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Atlantic forest tree species responses to silvicultural practices in a degraded pasture restoration plantation: From leaf physiology to survival and initial growth

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ABSTRACT

Deforestation has led to ecosystem degradation in many tropical regions. Re-establishment of native tree species on degraded land presents challenges due to environmental stressors such as water and nutrient limitations, particularly from weed competition. Ecophysiological studies can help assess responses of native tree species to silvicultural practices and improve our understanding of processes that influence their establishment and growth. Silvicultural treatments borrowed from commercial tree plantations such as greater nutrient applications and complete weed control can improve best silvicultural practices in forest restoration. Two contrasting silvicultural treatments, "traditional" based on common management practices for reforestation of native trees and "intensive" based on commercial plantation silviculture, were evaluated based on tree mortality, biomass, photosynthesis, chlorophyll content, soluble proteins, and nutritional status of 20 native Brazilian species, 2.5 years after planting. Intensive silviculture increased tree survival by 20%, showed higher aboveground biomass from 13% to 7-fold and increased photosynthesis of ~20% from 15.8 $\mu mol\ m^{-2}\ s^{-1}$ to 18.7 $\mu mol\ m^{-2}\ s^{-1}$, compared to traditional silviculture. Total soluble proteins were 14% higher with 6.7 $\mu g\ cm^{-2}$ in intensive silviculture compared to 5.9 $\mu g\ cm^{-2}$ under traditional silviculture. Eighty percent of trees showed greater N content, with a 13% higher average than under traditional silviculture (2.60 $g\ m^{-2}$ versus 2.92 $g\ m^{-2}$). Average values of chlorophyll A, B, and total were ~8% higher under intensive silviculture, but not significantly different between treatments. Overall, intensive silviculture provided a positive impact on the restoration plantation. During the initial years of plantation establishment, intensive silviculture methods were effective in leading to significant increases in growth and survival.

1. Introduction

Deforestation in tropical regions poses environmental threats to critical ecosystems. Every year, millions of hectares are converted from native tropical forests to other uses, such as agriculture, pasture and urbanized areas (FAO, 2011). In Brazil, the deforestation rate averaged 2.6 million hectares per year during the period of 2000–2010 (FAO, 2011), with a significant part of this process occurring on Atlantic Forest, an ecosystems formed by evergreen, seasonally deciduous and widely spaced gallery woodlands (Morellato and Haddad, 2000). Ranked as one of the 25 most important international areas for biodiversity, Brazilian Atlantic Forest supports over 20,000 species of vascular plants. Forty percent of these plants are endemic, representing 2.7% of the planet's total (Myers et al., 2002). Currently, there is ~15% of its original cover (Fundação SOS Mata Atlântica and Instituto de Pesquisas Espaciais, 2013). The process of deforestation results in fragmentation of the remaining patches (Calmon et al., 2011), loss of biodiversity, with particular concern for endangered species (Fearnside, 2005; Rands et al., 2010), carbon emissions to the atmosphere (Reich, 2011), and degradation of the natural resources, mainly soil and water (Metzger et al., 2010; Salemi et al., 2012).

Restoration ecology aims to assist and to manage a natural ecosystem, degraded by human-induced activities, to achieve its

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ecological integrity with a minimum level of biodiversity and variability of the ecological processes (Parrotta et al., 1997; Hobbs and Harris, 2001, Kageyama et al., 2003). Currently, different methodologies of forest restoration have been applied on deforested areas to reverse this situation. The strategies focus on different aspects of secondary succession such as auto resilience (Simões and Marques, 2007), fauna–flora interactions (Chazdon, 2008), soil seed bank germination (Martins and Engel, 2007), transference of the organic horizon (forest floor) from an intact native forest (Parrotta and Knowles, 2001), and tree plantation (Engel and Parrota, 2001; Campoe et al., 2010; Rodrigues et al., 2011). Among these methods, forest plantations are widely used in Brazil (Rodrigues et al., 2009), combining early (pioneers) and late (non-pioneers) successional species, and species from different functional groups (legume N-fixing and non-legume), at different proportions, aiming to achieve a forest structure of trees and restore ecological processes (Silver et al., 2004; Campoe et al., 2010). The combination of different tree species with inherent contrasting growth rates (pioneers and non-pioneers) and functioning (e.g. N-fixing trees) provide a wider potential to use the natural resources (light, water and nutrients) available on the site to be restored, due to their diverse strategies of canopy and soil colonization (Erskine et al., 2005; Chaer et al., 2011).

However, the chance of failure of tree species in plantations may be considerably significant when the area has been subjected to a high level of degradation. Deforested areas usually lack the organic horizon, and the mineral soil is eroded, acidic, and depleted of nutrients (Gonçalves et al., 2003). In addition to soil degradation, exotic C_4 grasses compete strongly with the planted trees for limited water and nutrients (Eyles et al., 2012). Environmental stresses in these degraded environments may be impossible for some tree species to overcome without improved silvicultural practices (Parrotta et al., 1997).

Establishment of seedlings in the field is a critical phase for a successful restoration. Reducing environmental stress during the initial stages (mainly within the first two years) of the new planted trees increase the chances of survival due to greater potential to access available resources on degraded environments. Vigorous initial growth leads to early canopy closure, providing conditions to catalyze natural regeneration and formation of a typical forest structure (Parrotta et al., 1997; Lamb et al., 2005). Silvicultural practices commonly used for the commercial production of wood products can be used to reduce environmental stressors in degraded areas and improve seedling survival by proportionally increasing available resources to the trees and reducing weed competition (Gonçalves et al., 2004; Campoe et al., 2010).

Most studies of forest restoration plantations limit their measurements to seedling survival, stem diameter, and height growth. While results centered on forest growth and survival are important, they are also incomplete since they do not address the processes driving differences in tree behavior response under contrasting situations. Few studies address physiological processes that control tree performance due to resource availability and environmental stress (Cooke and Suski, 2008). The lack of studies regarding the ecophysiology of tree species limits the development of improved strategies and techniques of restoration based on the physiological behavior of the planted native trees under field conditions of soil and climate.

Our objectives were to evaluate the aboveground tree biomass, rates of photosynthesis, chlorophyll content, soluble proteins and nutritional status on 20 different native Brazilian tree species planted under two silviculture systems. We aimed to determine the effect of reducing environmental stress by the use of intensive silviculture on the ecophysiology of the species. In addition, due to the inherent challenges associated with photosynthesis measurements and evaluating chlorophyll and soluble protein contents on several species, we also used a chlorophyll meter SPAD-502 as a simple, reliable, and efficient means to assess the performance of planted native tree species in the field.

We hypothesize that regardless of the successional status of tree species (pioneer and non-pioneer), or functional groups (legumes N-fixing and non-legumes), all planted tree species will respond positively to the reduction of environmental stress provided by intensive silviculture.

2. Materials and methods

2.1. Study site

The study site is located at the Anhembi Forest Research Station, owned by the University of São Paulo (22°58′04″S, 48°43′40″W). The experiment is located 460 m above sea level, on a 2% slope. The local biome is classified as Atlantic Forest, dominated by a semi-deciduous seasonal forest (Morellato and Haddad, 2000). On an adjacent native fragment of 2250 ha, Ferez (2010) found 67 tree species from 31 families, comprising with mean total height of 13.3 ± 5.2 m and mean DBH of 21.7 ± 14.5 cm.

Since the establishment of the restoration plantation, the mean annual rainfall was 1218 mm, with 75% concentrated from October to March. Mean annual temperature was 22.2 °C, ranging from 12.9 °C in the coldest months (from June to August) to 31.5 °C in the warmest months (from December to February). Minimum temperatures never fall below 5 °C, with no occurrence of frost. During dry season (May–August), the soil water deficit averaged 45 mm.

The soil type in the area is classified as an acidic (pH 4.0) sandy Oxisol (Typic Hapludox), comprising 5% silt, 13% clay and 82% sand, with relatively low organic matter content (~1.5%, in the top 45 cm, Cook, 2012).

2.2. Experimental design

In March 2004, we planted 20 different regional Brazilian native tree species (Table 1), after controlling the competing C_4 grass vegetation by the application of 5 L ha^{-1} of glyphosate (0.2%) across the experimental area. Leaf cutting ants (*Atta* sp. and *Acromyrmex* sp.) were controlled by systematic placement of baits (0.3% of sulfluramid), throughout the experimental area.

The experimental design consists of a 2 × 2 × 2 factorial design varying (a) the ratio of early (pioneer) to late colonizing (non-pioneer) species (50:50% versus 67:33%); (b) by modifying planting spacing (3 m × 1 m versus 3 m × 2 m); and (c) by varying the intensity of the silviculture of weed control and application of inorganic fertilizers. Each combination of treatments was replicated 4 times in randomized complete blocks design. Each plot is 42 m × 30 m (1260 m^2) to provide a buffer, with an interior plot of 36 m × 22 m (792 m^2) where measurements were made (Campoe et al., 2010).

In this study we report on the effect of the two levels of silviculture, traditional and intensive. For more information regarding the other treatments of this experiment, see Campoe et al. (2010).

We used the term "Traditional" for the silviculture commonly applied for the establishment of tree seedlings on abandoned pastures in Brazil (Rodrigues et al., 2009). It included subsoiling (50 cm deep), repeated manual weed control within planting rows (±50 cm), mechanized chopping between rows (at 6, 12, 18 and 24 months after planting) and the application of lower rates of fertilizers near each seedling in the first year (March and September of 2004), totaling 27 kg N, 21 kg P, 11 kg K and 24 kg Ca per hectare. The "Intensive" silviculture, also included subsoiling (50 cm deep), and aimed to eliminate all C_4 grass competition by quarterly application for the first 2 years of 5 L ha^{-1} of glyphosate