24	12
Plant 1	18	19	27	22	19	3	17	13	26	18	2	18	8	5	18	29	11	20	1	4

Figure 1 – Sketch of the positioning of the species along the area, corresponding to their respective registration number (Table 1).

Table 2 – Ratio of species to their ecological groups (GE) of Pioneer (P) and Non-Pioneer (NP) and number of individuals (N) planted in the experiment

Code	Common name	Scientific name	Family	GE	N
1	Albizia	*Albizia niopoides* (Spruce ex Benth.) Burkart	Leguminosae (Fabaceae)	P	6
2	Angelim	*Andira fraxinifolia* Benth.	Leguminosae (Fabaceae)	NP	13
3	Angico-vermelho	*Anadenanthera colubrina* var. *cebil* (Griseb.) Altschul	Leguminosae (Fabaceae)	P	31
4	Araçá	*Psidium cattleianum* Sabine	Myrtaceae	P	2
5	Aroeira-salsa	*Schinus molle* L.	Anacardiaceae	P	6
6	Barbatimão	*Stryphnodendron polyphyllum* Mart.	Leguminosae (Fabaceae)	P	5
7	Candeia	*Gochnatia polymorpha* (Less.) Cabrera	Asteraceae	P	6
8	Carrapateiro	*Ateleia glazioveana* Baill.	Rutaceae	NP	14
9	Cedro	*Cedrela fissilis* Vell.	Meliaceae	NP	1
10	Cutieira	*Joannesia princeps* Vell.	Euphorbiaceae	P	4
11	Farinha-seca	*Senna multijuga* (Rich.) H.S.Irwin & Barneb	Leguminosae (Fabaceae)	P	4
12	Faveiro	*Peltophorum dubium* (Spreng.) Taub	Leguminosae (Fabaceae)	P	59
13	Fedegoso	*Senna macranthera* (Collad.) Irwin et Barn.	Leguminosae (Fabaceae)	P	2
14	Garapa	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	Leguminosae (Fabaceae)	NP	33
15	Goiabeira	*Psidium guajava* L.	Myrtaceae	P	3
16	Guapuruvu	*Schizolobium parahyba* (Vell.) S.F. Blake	Leguminosae (Fabaceae)	P	2
17	Indeterminada	-	-		11
18	Ingá-miúdo	*Inga vera* Willd	Leguminosae (Fabaceae)	P	34
19	Ipê-preto	*Zeyheria tuberculosa* (Vell.) Bureau ex Verl	Bignoniaceae	P	22
20	Ipê-tabaco	*Handroanthus chrysotrichus* (Mart. ex DC.)	Bignoniaceae	NP	7
21	Jacarandá-branco	*Dalbergia nigra* (Vell.) Allemão ex Benth.	Leguminosae (Fabaceae)	NP	2
22	Jatobá	*Hymenaea courbaril* L.	Leguminosae (Fabaceae)	NP	24
23	Jenipapo	*Genipa americana* L	Rubiaceae	NP	16
24	Orelha-de-macaco	*Enterolobium contortisiliquum* (Vell.) Morong	Leguminosae (Fabaceae)	P	13
25	Paineira	*Ceiba speciosa* (A.St.-Hil) Ravenna	Malvaceae	P	2
26	Pau-viola	*Citharexylum myrianthum* Cham.	Verbenaceae	P	39
27	Saboneteira	*Sapindus saponaria* L.	Sapindaceae	NP	28
28	Sapucaia	*Lecythis pisonis* Camb.	Lecythidaceae	NP	2
29	Sobrasil	*Colubrina glandulosa* Perk.	Rhamnaceae	P	5
		Total			396

2.3 Variables Evaluated and Statistics

Census-type forest inventories were conducted annually from 2011 (12 months old) to 2018 (96 months old). The diameter at ground height (DAS) data were measured in mm using a precision digital caliper up to a diameter of 20 mm; above that diameter a tape measure was used (Table 3). The total height (H) in cm was obtained using a graduated rod up to 7 meters; above that a Vertex Laser 5 was used (Table 3).

Table 3 – Diameter at Ground Height (DAS), Total Height (HT) and Sectional Area (AS) and their respective Standard Deviations for the 16 species at 8 years of age

Species	Average of		
	DAS (mm)	Height (mm)	AS (mm^2)
A. colubrina	124.00 ± 79.01	554.42 ± 285.02	167.75 ± 237.55
A. fraxinifolia	56.87 ± 24.98	133.17 ± 108.87	29.49 ± 24.99
A. glazioveana	161.73 ± 45.86	641.74 ± 277.08	220.57 ± 106.98
A. leiocarpa	61.71 ± 31.67	399.67 ± 170.65	36.92 ± 34.27
A. niopoides	76.23 ± 42.46	350.92 ± 169.40	57.44 ± 50.61
C. myrianthum	98.16 ± 58.40	486.67 ± 483.46	93.51 ± 101.05
E. contortisiliquum	94.54 ± 45.04	412.31 ± 159.71	84.90 ± 75.85
G. polymorpha	146.02 ± 33.70	431.25 ± 38.38	174.16 ± 73.65
H. courbaril	48.50 ± 14.81	282.73 ± 92.23	20.04 ± 13.22
I. vera	145.61 ± 145.18	388.40 ± 171.02	325.70 ± 969.33
P. dubium	124.50 ± 49.27	478.08 ± 169.17	140.28 ± 96.06
S. molle	56.60 ± 22.24	264.00 ± 118.29	28.27 ± 22.88
S. multijuga	176.03 ± 105.32	632.50 ± 176.89	308.70 ± 281.93
S. polyphyllum	290.11 ± 91.69	886.00 ± 230.82	713.84 ± 349.54
S. saponaria	15.96 ± 11.05	67.30 ± 43.04	2.72 ± 3.53
Z. tuberculosa	62.31 ± 35.69	248.96 ± 171.05	39.66 ± 39.97

The percentage of survival (S) of the plants was determined by the equation: Sj = (Nfj/Noj) x 100, where Nfj = number of surviving individuals of the j-th species; N0j = initial number of planted individuals of the j-th species. The carbon stock was (C) obtained by the equation of Morais Junior (2017), represented by: Cij=(5.85996x10^-11) x (DAS^0.682085)x (H^3.83808) (Adjusted R^2 = 96.91%), where: Cij = carbon stock of the i-th individual of the j-th species (kg); DAS = diameter at ground height (mm); and H = total height of the individual (cm).

Carbon stock data among species were statistically analyzed with ANOVA at 1%. The hypotheses tested were, respectively: whether the carbon stocks between species were equal or different. Fisher's mean test was used, when the null hypothesis was rejected (p-value < 1%).

3. RESULTS AND DISCUSSION

3.1 Survival

The overall survival was 52.30% at 8 years (Table 4). The leguminous plants *A. niopoides*, *E. contortisiliquum*, *S. multijuga*, *S. polyphyllum* had 100% survival (Table 4). Plants belonging to the Leguminosae family grow faster and produce large amounts of organic matter, promoting long-term improvement in edaphic conditions. Some are used as green manure and are capable of fixing nitrogen when associated with bacterium of the genus *Rhizobium* (Sultani et al., 2007; Siddique et al., 2008; Fiore et al., 2019).

Table 4 – Survival (S), number of individuals planted (N) and survival in percentage (S%), for the respective species

Species	N	S	S%
A. niopoides	6	6	100.00
E. contortisiliquum	13	13	100.00
S. multijuga	4	4	100.00
S. polyphyllum	5	5	100.00
A. glazioveana	14	12	85.71
S. molle	6	5	83.33
A. colubrina	31	24	77.42
I. vera	34	26	76.47
G. polymorpha	6	4	66.67
P. dubium	59	36	61.02
Z. tuberculosa	22	12	54.55
G. americana	16	8	50.00
A. fraxinifolia	13	6	46.15
H. courbaril	24	11	45.83
A. leiocarpa	33	10	30.30
S. saponaria	28	6	21.43
C. glandulosa	5	1	20.00
H. chrysotrichus	7	1	14.29
C. myrianthum	39	3	7.69
J. princeps	4	0	0.00
Total	369	193	52.30

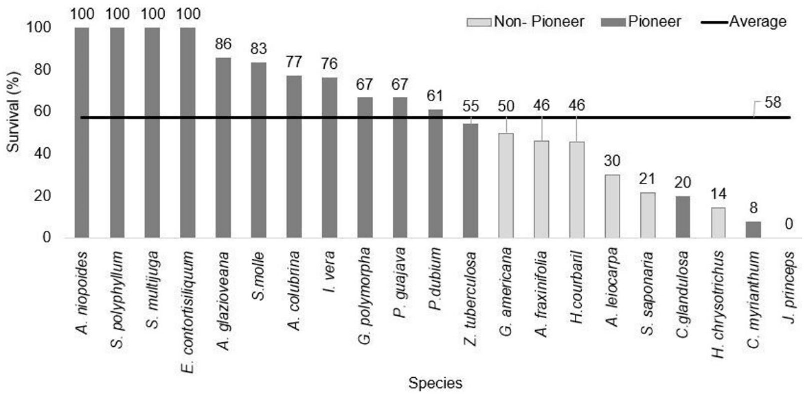

Figure 2 – Survival graph, for the respective species and their functional groups, being P the pioneer species and NP the non-pioneer species.

Other pioneer species that showed above average survival were: *A. glazioveana* (S = 85.71%), *S.molle* (S = 83.33%), *A. colubrina* (S = 77.42%), *I. vera* (S = 76.46%), *G. polymorpha* (S = 66.67%), *P. dubium* (S = 61.02%) e *Z. tuberculosa* (S = 54.55%) (Figure 2). Pioneer species had an average survival of 66.64%, while non-pioneer species had a survival rate of 34.67%.

A. niopoides, stood out by presenting a high survival rate. Besides belonging to the Leguminosae family, it is considered a rustic species with good adaptability to dry soils, being indicated for reclamation projects (Maia, 2012; Silva et al., 2017b). The pioneer species *E. contortisiliquum* has a rapid growth characteristic, reaching a height of four meters at three years of age. Due to this characteristic, is the recommended species for reforestation in degraded areas for mixed plantations (Araújo & Paiva Sobrinho, 2011).

S. multijuga is a potential species for studies for use in forest restoration projects, due to its high growth rates, indifferent to the physical conditions of the soil and adaptable to nutrient-poor soils (Araújo et al., 2021; Lorenzi, 2009; Carvalho, 2014). It is a food source for pollinators, being considered a melitopilous species, which contributes to the propagation and perpetuation of the species (Pinheiro et al., 2018).

On the other hand, *C. myrianthum* (S = 7.69%) is a species adapted to floodplain conditions; therefore it requires a water conditions. The planting region had long droughts in the winter period, which may have harmed the growth in the first years after the establishment of this species (Lorenzi, 2009; Silveira et al., 2013).

The cuts caused in the leaves by ants (*Atta sexdens*), on the other hand, are an important factor for the survival of plants because they reduce the photosynthetic area for the absorption of light radiation, which in turn interrupts the physiological and metabolic processes that are essential for the growth of the plants (Fürstenberg-Hägg et al., 2013; Morais Junior et al., 2019; Souza et al., 2020).

The invasive species, *Urochola decumbens* and *Mabea fistulifera* negatively influenced the establishment of the plants in the experiment. The attack of leaf-cutting ants (*Atta sexdens*) was registered throughout the inventories, being an important factor in the survival of the species. The presence of invasive trees (*Mabea fistulifera*) and weeds (*Urochola decumbens*), in the planting area impairs the survival of individuals due to competition for nutrients, water and light (Muzika, 2017; Dueñas et al., 2021).

The planting area, being a degraded pasture, has exposed subsoil patches with an erosive process, which leads to chemical degradation of the soil (Table 1). The area can be characterized as of low fertility, poor nutrient replacement and high acidity (Morais Junior et al., 2020).

The characteristics of area of the high light incidence and exposed soil increased the probability of pioneer species to obtain greater growth and development compared to non-pioneers. This is due to the low nutritional requirement that species belonging to the ecological group of pioneers have and, therefore, are able to adapt to adverse conditions (Lorenzi, 2009). In degraded areas, such as the one of the study, the surface layer is compromised, harming the development of seedlings at an early stage, as their roots are not developed enough to explore the deeper layers of the soil (Rodrigues et al., 2009; Morais Junior et al., 2019).

4. CARBON STOCK

S. polyphyllum (C = 658.60 kg) had the highest carbon stock among the species studied. *A. colubrina* (C = 207.68 kg) and *A. glazioveana* (C = 181.61 kg) showed statistical similarity with *S. polyphyllum* (Table 5). The species showed high stock variability, as can be seen by the Fisher's mean test result (Figure 3).

S. polyphyllum obtained the highest carbon stock, suggesting it to be a species with great potential for GHG removal. It also has a high initial growth rate, adaptability to the soil (soils low in nutrients and water), litter deposition and good crown formation. These factors provide shade in its early stages, confer resistance to brachiaria, and promote the development of secondary species around it (Pilon & Durigan, 2013; Morais Junior et al., 2020).

A. colubrina is widely used in forest restoration projects due to its germination capacity, high survival, rapid development, and adaptability to adverse soil conditions, as is *S. polyphyllum* (Lacerda & Figueiredo, 2009; Santos et al., 2018). *A. glazioveana*, is a species that presents a high rate of natural regeneration, showing good development in clearings and pastures, being recommended for plantations aimed at the recovery of degraded areas (Carvalho, 2014; Fontoura et al., 2017).

Table 5 – Mean observed Carbon Stock (kg.individual^{-1}) and their respective Standard Deviations, at 8 years of age

Specie	Carbon Stock average (kg.ind^{-1})
S. polyphyllum	658.60 ± 426.61
A. colubrina	207.68 ± 545.99
A. glazioveana	181.61 ± 171.27
C. myrianthum	180.85 ± 302.80
S. multijuga	158.18 ± 207.53
P. dubium	49.88 ± 60.73
E. contortisiliquum	33.15 ± 67.79
I. vera	27.92 ± 51.13
G. polymorpha	20.63 ± 9.48
A. leiocarpa	19.06 ± 29.27
A. niopoides	13.54 ± 14.11
Z. tuberculosa	8.42 ± 16.12
S. molle	3.92 ± 5.57
H. courbaril	3.40 ± 4.21
A. fraxinifolia	0.81 ± 1.29
S. saponaria	0.02 ± 0.04

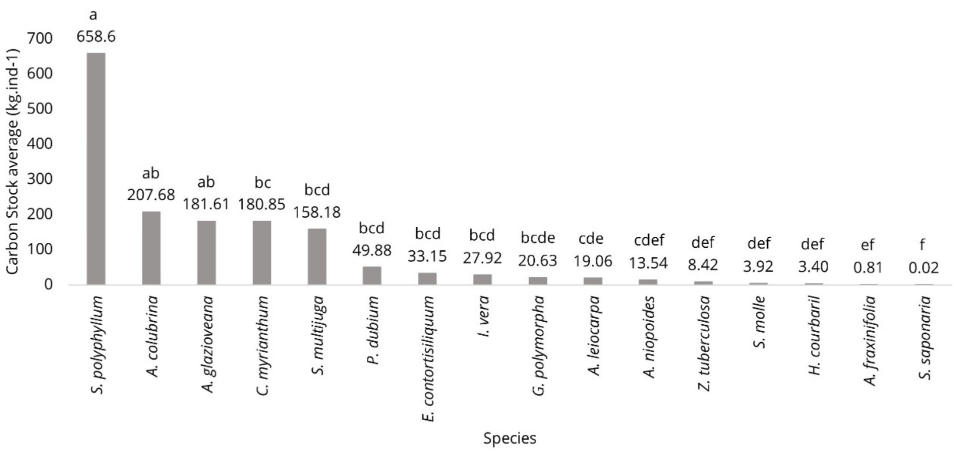

Figure 3 – Graph of average carbon stock (kg.ind^{-1}), with the results for Fisher's test of the species studied.

Among the ecological groups studied (pioneer and non-pioneer), the non-pioneer species showed lower carbon stock values: *G. americana* (C = 5.23 kg), *H. courbaril* (C = 3.40 kg) and *S. saponaria* (C = 0.01 kg).

Non pioneer species have difficulty growing in full sun, besides having less adaptive conditions to intense light (Martínez-Garza et al., 2013). However, the best use of resources by this group of species, such as light, water and nutrients, should be highlighted, in addition to having greater long-term carbon storage capacity (Piotto et al., 2020).

The stock variability among species is linked to the different uses of resources (light, nutrients, and water) by species. The difference in resource utilization is defined by the morpho-physiological structures of the plants that determine the growth rate of the species (Harper, 1982; Morais Junior et al., 2019).

Carbon neutralization plantations should aim at the use of two ecological groups: pioneers and non-pioneers. Pioneer species act by storing carbon in the short term and providing conditions for non-pioneers to develop (Campoe et al., 2014; Shimamoto et al., 2014; Morais Junior et al., 2019). Species with high initial development are important in restoration projects to facilitate and accelerate the process of ecological succession, in addition to acting as large carbon sequesters in the early stages of planting (Redondo-Brenes & Montagnini, 2006; Morais Junior, 2017).

5. CONCLUSIONS

It can be concluded that there are species with greater potential for use in restoration and carbon neutralization projects such as *S. multijuga, S. polyphyllum*, *A. glazioveana* and *A. colubrina*, due to the greater survival of the species and carbon stock.

Further studies of non-pioneer species are needed to assess the long-term carbon stock. For species with low survival and carbon stock, such as *S. saponaria, A. pavonina, H. courbaril*, and *G. americana*, more research is needed on their performance and development. Thus, the use of these species must be done with greater caution, in order to reduce the risk of planting failure in the long term.

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