

Restoration through trenches does not demand organic fertilization and sawdust coverage on plant establishment

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Research Article

Keywords: Forest restoration, soil reconstruction, selection of tree species, mining

Posted Date: October 9th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-3405947/v1>

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Additional Declarations: No competing interests reported.

Abstract

Forest restoration in post-open pit mining areas is complex and faces the challenge of “recreating” the soil under horizontal disruption, representing strong barriers to root growth. Hence, trenches (paths opened by digging) for planting are an alternative to improve root development conditions and plant growth. This study aimed to evaluate growth of six tree species planted in trenches under three treatments: Topsoil or control (TS), Sawdust (SD) and Cow manure (CM). The trenches (1 m in height and length by 40 m long) were filled with topsoil. In the 6-m space between trenches, two treatments were performed: soil covered and not covered by sawdust to test natural regeneration. Six tree species (250 individuals) in pits over trenches where Mean Annual Increment in height (MAI_{Ht}), diameter (MAI_{DSH}), crown area (MAI_{CA}), and survival were assessed. After 18 months, mortality was 2.4%, *Clitoria fairchildiana*, *Tachigali vulgaris*, and *Croton matourensis* showed highest MAI_{Ht} and MAI_{DSH} , and the *C. fairchildiana* presented the highest MAI_{CA} with no statistical differences among treatments. Sawdust coverage had no effects on litter amounts and on tree species from the natural regeneration. Herbs and grasses covered 45.5% and 57.2% of the soil with and without sawdust. Based on growth and mortality, *C. fairchildiana*, *T. vulgaris*, and *C. matarensis* can be recommended for initial restoration after kaolin mining.

Introduction

Wide mineral diversity in Brazil and growing world demand strengthen mining, including kaolin, which is the main raw material of cement, which essential in civil construction (Silva et al. 2021). In 2021, Brazil produced 1.7 Mt of kaolin, being the 5th world producer (Idoine et al. 2023). Mining, however, results in severe environmental impacts, which requires recovery plans for rehabilitation and/or restoration of degraded ecosystems (Gastauer et al. 2018). Hence, studies about restoration of post-mined environments have advanced rapidly in recent years (Martins et al. 2020b). They prioritize large numbers of tree species in post-mining sites in order to reach several habitats and ecological niches to increase biodiversity (Wozniak et al. 2015; Kałucka and Jagodziński 2016; Gastauer et al. 2018).

Restoration encompasses different methods, all in response to degradation level, expected recovery time, specific local constraints, and financial resources (Martins et al. 2021; Barbosa et al. 2022; Oliveira et al. 2022, 2023). Regarding kaolin mining, in which the return of soil conditions can exceed 150 years (Lane et al. 2020), trenches can be an efficient alternative to minimize impacts caused by intense soil compaction during mining operations (Ribeiro et al. 2021). Besides this, seedling planting has been the most recommended active restoration method that ensures high initial plant density and diversity, especially in sites with low resilience (Ribeiro et al. 2019; Brancalion and Holl 2020; Martins et al. 2020a). Normally, mortality rate are high in initial plantings with many tree species (Löf et al. 2019; Erickson and Halford 2020; Martins et al. 2020a). For this reason, species adapted to the local soil and climate conditions, with rapid growth, and attractive to the wild fauna are recommended (Brancalion and Holl 2020). Species adapted to hostile environments are also indicated, as they contribute to rebalance and stabilize the ecosystem through colonization mechanisms (Ramos et al. 2020).

Organic composts retain water, increase organic matter content, nutrient levels, and physiological performance of plants (Mingorance et al. 2017; Roy et al. 2021, 2022). Furthermore, organic waste has high potential to remediate soils contaminated by heavy metals (Hu et al. 2021). Organic waste is seen as a strategy to reduce restoration time, whether put in planting pits (Ribeiro et al. 2021; Oliveira et al. 2023) or spread over surface (Marcuzzo et al. 2013; Barbosa et al. 2022).

Monitoring the restoration process is important to understand the recovery trajectory (Hou et al. 2019) and species performance under the employed method (Ribeiro et al. 2019). For this, indicators such as mortality, average height,

canopy cover floristic diversity, forest structure, and natural regeneration can be chosen to check planting efficiency and understand the ecosystem dynamics (Grant et al. 2007). Litter stock is also an important indicator due to its nutrient transferring to the soil, which enables fertility and local productivity (Diniz et al. 2015), decrease of soil erosion (Józefowska et al. 2017), regulation of surface hydrological processes, and seed bank germination (Quideau et al. 2013; Martins et al. 2018a).

This work had the objective to answer the following questions related to trenches for the initial recovery of areas degraded by kaolin mining: What is the effect of sawdust and cow manure in planting pits over plant growth and the composition of natural regeneration? Can soil coverage with sawdust increase the litter stock? The hypothesis is that cow manure to favor development of planted trees and that sawdust coverage promote increase in density and floristic composition of natural regeneration.

Material and Methods

Study Area

The study was carried out in a kaolin mining belonging to Pará Pigmentos S.A. (PPSA) of the French company Imerys, located in the municipality of Ipixuna do Pará, Pará state, Brazil (Fig. 1). Mining in area, known as “Cota 85”, stopped in 2013. Soil reconstruction took place between the end of 2015 and beginning of 2016. The area was chosen for the experiment because it portrays most of the post-kaolin mining environments in the Amazonia, with unstructured soil horizons and high compaction. According to Koppen’s classification, the region’s climate is the Am, wet equatorial, with a moderate dry season from June to November (Alvares et al. 2013), mean annual rainfall of 1,750–2,500 mm (Andrade et al. 2017) and average temperature of 26.7°C. Soils are mainly Yellow Ferralsols, well drained, thick, and leached, with low natural fertility (João et al. 2013). The most common natural vegetation is lowland dense ombrophilous forest (IBGE 2012).

Experimental Design

In November 2017, nine trenches measuring 1 m in width, 1 m in depth and 40 m in length were opened and filled with topsoil in 0.35 ha. Trenches were 6 m apart from each other. Planting pits measuring 0.40 m x 0.40 m x 0.40 m (0.064 m³) were opened each 1.5 m along the trenches length (Fig. 2). Then 400 g pit⁻¹ of simple superphosphate, 130 g pit⁻¹ of urea and 130 g pit⁻¹ of potassium chloride (KCl) were applied, divided into two applications with a 60-day interval. Then, two experiments were established, where the first aimed to test two organic composts added to the pits; sawdust (SD) and cow manure (CM), as well as a control (CT) distributed in three trenches per treatment. For SD and CM, 40 liters per pit of the respective organic was used, which was mixed with topsoil to complete the volume. In all treatments, the initial soil chemical characterization was performed (Table 1). The second experiment consisted of spreading a 10-cm layer of sawdust between the trenches over 50% of the total area, which is soil covered (COV) and soil uncovered (UNCOV) with sawdust. The sawdust was composed of residues from sawmills near the PPSA mine.

Table 1
Initial characterization of early soil chemical properties in planting pits in kaolin mining areas, eastern Amazonia, Brazil.

Treatment	OM	C	N	C/N	P	Al	Ca	Mg	K	CEC _T	CEC _E	V	m	pH
	— g kg ⁻¹ —				mg dm ⁻³	— cmol _c dm ⁻³ —						— % —		H ₂ O
	0.0-0.1 m													
CT	6.9	4.0	6.8	0.59	0.6	0.9	0.05	1.2	0.02	4.3	2.1	29.9	40.8	5.0
SD	6.2	3.6	5.5	0.65	0.3	0.8	0.09	1.2	0.02	4.2	2.2	32.0	38.6	4.7
CM	4.7	2.7	6.8	0.40	0.3	0.9	0.07	1.2	0.02	4.1	2.2	31.9	40.3	4.8
	0.1-0.2 m													
CT	7.1	4.1	8.2	0.50	0.3	1.0	0.14	0.2	0.01	3.2	1.3	10.8	73.9	5.0
SD	5.3	3.1	6.8	0.46	0.4	0.9	0.17	1.2	0.02	4.1	2.3	33.8	39.2	4.7
CM	4.7	2.7	6.8	0.40	0.5	0.9	0.09	1.2	0.01	4.3	2.3	32.0	40.1	4.7
	0.2-0.4 m													
CT	8.0	4.6	6.8	0.68	0.3	0.9	0.13	1.1	0.01	3.8	2.2	34.0	41.0	4.9
SD	4.6	2.7	6.8	0.40	0.4	1.0	0.11	1.1	0.01	4.3	2.2	29.7	43.4	5.0
CM	4.8	2.8	6.8	0.41	0.9	1.0	0.13	0.3	0.01	3.2	1.5	12.0	66.8	4.9

Legend: OM (Organic Matter), C (Carbon), C/N (Carbon/Nitrogen ratio), P (Phosphorus), Al (Aluminum), Ca (Calcium), Mg (Magnesium), K (Potassium), CEC (Cation Exchange Capacity), V% (Base Saturation), m% (Aluminum Saturation), CT (Control), SD (Sawdust) and CM (Cow Manure).

At the beginning of the rainy season, in January 2018, 250 individuals distributed among the tree species *Byrsonima spicata* (Cav.) DC., *Clitoria fairchildiana* RA Howard, *Croton matarensis* Aubl., *Inga edulis* Mart., *Syzygium cumini* (L.) Skeels and *Tachigali vulgaris* L.F Gomes da Silva & HC Lima were randomly planted in the trenches' pits. The seedlings had an average height of 27.56 ± 8.87 cm, and each one was marked with aluminum plates for monitoring. The planting order was random, allowing, at most, the repetition of two individuals of the same species consecutively. Tree species were chosen according to i) rapid growth; ii) adaptability to the region's climate; iii) high survival rate; iv) N fixation in the soil and v) high litter production. The seedlings were produced in the company's nursery six months before planting with seeds collected from native forests around the mine and conservation areas under the company's responsibility.

Variables analyzed

Growth and survival of planted individuals

Total height (Ht), diameter at soil height (DSH), and canopy projection of all planted individuals were measured 18 months after planting area for all planted individuals. Crown area, mean annual increment as well as survival percentage were calculated (Eq. 1 to Eq. 5).

$$CA = \pi \times \left[\frac{(L_1 + L_2)}{4} \right]^2 \text{ Eq.1}$$

$$MAI_{DSH} = \frac{DSH}{T} \text{ Eq.2}$$

$$MAI_{Ht} = \frac{Ht}{T} \text{ Eq.3}$$

$$MAI_{CA} = \frac{CA}{T} \text{ Eq.4}$$

$$S\% = (N_1/N_i) \times 100 \text{ Eq.5}$$

Where: CA (Crown area; m²), L₁ (Length of the longest crown longitudinal line; m), L₂ (Length of the crown perpendicular line; m), T (Time, years), S% (Survival Percentage), N₁ (Number of living Plants), N_i (Total number of planted seedlings), MAI_{DSH} (Mean Annual Increment of diameter at soil height, cm), MAI_{CA} (Mean Annual Increment of crown area, m²), MAI_{Ht} (Mean Annual Increment of total height, m).

Natural Regeneration and Litter Stock

To evaluate natural regeneration in the experiment, 48 plots measuring 2 m x 2 m (4 m²) were installed, where 24 were placed in COV and 24 in the UNCOV treatment. In each coverage area, 12 plots were installed in the trenches and 12 between trenches (Fig. 2). Absolute density (AD) of the naturally regenerating trees was obtained by the ratio of number of individuals by the sampled area. Furthermore, the soil cover percentage was estimated according to the plant life form in: i) herbs, and ii) grasses. For these two variables, COV and UNCOV was a variation factor. Scientific names were obtained in Reflora database (<http://floradobrasil.jbrj.gov.br/>), under the APG IV system.

The litter stock collected was quantified by using a gauge measuring 0.25 m x 0.25 m and 0.10 m in height. Samples were collected in the center of all plots used to assess natural regeneration, considering two factors: plots in the trenches and plots between trenches and those in COV and UNCOV areas (Fig. 2). After collection, samples were dried at 60°C until reaching constant mass and weighed with analytical balance (0.01 g).

Statistical Analysis

The experiment had a completely randomized 6 x 3 design, with three replications (trenches), where the MAI (total height, diameter, and crown area) of the six species were analyzed in two organic composts (sawdust and cow manure) and a control in the planting pits. Litter was evaluated in a 2 x 2 factorial scheme, where the following variation sources were considered: soil coverage (COV and UNCOV) and the addition of different organic composts in planting pit (sawdust, cow Manure, and control). MAI and litter underwent normality analysis using the Shapiro-Wilk test ($p > 0.05$) and Levene's homoscedasticity test, both at 5% probability of error. For the variables that did not meet the abovementioned assumptions, transformation was performed by Box-Cox, which indicated the best transformation type. For MAI data of species by treatment, the Mauchly sphericity test was applied, with Greenhouse-Geisser correction ($p > 0.05$) for a two-way analysis of variance (Two-Way ANOVA, $p < 0.05$). After a significant difference, means were compared using the post-hoc test ($p < 0.05$), with Bonferroni correction. Statistical analyses and graphical representations were performed using the R software, version 4.3.0 (R Core Team 2023).

Results

Growth and Survival of Planted Species

The mean annual increment in height (MAI_{Ht}) was significantly different between the treatments applied in the pits ($F_{[2:224]} = 6.86$; $p = 0.001$) and between the species ($F_{[5:224]} = 72.87$; $p < 0.001$) (Fig. 3). The control showed the highest MAI_{Ht} ($2.19 \pm 0.60 \text{ m yr}^{-1}$ for all species), but did not differ from the sawdust treatment. *T. vulgaris* and *C. fairchildiana* showed the highest MAI_{Ht} , with 2.86 ± 0.19 and $2.61 \pm 0.37 \text{ m yr}^{-1}$, respectively, not differing from each other.

Regarding mean annual increment in diameter at soil height (MAI_{DSH}), there was a significant difference among species ($F_{[5:226]} = 139.78$; $p < 0.001$) and species interaction with different treatments ($F_{[10:226]} = 4.20$; $p < 0.001$). However, unlike MAI_{Ht} , the treatments alone did not differ ($F_{[2:226]} = 4.20$; $p = 0.076$). *C. fairchildiana* presented highest mean of MAI_{DSH} , especially in the treatments control (CT) and cow manure (CM) (Fig. 4). The lowest mean MAI_{Ht} and MAI_{DSH} values were at 1.46 m yr^{-1} and 2.39 cm yr^{-1} , respectively.

The total area occupied by the crowns of all individuals planted was of 0.30 hectares, representing 85.71% of the whole experimental area. Of this percentage, CT had 31.98%, and SD 30.37%. The mean annual increment in crown area (MAI_{CA}) differed statistically among species ($F_{[5:226]} = 100.34$; $p < 0.001$), treatments ($F_{[2:226]} = 8.58$; $p < 0.001$), and interaction between factors ($F_{[2:226]} = 2.57$; $p = 0.006$). CT presented higher growth rates compared to CM, but it did not differ from SD ($p = 0.330$). *C. fairchildiana* presented highest mean MAI_{CA} (Fig. 5), whereas *B. spicata* and *S. cumini* showed the lowest values. *C. matourensis*, *I. edulis*, and *T. vulgaris* presented the same means of MAI_{CA} . Finally, in 18 months, the mortality rate was only 2.4%, where only individuals of *B. spicata* died.

Natural regeneration

The percentage of non-tree soil coverage from natural regeneration was 45.5% and 57.2% for sawdust-covered (COV) and uncovered (UNCOV), respectively, with a predominance of herbs and grasses in both treatments (Fig. 6). Moreover, no liana was found between trenches.

The regeneration of tree species between trenches was numerically greater in UNCOV, but with no statistical difference of COV ($t = 0.73$; $p = 0.473$). Species richness was low, with lower values in COV and with only three species recorded. The invasive tree species *Acacia mangium* showed 0.10 individuals/ m^2 , which represented 40% of the density of individuals of COV (Table 2). Regarding the litter stock, we did not find alterations by COV ($t = 0.68$; $p = 0.421$) neither UNCOV ($F_{[2,18]} = 2.29$; $p = 0.130$) (Fig. 7).

Table 2

Absolute density of regenerating tree and shrub species under the treatments of a 10-cm sawdust layer coverage (COV) and with no coverage (UNCOV) in a restoring area after kaolin mining, PPSA, eastern Amazonia, Brazil.

Species	Absolute density of regenerating species (Individuals m ⁻²)			
	Life Form	COV	UNCOV	Representation (%)
<i>Acacia mangium</i> (Willd.) Pedley	Tree	0.05	0.10	39.48
<i>Solanum crinitum</i> Lam.	Shrub	0.08	0.06	36.84
<i>Solanum fulvidum</i> Bitter	Shrub	0.01	0.04	13.16
<i>Cecropia palmata</i> Willd	Tree	0.00	0.02	5.26
<i>Lecythis pisonis</i> Cambess	Tree	0.00	0.01	2.63
<i>Vismia guianensis</i> (Aubl.) Choisy	Tree	0.00	0.01	2.63
General		0.15	0.25	100

Legend: COV (soil covered with sawdust) and UNCOV (soil not covered, without sawdust).

Discussion

The effects of fertilization with organic composts on the development of six tree species in a restoring area after kaolin mining the eastern Amazonia did not overcome the control. Hence, the initial hypothesis that organic fertilization would increase plant growth was refuted. Overall, chemical and organic fertilization provide higher nutrient concentration to the rhizosphere and, together with the trenches opening, improve soil conditions and root development (Sloan and Jacobs 2013). Regarding the soil physical and chemical properties in the same study area, Ribeiro et al. (2021) found no improvements with trenches opening. Trenches provided less compacted substrate with the possibility of greater water infiltration, which was directly correlated with plant growth (Orozco-Aceves et al. 2017; Duncan et al. 2020). Thus, probably 18 months, is not time enough for conclusive responses about different substrates, because decomposition and nutrients release are directly influenced by soil features (physical, chemical, and microbiological), type of wood of the sawdust, and cow manure composition, which determines the nutrient availability.

Planted individuals commonly show higher growth than those from the natural regeneration in the Brazilian Amazonia (Salomão et al. 2014; Martins et al. 2020a), with mean increment higher than 1.40 m yr⁻¹ and 2.39 cm yr⁻¹ in height and diameter at soil height, respectively. The reestablishment of proper soil conditions comes through the insertion of pioneer species that accelerate forest succession and the structural characteristics of the forest over the years. Therefore, our results corroborate the choice of an appropriate restoring strategy with species that tolerate water stress and nutrient deficit conditions, helping N fixation and, consequently, favoring biogeochemical cycles of N and C, in order to return resilience conditions of the restoring area (Justino et al. 2017; Batterman 2018).

Legume species, for example, have N fixation characteristics, as is the case of *Inga edulis*, one of the most important multi-purpose tree legumes for cultivation in acidic and low fertility soils of the Amazonia (Jaquetti et al. 2014). Additionally, when combined with green and chemical fertilization, the establishment and growth of *I. edulis* can increase due to its photosynthetic performance (Jaquetti et al. 2014). Of the species used in the initial planting, *C. fairchildiana*, *T. vulgaris* and *C. matourensis* showed the best increment results for both height and diameter (Fig. 3; Fig. 4). These species belong to the ecological group of pioneers and/or initial secondary forest, with rapid growth, and

C. matourensis was identified as one of the most representative in the natural regeneration of bauxite mining areas close to this study site (Martins et al. 2020a). The high mean annual increment in crown area of *C. fairchildiana*, is a favorable characteristic for the restoration of intensely degraded ecosystems since the soil is quickly covered by the treetops. This feature helps to promote better microsite conditions and control of invasive trees and grasses as a natural mechanism to reduce light intensity.

Probably the strong presence of grasses had effects in plant mortality, because the mortality rate was low and represented only by *B. spicata*. Andrade and Sanchez (2014) recommended that up to 10% of mortality dispersed in the planted area is acceptable. So, in this study, the mortality rate of 2.4% was low, likely to the ecology of the planted species, high rainfall, which is typical of the region, and the soil conditions promoted by the experiment. In natural regeneration, the low density of tree and shrub species under the sawdust coverage may have been influenced by the sawdust decomposition time and the high layer thickness (10-cm), which may have hindered light incidence over seeds, thus hindering germination and seedling emergence. Although sawdust possibly hinders erosion processes by minimizing the impact of rainwater directly on the soil, we do not recommend its use in excess due to prevent conditions for the establishment of spontaneous species.

The presence of *S. crinitum*, *S. fulvidum*, *C. palmata*, and *V. guianensis* in natural regeneration is a clear indication of the initial succession phase, especially in intensely degraded ecosystems (Massoca et al. 2012). It is expected that these species will be replaced during the succession, increasing plant species richness as well as the availability and diversity of resources for the fauna (Cruz et al. 2020). The biodiversity of forest fragments is often referred to as islands, which is related to size and distance of the forest matrix. Larger and less isolated fragments are more favorable for biodiversity maintenance (Almeida et al. 2011). Besides these species, *L. pisonis* and *A. mangium* were also sampled. *L. pisonis* is native to the Amazonia and one of the most frequent species in the predominant phytophysognomy in the study site. It has commercial potential for both wood and non-wood products (Siviero et al. 2020) and is also indicated for planting in degraded areas of the Brazilian Atlantic Forest (Morais Junior et al. 2019). *L. pisonis* has long life and usually occupies the forest canopy. Its presence in the experiment is possibly due to forest remnants, where the closest remnant is less than 100 m South of the planting area. On the other hand, *A. mangium* is native to Australia, Papua New Guinea, and Indonesia, and is considered an invasive species of difficult control that can damage local biodiversity (Heringer et al. 2019; Koutika and Richardson 2019). This species was planted more than 15 years before the experiment (2003) in adjacent areas for restoration programs.

Increase in litter stock means the gradual return of biogeochemical cycles and nutritional self-sufficiency of vegetation (Londe et al. 2016), with greater capacity to infiltrate water into the soil and improve its fertility (Durigan et al. 2016). There was no significant difference between the organic fertilization treatments in planting pits and in the sawdust coverage (Fig. 6), but the dry mass values were similar to those found in studies carried out in the Amazonia (Martins et al. 2018b) and other biomes (Zhang et al. 2014).

Organic fertilization in planting pits did not differ among control and the composts sawdust and cow manure. However, monitoring with more indicators to assess the restoring process efficiency should remain, as the fertilization effects can emerge over the years. A financial viability study of the trenches to restore degraded areas would be an important step to consolidate the method. Trenches are initially more expensive than other methods, which can be balanced over the years with no need of further interventions, such as enrichment with seedlings.

Conclusions

Organic fertilizer addition in planting pits did not show increment in growth of individuals of the six pioneer species tested in the initial planting of a restoring area after kaolin mining in the eastern Amazonia. In relation to the planted

species, mortality was low. *Clitoria fairchildiana*, *Tachigali vulgaris*, and *Croton matourensis* showed the highest mean annual increment in height and diameter, and *C. fairchildiana* showed the highest crown area increment. The natural regeneration of tree species, percentage of non-tree soil coverage, litter density, and dry mass did respond to the soil sawdust coverage.

Based on 18 months of monitoring, the trenches method to restore areas degraded by mining indicates to be an efficient method with no need of organic fertilization in planting pits as well as sawdust coverage. However, more detailed financial studies and longer time monitoring are necessary to consolidate the method.

Declarations

Acknowledgment

To the Brazilian National Council for Scientific and Technological Development (CNPq) for providing the first author's doctoral grant. To the Federal Rural University of the Amazonia (UFRA), especially to the Graduate Program in Forest Sciences (PPGCF), for the opportunity to conduct this study. V.P. Oliveira acknowledges the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Finance Code 001. To Imerys, its employees and Embrapa Eastern Amazonia for their participation and coordination in the research project and logistical support during the activities. To colleagues, Ian Bassalo de Castro, Márcio Cordeiro and José Marques, for their help in the field assessment.

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Figures

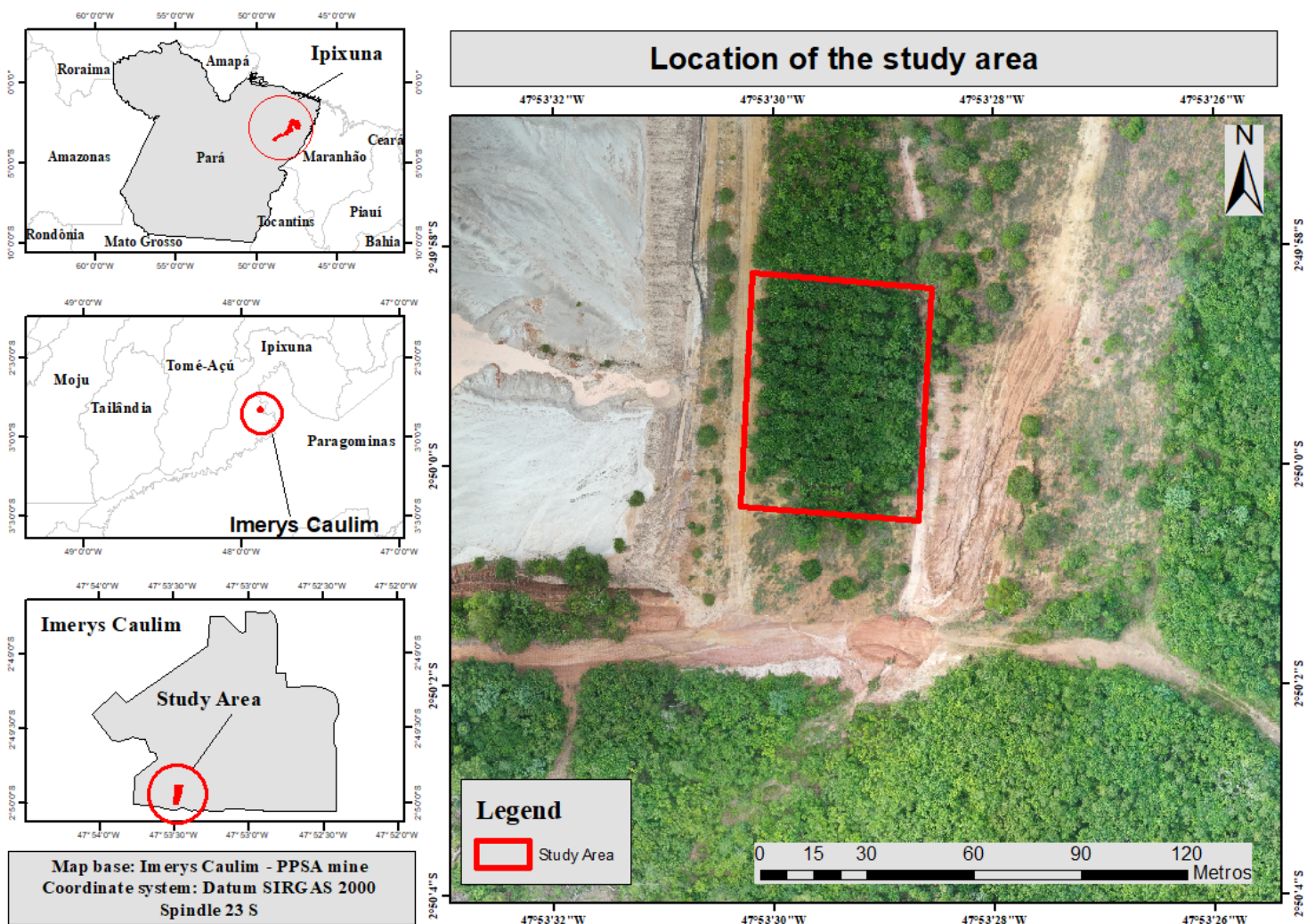


Figure 1

Location of the study area under restoration after kaolin mining, PPSA, in Ipixuna do Pará, Pará state, Brazil.

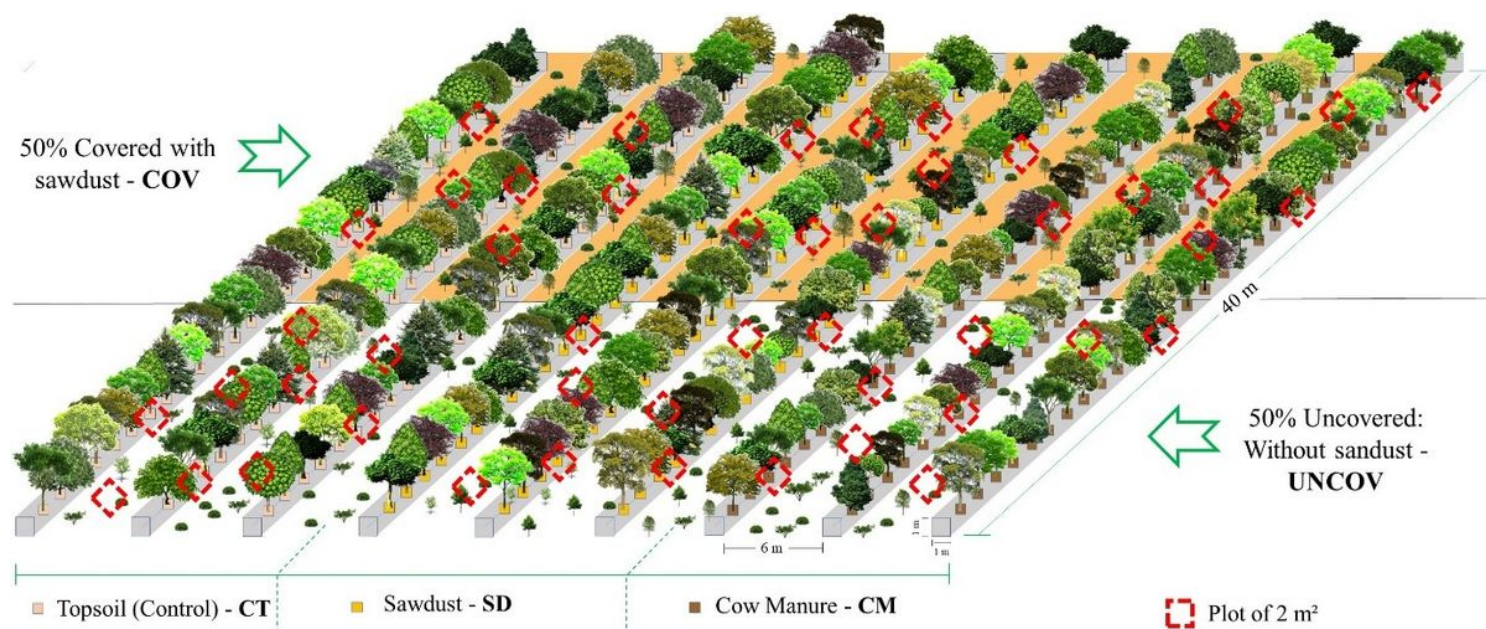


Figure 2

Experiments simulation 18 months after planting and distribution of CT (Topsoil), SD (Sawdust), and CM (Cow Manure) treatments, where 50% of the area had soil coverage with sawdust in degraded area by kaolin mining, PPSA, eastern Amazonia, Brazil. The square polygons show plots distribution to assess natural regeneration and litter.

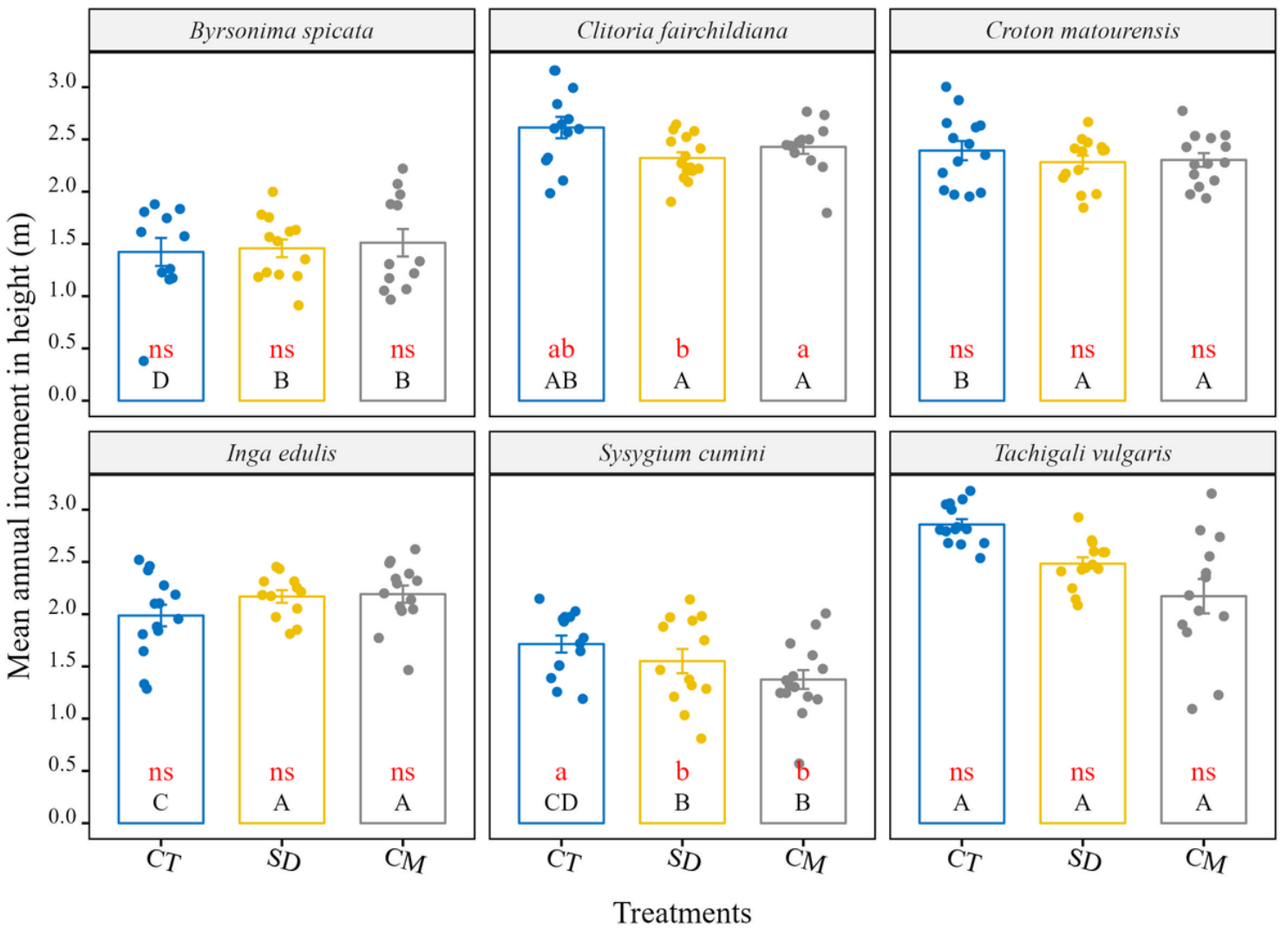


Figure 3

Mean ($\pm$ SE) of the Mean Annual Increment in height (MAI_{Ht}) of six species planted in a restoring area kaolin mining, PPSA, eastern Amazonia, Brazil. Capital letters indicate differences between species for the same treatment with fertilization, whereas lowercase letters indicate differences between treatments with fertilization in the same species, according to Tukey's test ($p \geq 0.05$). ns = non-significant difference, and each dot represents a plant of the respective species. CT (Control), SD (Sawdust), and CM (Cow Manure).

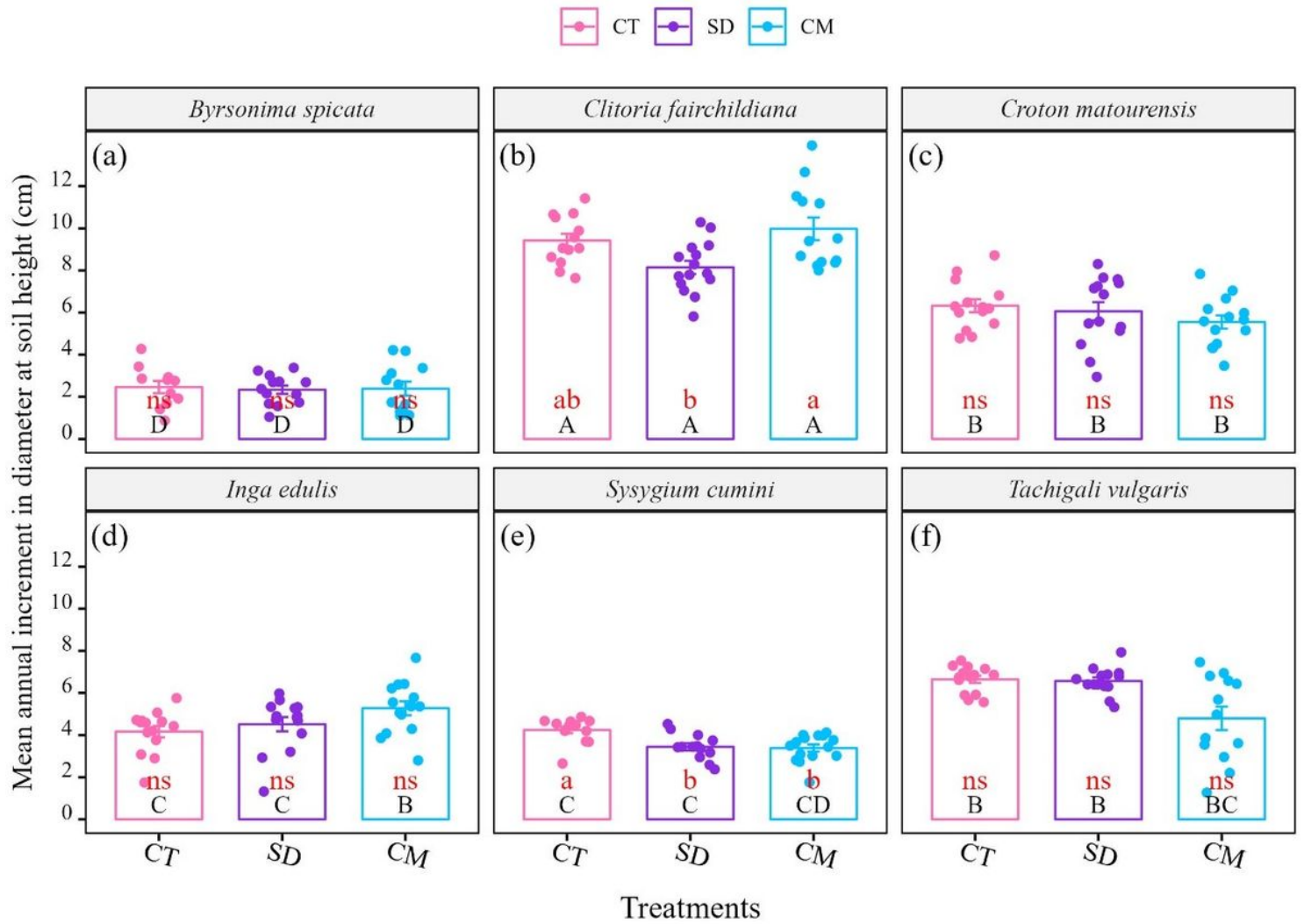


Figure 4

Mean ($\pm$ SE) of the Mean Annual Increment in diameter at soil height (MAI_{DSH}) of six species planted in a restoring area kaolin mining, PPSA, eastern Amazonia, Brazil. Capital letters indicate differences between species for the same treatment with fertilization, whereas lowercase letters indicate differences between treatments with fertilization in the same species, according to Tukey's test ($p \geq 0.05$). ns = non-significant difference, and each dot represent a plant of the respective species. CT (Control), SD (Sawdust), and CM (Cow Manure).

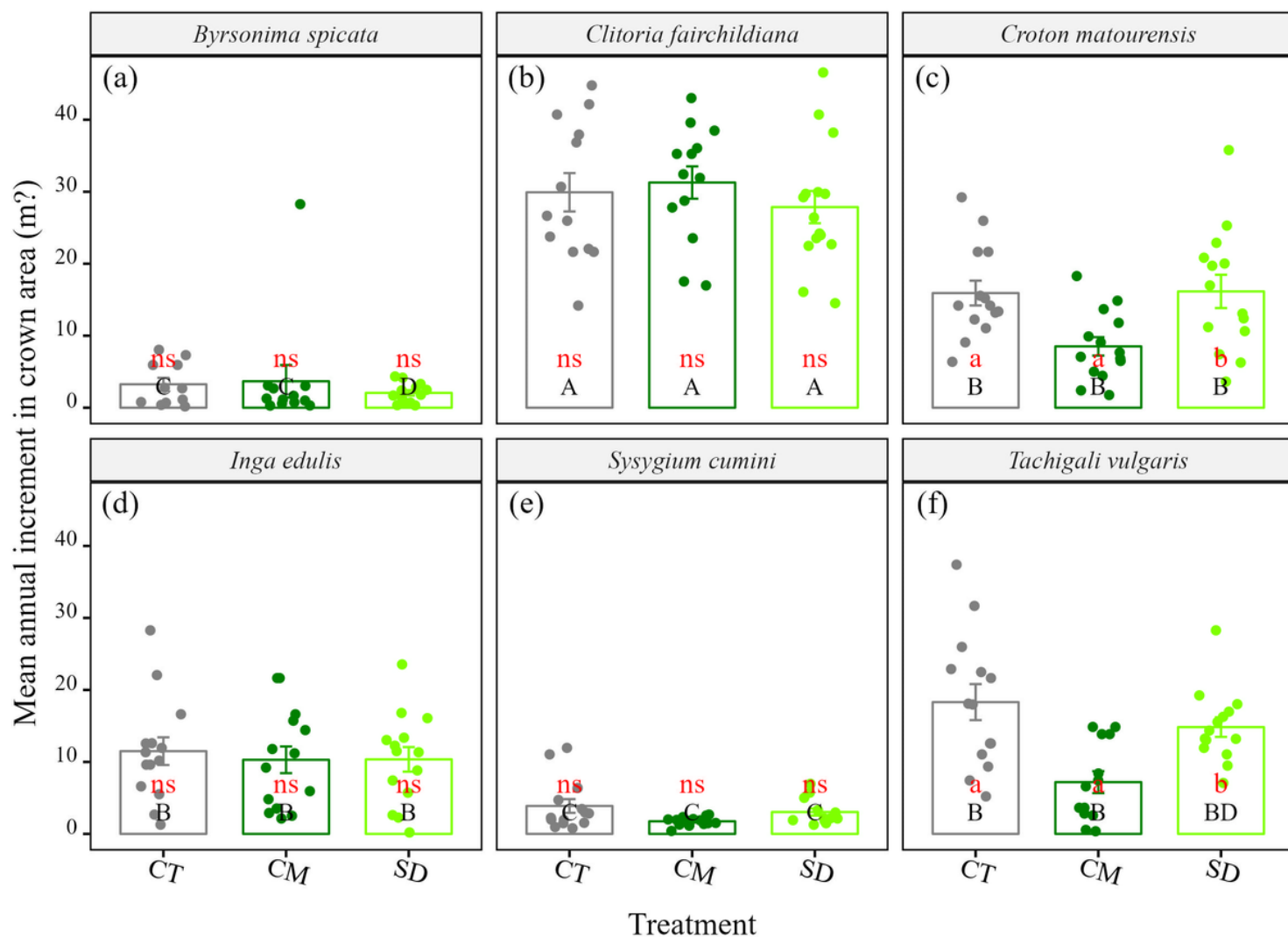


Figure 5

Mean ($\pm$ SE) of the Mean Annual Increment in crown area (MAI_{CA}) of six species planted in a restoring area kaolin mining, PPSA, eastern Amazonia, Brazil. Capital letters indicate differences between species for the same treatment with fertilization, whereas lowercase letters indicate differences between treatments with fertilization in the same species, according to Tukey's test ($p \geq 0.05$). ns = non-significant difference, and each dot represents a plant of the respective species. CT (Control), SD (Sawdust), and CM (Cow Manure).

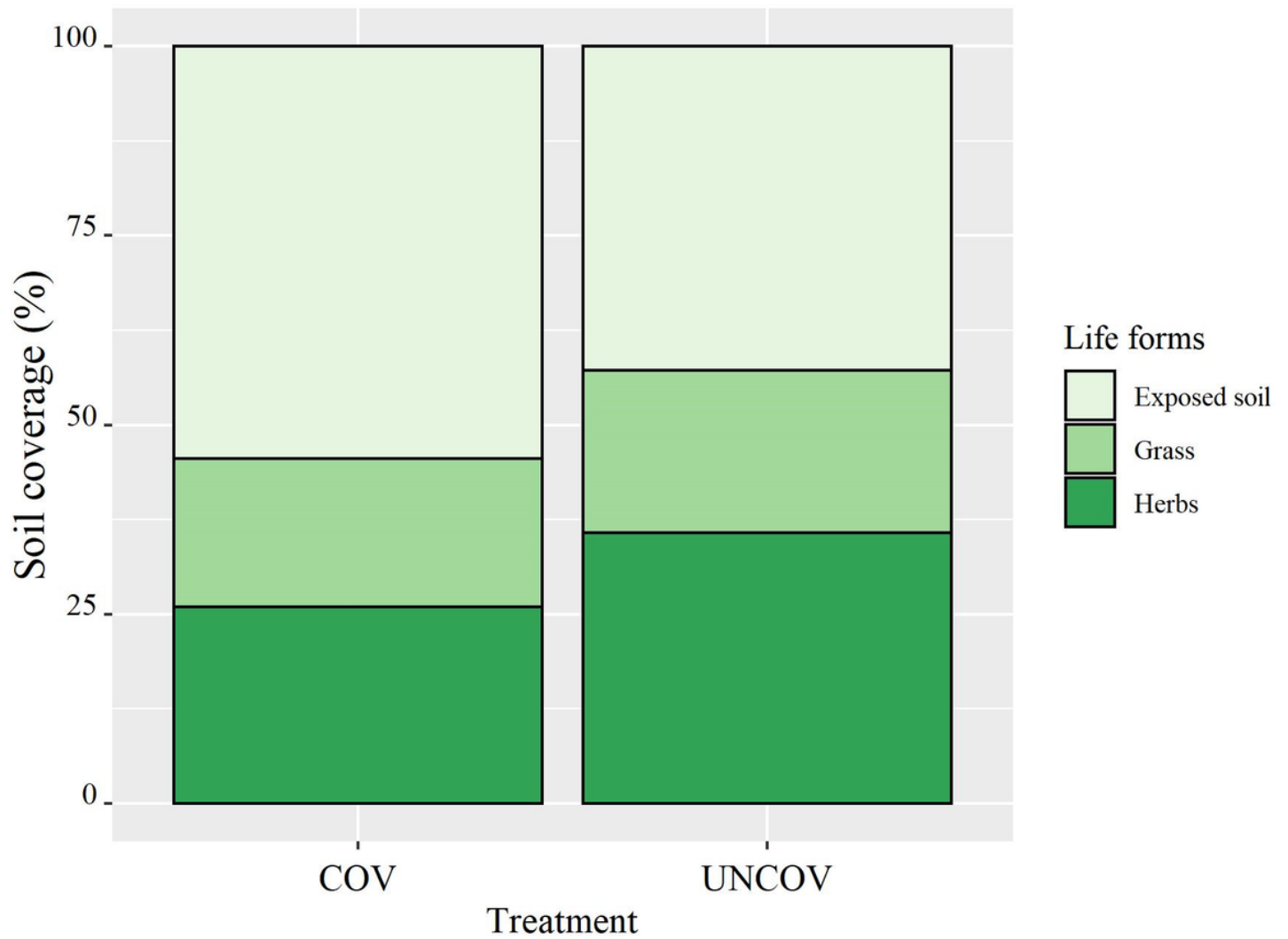


Figure 6

Percentage of soil covered by herbs, and grasses in three fertilizations treatments in planting pits in a restoring area after kaolin mining, PPSA, eastern Amazonia, Brazil. COV (Soil covered with sawdust), UNCOV (Soil not covered, without sawdust).

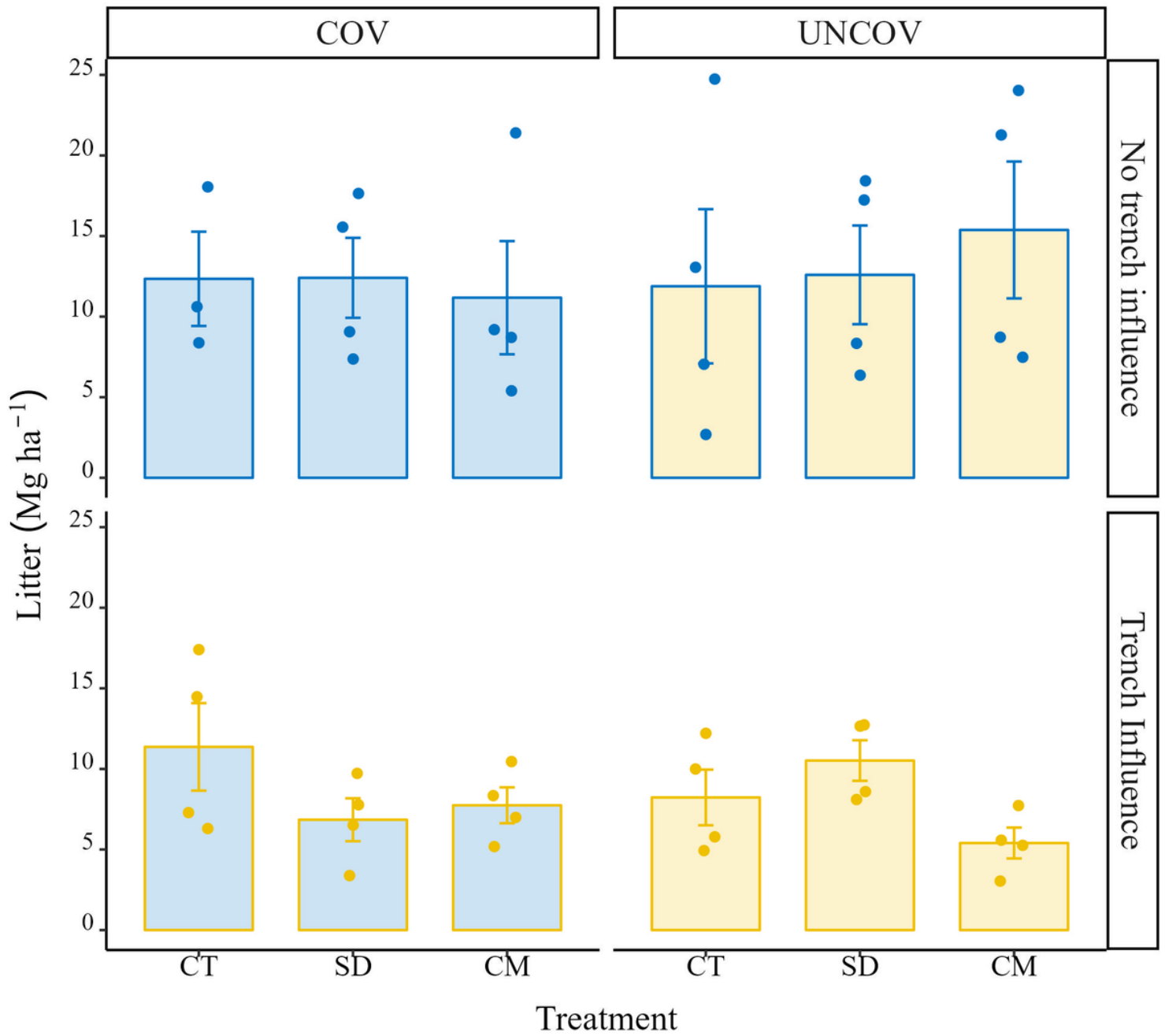


Figure 7

Mean ($\pm$ SE) of the litter in the planting rows with (COV) and without sawdust coverage (UNCOV), under the influence of fertilization treatments in planting pits. Each dot represents a sub-sample unit collected from COV and UNCOV.