Development of *Swietenia macrophylla* King in escape areasDesenvolvimento de *Swietenia macrophylla* King em área de escapeKaren Janones da Rocha¹, Sidney Fernando Caldeira² e Gilvano Ebling Brondani³**Resumo**

O cultivo de *Swietenia macrophylla* King é inviabilizado pela ação de leptobroca. Assim, os objetivos para o estudo foram avaliar o desenvolvimento da espécie em plantio homogêneo no Sudoeste do estado de Mato Grosso, Brasil, e a região como área de escape à ação da *Hypsipyla grandella* Zeller. Foram plantadas 150 árvores no espaçamento 3,0 m x 3,0 m, distribuídas em quatro blocos de 21 árvores, além da bordadura. Cinco meses após o plantio foram avaliados a sobrevivência e o diâmetro à altura do colo. Periodicamente, até 152 meses, foram registrados densidade, diâmetro à altura do peito, altura total e altura comercial e determinadas área transversal média e área basal. Complementarmente, cada árvore foi classificada pela forma do fuste e seu estado fitossanitário. Aos 152 meses, com de 53,6% de sobrevivência, os valores médios e coeficientes de variação foram, respectivamente, de 20,6 cm (4,7%), 16,3 m (4,3%), 5,5 m (6,4%), 0,0346 m² árvore⁻¹ (9,3%) e 20,5295 m² ha⁻¹, e mais de 50% das árvores com fuste reto sem ou com galhos. A mortalidade foi devida a causas abióticas e não foram registrados problemas fitossanitários. A região apresenta potencial para o cultivo de *S. macrophylla* e pode ser considerada como área de escape para a leptobroca.

Palavras-chave: Silvicultura, mogno, leptobroca, evasão.

Abstract

Swietenia macrophylla King cultivation is made difficult by the shoot borer action. Thus, the objectives of this research were to evaluate the development of the species in a homogeneous plantation in south western Mato Grosso State, Brazil, and to evaluate if the region could act as an escape area from the action of *Hypsipyla grandella* Zeller. 150 *S. macrophylla* seedlings were planted in 3.0 m x 3.0 m row spacing, distributed into four 21 trees blocks, in addition to the border. Five months after planting, the survival and diameter at ground level were measured. Periodically, until 152 months of age, density, diameter at breast height, total height and commercial height were measured, and the average cross-sectional area and basal area were determined. In addition, each tree was rated by stem shape and health. At 152 months, with 53.6% survival, the average rates and coefficient of variation were 20.6 cm (4.7%), 16.3 m (4.3%), 5.5 m (6.4%), 0.0346 m² tree⁻¹ (9.3%) and 20.5295 m² ha⁻¹, respectively, and over 50% of the trees had a straight stem with or without branches. Mortality was due to abiotic causes, and no crop health problems were recorded. The region shows potential for *S. macrophylla* growth and may be considered as an escape area from the *Hypsipyla grandella* Zeller borer.

Keywords: Forestry, mahogany, shoot borer, evasion.

INTRODUCTION

The demand for forest products is influenced by population growth and the increase of profiteering from natural forests. Thus, reforestation, in addition to being an economic alternative, leads to social and environmental benefits and can relieve some of the pressure on native forests. However, most of the species used are exotic, due to the ease of establishing homogeneous plantations; their quick development and because stems produced are straighter due to strong apical growth.

Such features are not so common in tropical native species and, among the exceptions, *Swietenia macrophylla* King is worth highlighting within the Meliaceae. This species is classified as late secondary and usually rare, despite the fact that it is found in groups of natural glades or as a result of anthropic activity (CARVALHO, 2007). It is known for the quality of its wood which possesses

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durability, dimensional stability and is easy to handle (RIBEIRO, 2010). However, the action of *Hypsipyla grandella* Zeller shoot borer is the main limiting factor for its growth in regions where it occurs naturally in Latin America and the Caribbean (LAMB, 1966; CARVALHO, 2007).

The insect consumes the apical meristem and frustrates the establishment of commercial plantations of *Swietenia*, *Cedrela* and *Carapa* species (GRIJPMA; RAMALHO, 1969; GRIJPMA, 1974; NEWTON et al., 1993; HILJE; CORNELIUS, 2001; RIBEIRO, 2010). The shoot borer action decreases the tree's growth rate and subsequent attacks may occur, though the attacks rarely result in the death of the plant (GRIJPMA, 1970; NEWTON et al., 1993; MAUÉS, 2001; OHASHI et al., 2008).

In *S. macrophylla* plantations in Malaysia in 1982 (GHEE, 2001) and on the Australian continent (GRIFFITHS, 1997), severe attacks from another shoot borer species, *Hypsipyla robusta* Moore, have been recorded. In Sri Lanka, from 1980 to 2001 moderate attacks from this species (TILAKARATNA, 2001) have occurred, which significantly affected productivity. In Brazil, the high infestation rate of *H. grandella* was one of the reasons for the failure of pure mahogany plantations in Pará (GROGAN et al., 2002). In addition to affecting productivity, the coppicing that takes place below the insect attack area also leads to forking, which affects the stem's quality and length.

According to Carvalho (2003), the low distribution and density of *S. macrophylla* in indigenous forests, with a mean of one tree per hectare, might be the escape strategy from the borer's attacks to ensure its perpetuation and, according to Ribeiro (2010), even in small plantations; the occurrence of borer attacks is rare, most likely because they qualify as escape areas.

In light of this, the objective of this research was to evaluate the development of *Swietenia macrophylla* in homogeneous plantations in southwestern Mato Grosso State, Brazil, and that region as an escape area from *Hypsipyla grandella* activity.

MATERIAL AND METHODS

The study was developed in the city of Nossa Senhora do Livramento, Mato Grosso State, Brazil, 73 km southwest of the capital Cuiabá, in an area within the coordinates 16°12'32"S and 56°22'57"W.

The climate in the region is classified as Aw, according to Köppen, with defined dry and rainy seasons, 1,300 mm year⁻¹ mean rainfall, 25°C mean temperature, with averages between 20°C minimum and 32°C maximum, and 70% to 75% air humidity (ALVARES et al., 2013). According to EMBRAPA (2006), the relief is slightly rugged and the soil is rated as "PLANOSSOLO HÁPLICO Eutrófico" (Eutrophic Haplic Planosol), with a texture of loamy-sandy with clay (Table 1). The original vegetation of the experimental area was savannah and park savannah without gallery forests (IBGE, 2012) and, after removal of the original vegetation; the area was initially destined for agriculture with rice production and subsequently for grazing.

Table 1. Physical-chemical analysis of two soil samples from the experimental area in south western Mato Grosso State, Brazil.

Tabela 1. Análise físico-química de duas amostras de solo da área experimental na região Sudoeste do estado de Mato Grosso, Brasil.

Sample	Physical			Chemical				
	Sand g kg ⁻¹	Silt g kg ⁻¹	Clay g kg ⁻¹	Ca cmol _c dm ⁻³	Al cmol _c dm ⁻³	P mg dm ⁻³	O.M.* g dm ⁻³	pH H ₂ O
1	620	50	330	3.4	0.0	19.1	19	6.0
2	610	50	340	4.9	0.0	19.5	14	6.3

* organic matter.

The soil in the area was previously decompressed, ploughed and levelled and, in February 2001, 150 *S. macrophylla* seedlings were planted in 3.0 m x 3.0 m row spacing, distributed into four 21 tree-blocks, with the remainder used as a border. The seedlings were produced from seeds collected in the Sinop city region, in an area within the coordinates 11°51'S and 55°30'W, in Mato Grosso State, Brazil.

Five months after planting, survival rates and diameter at ground level were recorded. Yearly, until 152 months after planting, density, diameter at breast height (DBH), total height and commercial hei-

ght were recorded, as well as their mean values calculated. Commercial height was considered from the base of the stem to the first branch. Additionally, the average cross-sectional area was calculated and the basal area per hectare was estimated, along with the respective average and current increase.

Each tree was classified by stem shape according to the criteria by Jankauskis (1979) (Table 2) and by plant health state, as established by Schneider et al. (1988) (Table 3), with the values expressed as a frequency. 152 months after planting, the trees were classified by the dominance class by criteria established by Hosokawa and Souza (1987) (Table 4), also expressed as a frequency.

Table 2. Criteria for classification of individuals due to stem shape or quality, according to Jankauskis (1979).

Tabela 2. Critério para classificação dos indivíduos quanto à forma ou qualidade de fuste segundo Jankauskis (1979).

Code	Description
SS1	Straight stem, no side branches, well defined canopy, typically commercial.
SS2	Straight stem, with side branches, but commercially usable.
SS3	Somewhat tortuous, no side branches and partial usage.
SS4	Tortuous stem, with side branches, low commercial usage.
SS5	Tortuous or other defects, with side branches, almost no commercial usage.

Table 3. Criteria to classify individuals for their plant health state (A) and intensity (B) of the anomaly observed, according to Schneider et al. (1988).

Tabela 3. Critério para classificação dos indivíduos quanto ao estado fitossanitário (A) e a intensidade (B) da anomalia observada segundo Schneider et al. (1988).

Code A	Cause	Code B	Intensity*
1	Healthy individual	0	None
2	Abiotic damage		
3	Damage by insects or pests	1	Low
4	Damage by fungi or diseases		
5	Damage by animals	2	Average
6	Complex damages		
7	Dead tree standing	3	High

* low: below 10% of the area affected; average: above 10% and below 30% of the area affected; high: above 30% of the area affected.

Table 4. Criteria to determine the amplitude of dominance classes, according to Hosokawa and Souza (1987).

Tabela 4. Critério para determinar amplitude das classes de dominância, segundo Hosokawa e Souza (1987).

Code	Name	Criteria
D	Dominant	$DAP_i \geq DBH + 2 \cdot S_{n-1}$
CD	Co-dominant	$DBH + 1 \cdot S_{n-1} \leq DBH_i < DBH + 2 \cdot S_{n-1}$
I	Intermediate	$DBH - 1 \cdot S_{n-1} < DBH_i < DBH + 1 \cdot S_{n-1}$
S	Suppressed	$DBH - 2 \cdot S_{n-1} < DBH_i \leq DBH - 1 \cdot S_{n-1}$
O	Oppressed	$DBH_i \leq DBH - 2 \cdot S_{n-1}$

where: DBH_i = tree diameter at breast height i (cm); DBH = average diameter at breast height (cm); S_{n-1} = population standard deviation.

To interpret tree distribution features, the variables' descriptive statistics were calculated and the distribution of frequencies was determined by the empirical method. The Kendall correlation was calculated to understand the behaviour of the variables with respect to density since it did not meet the criteria of the Shapiro-Wilk normality statistic ($W = 0.0292^*$). The Chapman and Richards model (1959) was used, $Y = a \cdot (1 - e^{-b \cdot age})^c$ to estimate the behaviour of the dendrometric variables from the fifth to the 152nd month, and the underlying assumptions of residues' normality by Shapiro-Wilk test was checked; also the homogeneity of variance by the White test and the independence of residues by the Durbin-Watson test, all at 5% level of significance. The degree of explanation of the independent variables in relation to the dependent variable was assessed by the coefficient of determination (R^2) and accuracy by the standard error of estimate in percentage ($S_{yx} \%$).

RESULTS AND DISCUSSION

For the assessed dendrometric variables (Table 5), asymmetry was positive, which means that some of the higher class individuals differ from the majority of the individuals by displaying markedly higher values. As for the asymmetry coefficients for total height, commercial height and cross-sectional area, the values were moderate in modules from 0.15 to 1.00, while values of DBH were low, in modules below 0.15 (RENCHE, 2002).

Table 5. Descriptive statistics of diameter at breast height (DBH), total height (TH) and commercial height (CH), basal area (G) and average cross-sectional area ($\bar{g}$) for *Swietenia macrophylla* King in a homogeneous plantation in south western Mato Grosso State, Brazil, 2001–2013.**Tabela 5.** Estatística descritiva de diâmetro à altura do peito (DBH), altura total (TH) e comercial (CH), área basal (G) e área transversal média ($\bar{g}$) para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013.

Descriptive statistics	DBH (cm)	TH (m)	CH (m)	G (m ² ha ⁻¹)	$\bar{g}$ (m ² tree ⁻¹)
Average	13.4631	8.8980	3.6646	9.8207	0.01599
Standard error	1.8991	1.2888	0.4589	2.0885	0.00354
Median	14.9919	9.5212	3.8908	10.3748	0.01607
Standard deviation	6.2986	4.4645	1.5897	7.2347	0.01227
Interval	20.2061	15.1906	5.1794	20.5249	0.03460
Minimum	0.3742	1.1368	0.3695	0.0046	0.00001
Maximum	20.5804	16.3275	5.5490	20.5295	0.03461
Variance	39.6723	19.9317	2.5272	52.3405	0.00015
Skewness coefficient	-1.0089	-1.3509	-0.7825	*	-0.3570
Asymmetry coefficient	-0.1272	0.1504	0.2078	*	0.6798

* data from the extrapolation to the hectare

The skewness coefficient values for all variables were negative, so the distribution of these variables is a platykurtic curve (SPIEGEL, 1976). This demonstrates a uniform distribution of individuals among the classes for all variables.

At five months, the survival index was 0.79, which translated to a density of 873 trees per ha⁻¹. The seedlings had an average diameter at ground level of 0.5 cm (CV = 3.0%) and height of 30 cm (CV = 2.9%). In a homogeneous plantation using the same species, the mortality rate was similar to the one observed in the Federal District at seven months (GUIMARÃES NETO et al., 2004), and leaf cutting ant attacks were the main cause of mortality. The mortality rate was 15% in Pará at six months (SILVA et al., 2013), and the intensity of *H. grandella* attacks were lower in the first months of the year, with higher rainfall.

At 17th month, the mortality rate was 12%; from the 29th to the 103rd month, the average mortality was 1.9%; and, from then until the 152nd month, there was no mortality (Table 6). No symptoms of biotic causes were associated to mortality; however it was associated with the time of planting at the end of the rainy season, considering that the species is rated as late secondary, and the planting area is not the natural occurrence area for the species, and there were records of intense winds. From the above it follows that mortality was associated with succession features of the species (BUDOWSKI, 1965; CARVALHO, 2007).

With the decrease in density, there was no need of thinning because of the continuous availability of area for the trees to grow.

Table 6. Average rates of density, diameter at breast height (DBH), total height (TH), commercial height (CH), basal area (G) and average cross-sectional area (g) for *Swietenia macrophylla* King in a homogeneous plantation, in south western Mato Grosso State, Brazil, 2001–2013.**Tabela 6.** Valores médios de densidade, diâmetro à altura do peito (DBH), altura total (TH), altura comercial (CH), área basal (G) e área transversal média (g) para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013.

Age (months)	Density (trees ha ⁻¹)	DBH (cm)	TH (m)	CH (m)	G (m ² ha ⁻¹)	g (m ² tree ⁻¹)
17	741	0.3*(106.2)	1.1(6.2)	0.4(7.0)	0.0046	0.0000(2325.5)
29	728	0.4(62.5)	3.1(7.7)	1.3(13.2)	0.0083	0.0000(1509.6)
42	714	6.6(8.8)	4.3(9.6)	3.1(14.8)	2.5598	0.0036(6.8)
54	661	8.5(2.4)	6.5(5.3)	3.1(14.8)	3.8983	0.0059(6.6)
67	661	10.8(4.7)	8.2(5.9)	3.5(14.8)	6.2730	0.0094(9.0)
79	648	13.5(8.8)	8.5(9.6)	3.9(14.8)	8.9591	0.0137(6.8)
93	635	15.0(4.1)	10.6(7.2)	3.9(9.4)	11.7905	0.0184(7.1)
103	595	16.8(4.3)	11.2(9.6)	3.8(14.8)	13.5213	0.0227(7.7)
115	595	17.8(8.8)	11.6(9.6)	4.6(14.8)	15.2573	0.0246(6.8)
128	595	18.6(1.9)	12.2(3.4)	5.4(6.9)	16.6538	0.0280(2.5)
141	595	19.5(4.0)	13.0(4.5)	5.4(13.1)	18.3929	0.0310(7.9)
152	595	20.6(4.7)	16.3(4.3)	5.5(6.4)	20.5295	0.0346(9.3)

* diameter at ground level. The values in parentheses correspond to the coefficient of variation (%).

The stabilised 53.6% survival rate starting at 103 months after planting is similar to the 50% recorded by Souza et al. (2010) at 72 months, and superior to the 36.1% recorded by Souza et al. (2008) at 132 months (Table 7). However, for the same periods, the DBH values obtained by those authors are lower than those in this paper, despite of the lower density. When compared to other researches (Table 7), the variable values recorded here are similar or better, even if the experimental area does not show all of the conditions considered ideal by CATIE (2000) for the development of *S. macrophylla*.

Table 7. Experimental results for diameter at breast height (DBH) and total height (TH) due to age, with *Swietenia macrophylla* King, in homogeneous and combined plantations.

Tabela 7. Resultados experimentais de diâmetro à altura do peito (DAP) e de altura total (Ht) em função da idade, com *Swietenia macrophylla* King em plantios homogêneos e consorciados.

Age (months)	DBH (cm)	TH (m)	Type of plantation (homogeneous or combined)	Author
13	1.0*	1.2	Homogeneous	Grijpma (1971)
	1.0*	1.2	With meliaceae	
24	4.0*	1.8	Homogeneous	Silva et al. (2013)
23	5.4*	2.4	Homogeneous	Mazzei & Felfili (2001)
	4.5*	1.6	With <i>Dipterix alata</i>	
24	4.3	1.6	Homogeneous	Guimarães Neto et al. (2004)
	3.6	1.3	With <i>Eucalyptus urophylla</i>	
25	6.4	6.5	Homogeneous	Mazzei & Felfili (2001)
	6.8	7.5	With <i>Copaifera langsdorffii</i>	
26	2.6	3.0	Homogeneous	Ribeiro (2010)
36	6.3	3.3	Homogeneous	Guimarães Neto et al. (2004)
	3.9	2.3	With <i>Eucalyptus urophylla</i>	
40	6.9	3.4	Homogeneous	Guimarães Neto et al. (2004)
	4.1	2.3	With <i>Eucalyptus urophylla</i>	
42	5.0	3.8	Homogeneous	Melo (2003)
	7.6	5.1	With <i>Syagrus oleracea</i>	
72	10.9	7.7	Homogeneous	Souza et al. (2010)
132	16.1	12.0	Homogeneous	Souza et al. (2008)

* diameter at ground level.

The assumptions of regression normality and independence of residues were fully met by the Shapiro-Wilk test (W) and the Durbin-Watson test (DW), respectively, at 5% level significance. The same applied to the homogeneity of variances by the White test (LM) (Table 8).

Table 8. Adjustment statistics and accuracy of the Chapman and Richards model (1959) for the variables diameter at breast height (DBH), total height (TH), commercial height (CH), average cross-sectional area ($\bar{g}$) and basal area (G), with their respective estimated parameters and statistics tests of Durbin-Watson (DW), serial correlation (r), White (LM) and Shapiro-Wilk (W) for *Swietenia macrophylla* King in a homogeneous plantation, in southwestern Mato Grosso State, Brazil, 2001–2013.

Tabela 8. Estatísticas de ajuste e precisão do modelo de Chapman e Richards (1959) para as variáveis diâmetro à altura do peito (DAP), altura total (Ht), altura comercial (Hc), área transversal média ($\bar{g}$) e área basal (G), com seus respectivos parâmetros estimados e as estatísticas dos testes de Durbin-Watson (DW), correlação em série (r), White (LM) e Shapiro-Wilk (W) para *Swietenia macrophylla* King, em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001-2013.

Y	a	b	c	S _{yx} %	R ²	DW	LM	W
DBH	21.26885*	0.02703*	3.68493*	8.81	0.99	0.5046 ^{ns}	0.4954 ^{ns}	10.96 ^{ns}
TH	64.47218*	0.00143*	0.90668*	9.59	0.98	0.0946 ^{ns}	0.9054 ^{ns}	10.78 ^{ns}
CH	4.99775*	0.02705*	1.92220*	14.79	0.94	0.3750 ^{ns}	0.6250 ^{ns}	9.12 ^{ns}
$\bar{g}$	0.05666*	0.01216*	2.94096*	6.81	0.99	0.3713 ^{ns}	0.6287 ^{ns}	10.61 ^{ns}
G	22.80237*	0.02193*	4.79730*	3.84	0.99	0.3713 ^{ns}	0.6287 ^{ns}	10.61 ^{ns}

* significant at 5% level of error probability; ns not significant at 5% level of error probability. R² = coefficient of determination; S_{yx} % = standard error of estimate in percentage.

The increase in DBH of *S. macrophylla* was continuous until 152 months. However, from the 93rd month, such increase was lower and coincides with density stagnation (Figure 1A). For total height, the increase was continuous throughout the period, and the commercial height displayed lower increases from the 79th month (Figure 1B). The criteria for commercial height consider the length

of the stem from the ground surface to the first branch that composes the canopy. Thus, the canopy length increased beginning in the 79th month, due to the bifurcation that took place during this period (Figure 1B).

Figure 1. Variation in density and behaviour of the estimated diameter at breast height (A), of the total and commercial (B) heights, and the basal (C) and average cross-sectional (D) areas, with respect to the time period for *Swietenia macrophylla* King in a homogeneous plantation in the south western region of Mato Grosso State, Brazil, 2001–2013.

Figura 1. Variação da densidade e comportamento da estimativa do diâmetro à altura do peito (A), das alturas total e comercial (B), e das áreas basal (C) e transversal média (D), em função do período para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013.

Until the 93rd month, the behaviour of the basal area was similar to that of the average cross-sectional area. From that point on, the increase in basal area was lower, while the increase rate in the average cross-sectional area was continuous until 141 months (Figure 1C). For all of the variables, the behaviour displayed a strong negative correlation with density (Table 9).

Table 9. Correlation between density, diameter at breast height (DBH), total height (TH), commercial height (CH), basal area (G) and average cross-sectional area ($\bar{g}$) for *Swietenia macrophylla* King in a homogeneous plantation, in south western Mato Grosso State, Brazil, 2001–2013.

Tabela 9. Correlação entre os valores de densidade, diâmetro à altura do peito (DBH), altura total (TH), altura comercial (CH), área basal (G) e área transversal média ($\bar{g}$) para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013.

Variable	Density (tree ha ⁻¹)	DBH (cm)	TH (m)	CH (m)	G (m ² ha ⁻¹)
DBH (cm)	-0.9129*	1.0000	-	-	-
TH (m)	-0.9129*	1.0000*	1.0000	-	-
CH (m)	-0.8805*	0.9614*	0.9614*	1.0000	-
G (m ² ha ⁻¹)	-0.9129*	1.0000*	1.0000*	0.9614*	1.0000
$\bar{g}$ (m ² tree ⁻¹)	-0.9031*	0.9924*	0.9924*	0.9528*	0.9924*

* significant at 5% level of error probability.

The variation of the current annual increase (CAI) of total height (Figure 2A) and DBH (Figure 2B) displayed similar behaviour to the alternating periods of higher and lower increase, and such periods were not coincident. Until 96 months, the higher height increase values occurred in periods before higher DBH increases and it is possible to interpret that primary growth preceded secondary growth.

The variation of the mean annual increase (MAI) for total height (TH) alternated between lower and higher values that, in three assessments, were approximately 1.4 m year⁻¹ (Figure 2A), while

the DBH from the 36th to the 115th month varied by approximately 2.0 cm year⁻¹ before decreasing slowly and constantly (Figure 2B). Such values are above those recorded by Guimarães Neto et al. (2004) at 40 months and by Souza (2008) at 132 months and were above the worldwide averages reviewed by Veríssimo et al. (1995) and Veríssimo and Grogan (1998).

Figure 2. Variation of current annual increase (CAI) and mean annual increase (MAI) of total height (A), of diameter at breast height (B), basal area (C), and average cross-sectional area (D), with respect to the time period for *Swietenia macrophylla* King in a homogeneous plantation, in south western Mato Grosso State, Brazil, 2001–2013.

Figura 2. Variação dos incrementos corrente anual (CAI) e médio anual (MAI) da altura total (A), do diâmetro à altura do peito (B), da área basal (C), e da área transversal média (D), em função do período para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013.

The variation of the CAI of basal area (Figure 2C) and average cross-sectional area (Figure 2D) displayed similar behaviour and there was coincidence between the periods of higher and lower increases until 152 months. The MAI variation was also similar, with a continuous increase until 115 months, when it stabilised.

Until 42 months, *S. macrophylla* displayed typical apical growth which led to straight stems with no branches (SS1), as classified by Jankauskis' criteria (1979). From 54 to 115 months, the straight stems with branches (SS2) were dominant, this is a period in which many trees went into bifurcation and formed canopies and, as a consequence, stems were found at lower heights and canopies had greater length. Artificial pruning starting in the 42nd month might have contributed to stem quality. In the last three assessments, the trees presented stems in every quality class, with a dominance of stems without branches, straight (SS1) or tortuous (SS3), whose frequency was approximately 50% (Figure 3A).

The distribution of individuals in dominance classes, following the criteria established by Hosokawa and Souza (1987), was similar for the *S. macrophylla* trees, except for the 54th, 103rd and 115th months (Figure 3B). Until 42 months, the lack of dominant trees was associated with the natural decrease observed in density and the small diameter of the canopy, a feature of the species with the presence of leaves that grow directly from the stem. Thus, there was no light and space limitations, and, as a result, an absence of competition between individuals.

Figure 3. Stem frequencies due to quality (A), and dominance class (B) with respect to the time period for *Swietenia macrophylla* King in a homogeneous plantation, in south western Mato Grosso State, Brazil, 2001–2013. SS1 = Straight stem, no side branches, well defined canopy, typically commercial; SS2 = Straight stem, with side branches, but commercially usable; SS3 = Somewhat tortuous, no side branches and partial usage; SS4 = Tortuous stem, with side branches, low commercial usage; SS5 = Tortuous or other defects, with side branches, almost no commercial usage; O = Oppressed; S = Suppressed; I = Intermediate; CD = Co-dominant; D = Dominant.

Figura 3. Frequências de fustes quanto à sua qualidade (A), e quanto à classe de dominância (B) em função do período para *Swietenia macrophylla* King em plantio homogêneo, na região Sudoeste do estado de Mato Grosso, Brasil, 2001–2013. SS1 = Fuste reto, sem galhos laterais, copa bem definida, tipicamente comercial; SS2 = Fuste reto, com galhos laterais, mas aproveitável comercialmente; SS3 = Alguma tortuosidade, sem galhos laterais e aproveitamento parcial; SS4 = Fuste tortuoso, com galhos laterais e pouco aproveitável comercialmente; SS5 = Tortuoso ou defeituoso, com galhos laterais, praticamente sem aproveitamento; O = Oprimida; S = Suprimida; I = Intermediária; CD = Co-dominante; D = Dominante.

With regard to plant health, the *S. macrophylla* trees were healthy during the entire period of the study, without records of pests or diseases, even if the study region displays favourable weather conditions for the occurrence of *Hypsipyla grandella* (TAVERAS et al., 2004).

Many studies have been conducted to avoid or minimize the action of this shoot borer, such as: homogeneous low density plantations in areas of secondary vegetation (STEVENSON, 1927; SWABEY, 1941; MARIE, 1949; YARED; CARPANEZZI, 1981; OLIVEIRA, 2000; GROGAN et al., 2002); mixed or combined plantations of *S. macrophylla* with many species, *Azadirachta indica* A. Juss (SILVA et al., 2013), *Eucalyptus urophylla* S. T. Blake (GUIMARÃES NETO et al., 2004), *Toona ciliata* M. J. Roem (COSTA, 2000; BATISTA, 2005) and with many forest species for multiple use in the Amazon (SOUZA, 2008; LUNZ et al., 2009) have also been studied. However, in all of these studies, *H. grandella* occurred and caused damage.

Because this shoot borer selects its hosts due to the ability to seek and attack trees that release specific volatile materials (GRIJPMAN, 1970), this would explain the ineffective results of combined or mixed plantations. On the other hand, Ribeiro (2010) stated that the cases of small *S. macrophylla* plantations that do not suffer borer attacks are rare, most likely because they fit in escape areas where the occurrence of the pest is not found.

The above hypothesis could explain the results found. On the other hand, *Cedrela fissilis* Vell occurs in the region, which was also experimentally planted approximately 400 m from the *S. macrophylla* region, and this plantation has displayed the damage typical of the shoot borer in the apical meristem. Thus, other studies must take place in order to verify a possible genetic resistance. In a complementary way, new plots must be established in the region to confirm the area as an escape area, considering that *S. macrophylla* is not indigenous to the region and its natural occurrence is recorded in a region over 150 km away.

Therefore, with the development recorded and the quality of stem shapes, the lack of *H. grandella* occurrence and the possibility to apply in forest plantations techniques for homogeneous *S. macrophylla* plantations to increase the development and quality of the trees, emphasize the importance of new studies to assess the region as an escape area from the pest and to study the genetic features of such trees.

CONCLUSION

Swietenia macrophylla King displays potential for homogeneous plantations in south western Mato Grosso State, with development above average when compared to plantations in other re-

gions. Until 152 months of age, no plant health problems were recorded, in addition to a lack of action from the borer *Hypsipyla grandella* Zeller, and the region may be considered as an escape area.

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