

# FACTORS AFFECTING THE ABUNDANCE OF RUDERAL SPECIES AND *Megathyrus maximus*, AN INVASIVE C4 GRASS IN ATLANTIC FOREST RESTORATION SITES

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## Resumo

*Fatores afetam a abundância de espécies ruderais de Megathyrus maximus, uma gramínea C4 invasora em áreas de Restauração da Floresta Atlântica.* A gramínea exótica invasora *Megathyrus maximus* (Capim - Guiné) tem sido reportada como um filtro para a regeneração de espécies lenhosas nos primeiros anos da restauração de florestas tropicais. Objetivou-se avaliar sítios de restauração florestal, correlacionando a densidade e biomassa de *M. maximus* e de outras espécies ruderais com a idade das áreas, abertura de dossel, riqueza e abundância de árvores plantadas e a fertilidade do solo. Foram selecionados dezesseite sítios de restauração, com plantios entre 40 e 110 meses, no Reservatório de Capivara no Sul do Brasil. Em cada área, dez parcelas de 10m<sup>2</sup> cada, com quatro subparcelas de 1m<sup>2</sup> foram alocadas, onde foi verificada a fertilidade do solo, abundância (*M. maximus*, plantas nativas e ruderais) e a biomassa seca (*M. maximus* e ruderais). Todas as áreas apresentaram alta fertilidade do solo, e a abertura do dossel (21.5% a 38.5%) decresceu com o tempo. A abundância de espécies ruderais esteve relacionada com a abertura do dossel e a idade do plantio. A biomassa seca (que variou de 0 a 182g/m<sup>2</sup>) e densidade de *M. maximus* (que variou de 0 a 2 moitas por m<sup>2</sup>) não estiveram relacionadas com a idade ou abertura do dossel. Ainda, com exceção da concentração de magnésio no solo, nenhuma das variáveis relacionadas à fertilidade do solo, explicaram a abundância de *M. maximus*, indicando alta plasticidade fenotípica. É importante destacar que quase 10 anos após o plantio, os locais reflorestados não suprimiram com sucesso o *Megathyrus maximus*, embora a abertura do dossel tenha diminuído.

*Palavras-chave:* abertura de dossel, biomassa seca, fertilidade do solo, gramínea exótica, reflorestamento.

## Abstract

The non-native grass *Megathyrus maximus* (Guinea grass) have been reported as a threat for woody species regeneration in the first years of tropical forest restoration, in some cases persisting for several years. The objective of this work was to evaluate forest restoration sites, correlating *M. maximus* and other ruderal species density and dry biomass with reforestation age, canopy openness, species richness, abundance of planted trees, and soil fertility. Seventeen sites reforested with native species were selected, with planting ages between 40 and 110 months, at the Capivara Reservoir, Southern Brazil. In each site, ten 10-m<sup>2</sup> plots each with four 1-m<sup>2</sup> subplots were installed, where soil fertility, plant abundance (*M. maximus*, native and ruderal species) and dry biomass (*M. maximus* and ruderal species only) were recorded. All sites showed high fertility soils, and the canopy openness (21.5 a 38.5 %) decreased with time. Ruderal species abundance were positively correlated with canopy openness and negatively correlated with planting age. Both dry biomass (ranging from 0 to 182 g/m<sup>2</sup>) and clump density (ranging from 0 to 2 clumps per m<sup>2</sup>) of *M. maximus* were not correlated with reforestation age or canopy cover. Moreover, with the exception of soil magnesium concentration, none of soil fertility variables could explain *M. maximus* abundance or biomass, indicating a high phenotypic plasticity in this non-native grass species. It was remarkable that almost 10 years after planting, the reforested sites did not successfully suppress *Megathyrus maximus* even though canopy openness decreased.

*Keywords:* canopy openness, dry biomass, non-native grass, reforestation, soil fertility.

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## INTRODUCTION

Reforestation with native species has been considered the most appropriate forest restoration action in highly degraded sites because it can accelerate the re-creation of conditions needed to enhance the establishment of native species. Reforestation development should lead to an increasing canopy cover, which can displace shade-intolerant non-native species and ameliorate soil and microclimatic conditions for native species, giving rise to natural regeneration (SOUZA & BATISTA 2004). However, some non-native species can persist in reforestation sites (MANTOANI *et al.* 2012), and thus compete with native species.

One notorious case in tropical forest restoration is Guinea grass (*Megathyrsus maximum* (Jacq.) B. K. Simon & S. W. L. Jacobs), a non-native C4 grass that remains in the understory of many sites for several years after planting and has been reported for negative effects on natural regeneration (AMMONDT & LITTON 2012; MANTOANI *et al.* 2012; AMMONDT *et al.* 2013; MANTOANI & TOREZAN 2016). Guinea grass is an African species that was introduced in Brazil centuries ago for feeding cattle and has since expanded throughout the country, occupying degraded lowland sites, it was recently listed as an exotic invasive species in Brazil (DIAS *et al.* 2013; SAMPAIO & SCHMIDT, 2013). The species shows an intense seed set during almost all year, has a long-lasting soil seed bank, and can regrow after fire (FERREIRA & MAIA-BARBOSA, 2013; ELLSWORTH *et al.* 2015).

A research priority in restoration ecology is to find alternatives to control problem species, such as *M. maximum*, in restoration sites, as they can increase restoration failure by slowing succession and increasing fire frequency and intensity (MANTOANI *et al.* 2012; ELLSWORTH *et al.* 2015; MANTOANI & TOREZAN 2016). Indeed, in many reforestation sites, the understory is dominated by invasive grasses even after several years and under increased canopy cover (MANTOANI *et al.* 2012; QUESTAD *et al.* 2012). Factors other than age and canopy cover, and interactions among factors, need to be investigated to explain grass abundance and to guide site management.

Therefore, the goal of this study was to investigate the effects of planting age, canopy openness, reforestation species richness and abundance, and soil fertility on the abundance of ruderal species, *M. maximum* and other grasses. Given that some degree of shade tolerance is already reported for this species, we asked the following question: Is there a threshold in reforestation canopy openness that leads to grass displacement?

The answers to these questions should be useful in understanding the ecology of early-successional ecosystems and for designing or adapting restoration practices such as tree spacing, fertilizing, and weeding.

## MATERIAL AND METHODS

At the Capivara Reservoir of the Parapanema River in southern Brazil, 17 reforestation sites with native species were sampled. The original vegetation was semideciduous Atlantic Forest, which was cleared in the 1940's; the land was used for coffee plantations and cattle ranching until the 1970's.

Before restoration, soybean was cultivated on all sites. Since 2001, a hydroelectric power company has reforested the sites using an average 45 native tree species with 2 × 3-m spacing. Neither pH correction nor nutrient enrichment was used in the tree seedling plantings, but the previous soybean cultivation included heavy dolomite liming and phosphorus fertilization. The area around each seedling was weeded by hand, and rows between seedlings were mechanically weeded for 24 months from planting. After restoration began, the sites were not burned or cut.

The reforestation age varied from 40 to 110 months. In each site, 10 plots (10 m<sup>2</sup>) were established to sample planted trees and locate measuring points for canopy openness. Canopy openness was estimated by hemispherical photographs taken one meter above the soil and analyzed using Gap Light Analyzer v. 2.0.

To record the dry biomass of ruderal species, *Megathyrsus maximum* alone and other grasses together, one subplot (1 m<sup>2</sup>) was established in each corner of each plot. In these subplots, all aerial portions of grass were cut and dried in paper bags at 85°C. Independent grass clumps above the ground layer of vegetation were counted as separated individuals. All data were collected in the rainy season.

One pooled surface soil sample (0–20 cm deep) was collected per plot, taken from each of the subplots. Samples were analyzed by the Instituto Agronômico do Paraná laboratory in Londrina, Brazil for pH and nutrient content (phosphorus, potassium, calcium, and magnesium) according to the methods of Pavan *et al.* (1992).

Ruderal species, *Megathyrsus maximum* and other grasses density (in clumps per m<sup>2</sup>) and dry biomass (g/m<sup>2</sup>) were treated as dependent on planting age, canopy openness, and soil fertility. Data were analyzed using sites as replications, and the reported values for sites are averages of 10 plots. Data normality was verified using the Kolmogorov-Smirnov test and linear or exponential regression was performed. Canopy openness was transformed with arcsine of the square root of the proportion, and other variables were log transformed. For all tests,  $\alpha = 0.05$  was considered.

## RESULTS

Guinea grass dry biomass ranged between 0 and 182 g/m<sup>2</sup> and density ranged from 0 to 2 occurrences per square meter, but abundance did not decrease with time (Fig. 1).

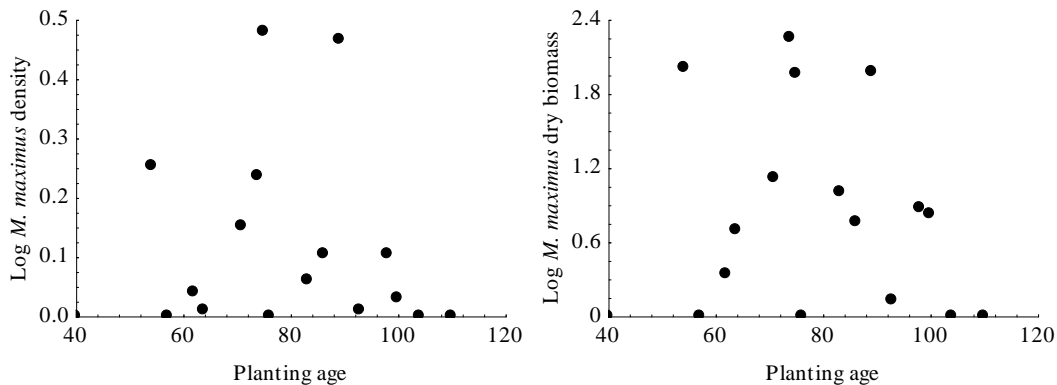


Figure 1. Planting age and A. Log *M. maximum* density and Log *M. maximum* dry biomass in restoration sites in Semideciduous Atlantic Forest in Brazil.

Figura 1. Idade do Plantio e densidade de *M. maximum* (Log) e biomassa seca de *M. maximum* (Log) em áreas de restauração de Floresta Estacional Semidecidual no Brasil.

Planted tree density ranged from 94 to 293 per 1000 m<sup>2</sup> but did not explain grass abundance or dry biomass. Canopy openness ranged from 21% to 43% and while there was a negative relationship between planting age and canopy openness (Fig. 2), *M. maximum* abundance did not depend on the canopy openness (Fig. 3). Nutrient concentrations in soil samples indicated an overall high fertility in soils of all sites. Nonetheless, under high concentrations of most nutrients, neither *M. maximum* abundance nor dry biomass correlated with nutrient availability, with exception for magnesium, which explained grass density (Fig. 4). Ruderal species biomass ranged between 0 and 36 g/m<sup>2</sup> and density ranged from 0 to 13 occurrences per square meter. Ruderal species abundance, but not biomass, showed a positive relationship with canopy openness and a negative correlation with planting age (Fig. 5).

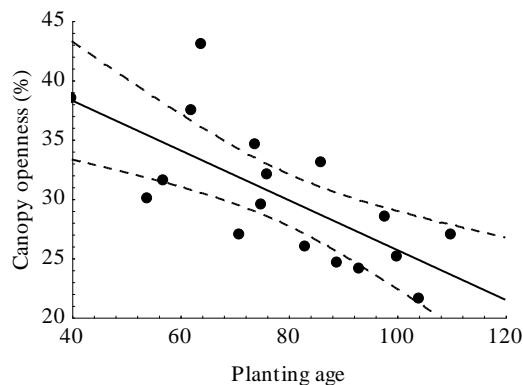


Figure 2. Canopy openness and planting age ( $n = 17$ ;  $r^2 = 0.50$ ;  $\beta = -0.70$ ;  $p = 0.001$ ) in restoration sites on semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 2. Abertura de dossel e idade do plantio ( $n = 17$ ;  $r^2 = 0.50$ ;  $\beta = -0.70$ ;  $p = 0.001$ ) em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

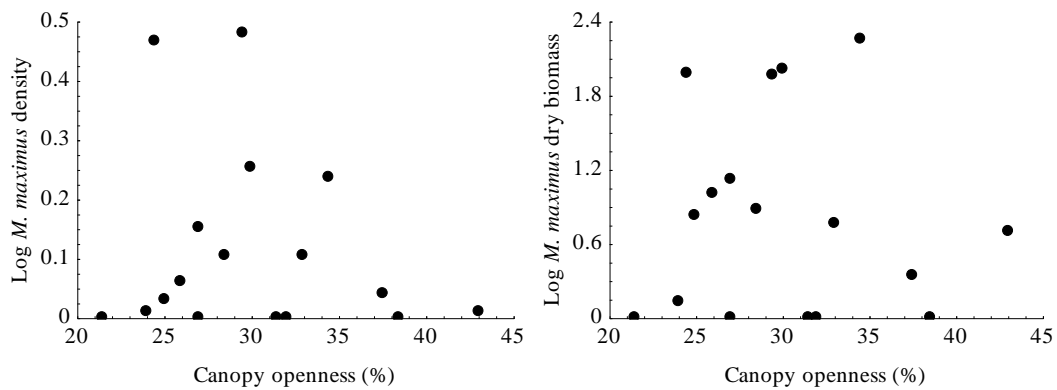


Figure 3. Canopy openness and: Log *M. maximus* density; Log *M. maximus* dry biomass in restoration sites in semideciduous Atlantic Forest in Brazil.

Figura 3. Abertura de dossel e: Densidade de *M. maximus* (Log); biomassa de *M. maximus* (Log), em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil.

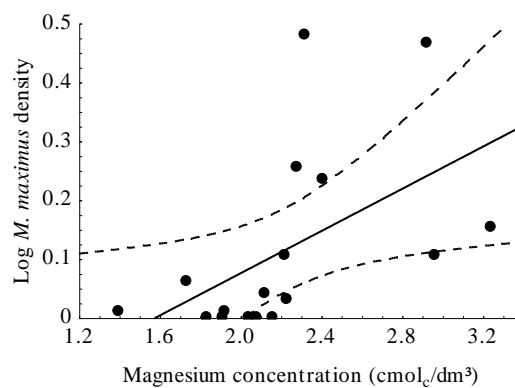


Figure 4. Magnesium concentration and Log *Megathyrsus maximus* density ( $n = 17$ ;  $r^2 = 0.52$ ;  $\beta = 0.68$ ;  $p = 0.02$ ) in restoration sites on semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 4. Concentração de Magnésio e densidade de *Megathyrsus maximus* (Log) ( $n = 17$ ;  $r^2 = 0.52$ ;  $\beta = 0.68$ ;  $p = 0.02$ ) em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

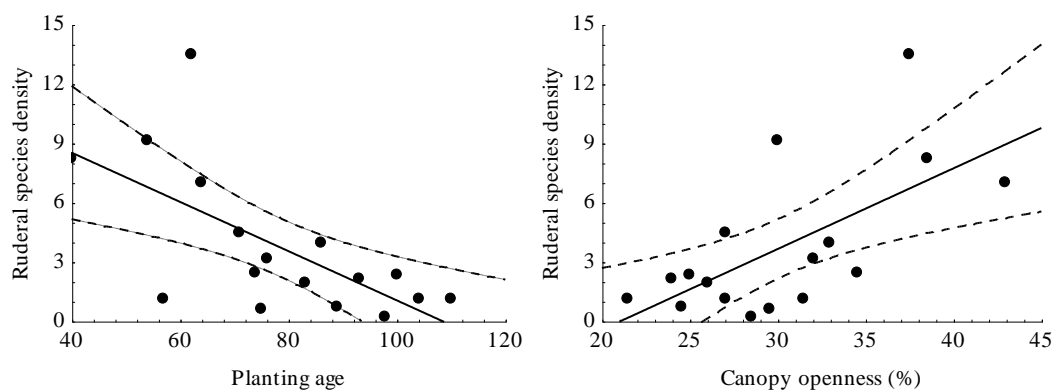


Figure 5. Planting age ( $n = 17$ ;  $r^2 = 0.43$ ;  $\beta = -0.65$ ;  $p = 0.004$ ) and Canopy openness ( $n = 17$ ;  $r^2 = 0.41$ ;  $\beta = 0.64$ ;  $p = 0.005$ ) x ruderal species density in restoration sites in semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 5. Idade do plantio ( $n = 17$ ;  $r^2 = 0.43$ ;  $\beta = -0.65$ ;  $p = 0.004$ ) e abertura de dossel ( $n = 17$ ;  $r^2 = 0.41$ ;  $\beta = 0.64$ ;  $p = 0.005$ ) x densidade de espécies ruderais em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

The biomass of other grasses, such as *Cenchrus echinatus* L., *Chloris elata* Desv. and *Digitaria insularis* (L.), ranged between 1 and 142 g/m<sup>2</sup> and the density ranged from 1 to 5 occurrences per square meter. Both dry biomass and density decreased with planting age (Fig. 6), and the density also correlated with canopy openness (Fig. 7). Among all soil fertility variables, only phosphorus concentration explained the density and dry biomass of other grasses (Fig. 8).

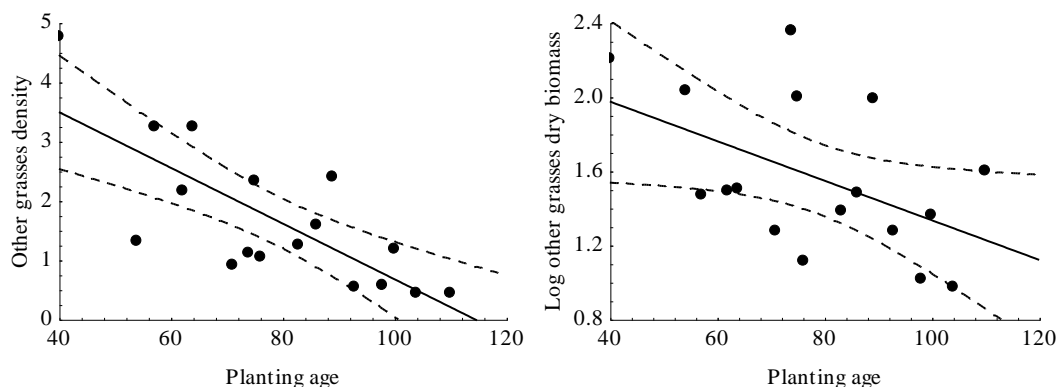


Figure 6. Planting age and density of other grasses, except *M. maximus* (n=17;  $r^2=0.57$ ;  $r = -0.75$ ;  $0.66$ ;  $p = 0,0004$ ); Planting age and other grasses dry biomass, except *M. maximus* (n = 17;  $r^2 = 0.41$ ;  $\beta = 0.64$ ;  $p = 0.005$ ) in restoration sites in semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 6. Idade do plantio e densidade de outras gramíneas, exceto *M. maximus* (n=17;  $r^2=0.57$ ;  $r = -0.75$ ;  $0.66$ ;  $p = 0,0004$ ); Idade do plantio e biomassa seca de outras gramíneas, exceto *M. maximus* (n = 17;  $r^2 = 0.41$ ;  $\beta = 0.64$ ;  $p = 0.005$ ) em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

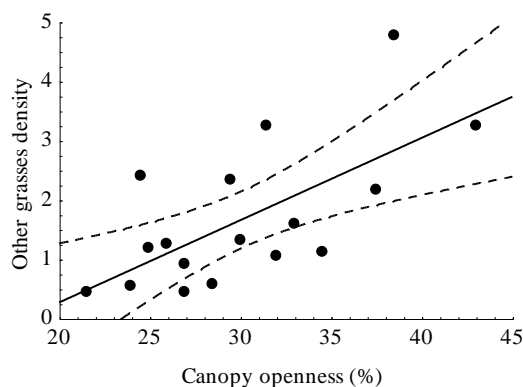


Figure 7. Canopy openness and other grasses density, except *M. maximus* (n = 17;  $r^2 = 0.44$ ;  $\beta = 0.66$ ;  $p = 0.003$ ) in restoration sites in semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 7. Abertura de dossel e densidade de outras gramíneas, exceto *M. maximus* Canopy openness and other grasses density (n = 17;  $r^2 = 0.44$ ;  $\beta = 0.66$ ;  $p = 0.003$ ) em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

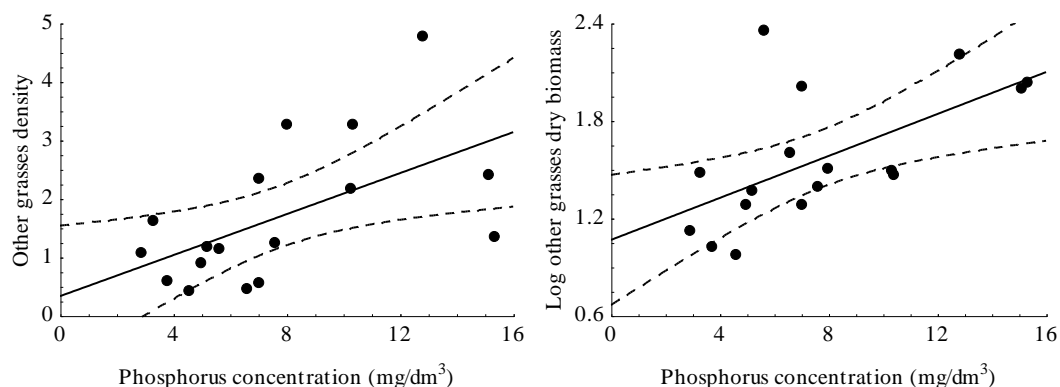


Figure 8. Phosphorus concentration and other grasses density, except *M. maximus* ( $n = 17$ ;  $r^2 = 0.31$ ;  $\beta = 0.56$ ;  $p = 0.01$ ); Phosphorus concentration and other grasses dry biomass ( $n = 17$ ;  $r^2 = 0.36$ ;  $\beta = 0.60$ ;  $p = 0.01$ ) in restoration sites in semideciduous Atlantic Forest in Brazil. The continuous line is the regression line and dotted lines indicate the 95% confidence interval.

Figura 8. Concentração de Fósforo e densidade de outras gramíneas, exceto *M. maximus* ( $n = 17$ ;  $r^2 = 0.31$ ;  $\beta = 0.56$ ;  $p = 0.01$ ); Concentração de Fósforo e biomassa seca de outras gramíneas, exceto *M. maximus* ( $n = 17$ ;  $r^2 = 0.36$ ;  $\beta = 0.60$ ;  $p = 0.01$ ) em sítios de restauração da Floresta Estacional Semidecidual no sul do Brasil. A linha contínua é a regressão e as linhas pontilhadas indicam o intervalo de confiança de 95%.

Planted tree density ranged from 94 to 293 per 1000 m<sup>2</sup>, but did explain neither abundance nor biomass of ruderal species, Guinea grass or other grasses.

## DISCUSSION

While it has been suggested that higher tree density can reduce grass abundance, this was not valid for *M. maximus* at the studied reforestation sites. There was a negative relationship between planting age and canopy openness, which led to a decrease in abundance of ruderal species, including grasses but not *M. maximus*.

Thus, despite the fact that planted trees likely impose competition for water and light on understory plants, *M. maximus* remained in the understory, suggesting a higher tolerance to competition than other ruderal species. Indeed, several reports on *M. maximus* as a forage plant pointed to a high tolerance to shading (DIAS *et al.* 2016). Both Castro *et al.* (2001) described high shade tolerance in this species, and Ferreira *et al.* (2010) reported higher grass dry biomass under moderate shade. Thus, the lack of correlation between grass dry biomass and canopy openness in this study might be related to some degree of shade tolerance by *M. maximus*. Souza and Batista (2004) also studied semideciduous Atlantic Forest restoration sites and found that increases in canopy cover led to a reduction in *M. maximus* cover. However, their data did not include grass biomass.

Nutrient concentrations in the soil samples were high, indicating an overall high fertility in soils of all sites (Table 2). Restoration sites showed higher concentrations of nutrients than remnant Atlantic Forest fragments in the same region, which is probably attributable to previous agricultural use. High fertility can benefit all fast-growing plants, including *M. maximus*. Nonetheless, with high concentrations of most nutrients, neither *M. maximus* abundance nor dry biomass correlated with nutrient availability, with the exception of magnesium concentration, which explained grass density.

The response of *M. maximus* to soil nutrient content can be inferred from forage science research, although data are scarce regarding its requirements in degraded and early successional sites. According to Sousa *et al.* (2010), the productivity of Brazilian pastures is low owing to low soil fertility, but the production of grasses from the genera *Panicum* and *Brachiaria* (including species now treated as *Megathyrsus* and *Urochloa*) can be high if soil corrections are made; *M. maximus* is adapted to soils with high fertility (COSTA *et al.* 2004).

Indeed, Costa *et al.* (2004) reported that a phosphorus concentration greater than 6.1 mg/dm<sup>3</sup> is considered “medium to high” in the context of *M. maximus* pastures, and 10 out of 17 sites studied here had phosphorus concentrations above that level, which can explain why grass abundance and phosphorus content in the soil were not correlated. Castro *et al.* (2001) suggested that tropical grasses under shading show higher nutrient concentrations in the leaves and stems as a result of metabolic changes. Magnesium is a constituent of chlorophyll and is also required for many enzymes that are involved in phosphate transfer and nutrient absorption. Eriksen & Whitney (1981) reported an increase in magnesium concentration in *M. maximus* leaves

and stems when cultivated in 75% shade. Thus, an increase in soil magnesium concentration will likely result in a higher shade tolerance for *M. maximus*.

## CONCLUSIONS

- After 10 years of restoration with native species in Atlantic Forest sites with high soil fertility, ruderal species and most grasses are being displaced, but *Megathyrsus maximus* are still growing in the forest understory.
- Reforestation age, canopy cover, and planted tree abundance did not explain variations in *M. maximus* abundance, nor did most nutrient concentrations, which were high in all soil samples.
- The positive correlation between magnesium concentration and grass abundance points to an interesting question, of whether high soil magnesium content is related to higher chlorophyll content in the grass leaves and thus to an increased shade tolerance by *M. maximus*.

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