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Cost-benefit analysis of industrial and homemade dendrometer bands[1]

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RESUMO

(Análise do custo-benefício de dendrômetros industriais e artesanais). Os dendrômetros são utilizados para realizar medidas repetidas de crescimento radial arbóreo. Dois tipos de dendrômetros são mundialmente utilizados, o industrial e o artesanal. Os dendrômetros artesanais predominam nos estudos florestais no Brasil, mas os pesquisadores têm o trabalho de construí-los e instalá-los. Uma solução mais fácil é o uso de dendrômetros industriais, mas eles não são produzidos no Brasil e, portanto, são mais caros e podem não ser adequados às condições ambientais locais. Foram analisadas as medidas pareadas mensais de crescimento do tronco (de fevereiro de 2008 a janeiro de 2009) de dendrômetros industriais (importados) e artesanais (feitos com componentes nacionais), instalados em 20 árvores de *Acacia tenuifolia* numa floresta estacional decidual sobre afloramentos calcários no Brasil Central. A análise de custo-benefício entre das medidas e dos preços dos dois instrumentos indicou que os dendrômetros artesanais possuem todos os benefícios e nenhum dos problemas dos industriais importados: (1) precisão semelhante nas medidas (análise de correlação: $r \geq 0,930$, $P < 0,01$; teste *t* permutado: $P \geq 0,55$), (2) custos bem menores (10 a 15 vezes mais baratos), (3) facilidade na manipulação e instalação no campo, e (4) ausência de alguns danos nos troncos que foram provocados pelos dendrômetros industriais.

Palavras-chave: Crescimento arbóreo, medidas diamétricas, medidas repetidas, dinâmica florestal

ABSTRACT

(Cost-benefit analysis of industrial and homemade dendrometer bands). Dendrometer bands are used to make repeated measurements of tree radial growth. Two types of dendrometers are used worldwide, the industrial and the homemade. Homemade dendrometers prevail in Brazilian forestry studies, but researchers have trouble constructing and installing them. An easier solution is to use industrial dendrometer bands, but they are not produced in Brazil and, therefore, are expensive and might not be appropriate for local environmental conditions. We analyzed trunk growth measurements each month (from February 2008 to January 2009) using both industrial (imported) and homemade (national components) dendrometer bands installed on 20 trees of *Acacia tenuifolia* in a seasonally dry forest on limestone outcrops in central Brazil. Cost-benefit comparative analysis of measurements and prices indicates that homemade dendrometer bands have all benefits, and none of the problems, of the imported industrial dendrometer bands, such as the following: (1) similar precision of measurements (correlation analysis: $r \geq 0.930$, $P < 0.01$; permutation t-test: $P \geq 0.55$), (2) much lower costs (10 to 15 times cheaper), (3) easily manipulated and installated in the field, and (4) absence of some damage to tree trunks that are caused by industrial dendrometers.

Key words: Tree growth, diametric measurements, repeated measurements, forest dynamics

Introduction

Many studies in forest ecology and forestry require taking radial growth measurements. The common methods involve the use of diameter tapes and calipers, with measurements taken at fixed intervals (generally years). However, these methods may be inappropriate for short-term measurements, such as months, where errors may be large in relation to the expected growth (Clark *et al.* 2000). For example, it is impossible to position the diameter tape or caliper in the exact same place on a tree stem during repeated measurements, and the scale (to less than 1.0 mm)

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makes extremely accurate measurements difficult (Yocom 1970; Clark *et al.* 2000). Therefore, when short measurement intervals are needed, an appropriated measurement technique is required. Accurate short term measurements can be achieved using dendrometer bands (Keeland & Sharitz 1993).

The dendrometer band consists of a strap of metal that is permanently wrapped around the stem and secured back to itself with a spring. As the tree grows, shrinks, or swells, the spring allows the band to move with the circumference of the trunk. Therefore, accurate repeated measurements can be made, since the instrument is fixed on a same place on the trunk, and great precision is obtained (< 0.25 mm) (Keeland & Sharitz 1993). For this reason, dendrometer bands are largely used in tree radial growth studies (Keeland & Sharitz 1993; Clark *et al.* 2000; Deslauriers *et al.* 2007).

Dendrometer bands can be separated in two distinct types, the industrial and the homemade (Keeland & Sharitz 1993; Deslauriers *et al.* 2007). They basically differ in terms of measurements and costs. Homemade dendrometers bands are cheaper, but allow precise measurements only for months or, according to the tree, weekly intervals. Industrial dendrometer bands allow precise measurements to the day, hour, or minute intervals, with the use of a data logger, but are more expensive. The cost-benefit relations of the two types vary according to the aim of the research. In Brazil, homemade dendrometer bands prevail in the majority of forestry and forest ecology research (Lisi 2006), especially due to their lower costs.

However, when the researchers need to use homemade dendrometers bands in Brazil, they deal with several problems. The first and major problem is to find adequate materials to construct the instrument, since the components are usually imported, which implies high costs and, sometimes, delay in their acquisition. Although there are published studies using homemade dendrometer bands in Brazil (Schöngart *et al.* 2002; Silva *et al.* 2002, 2003; Figueiredo-Filho *et al.* 2003; Hoffman 2002; Bucci *et al.* 2004; Ferreira-Fedele *et al.* 2004; Scholz *et al.* 2008; Rossatto *et al.* 2009), none of them quote clearly the origin and properties of the components. Another problem is to find adequate guides to construct, install and measure the homemade dendrometers bands. Therefore, an easier solution is to import industrial dendrometers, even if they might not be the most appropriate for some environmental conditions in Brazil.

In this work we measured the monthly radial growth of the fast growing tree species *Acacia tenuifolia*, in a seasonally deciduous dry forest on limestone outcrops in central Brazil, using both industrial (imported) and homemade (national) dendrometer bands, installed on the same trunks. Specifically, we aimed to: (1) compare the measurements of both instruments; and (2) analyze the costs and benefits of their use.

Materials and methods

The study was undertaken in a ca. 50 hectare patch of seasonally deciduous dry forest on limestone outcrops at Fazenda Sabonete, in the municipality of Iaciara, Paranã valley, in the northeastern part of Goiás State, in central Brazil (14°03'53" S and 46°29'15" W). These forests occur on limestone outcrops with steep slopes in patches that form naturally fragmented vegetation that occur scattered over central Brazil and are found in a matrix of *cerrado* vegetation composed mainly of savannas and grasslands. The forest floor has a shallow rocky layer, and the trees grow on the rock surface and in the fissures of the rocks, where cactus and other succulent plants are common. The regional climate is warm and tropical with wet summer and dry winter, classified as Aw, according to Köppen's system. Mean annual rainfall and temperature are around 1,300 mm and 23ºC, respectively. The study site is at ca. 500 m elevation, with a hilly and undulating (>20%) topography. The forest appeared undisturbed and was described in greater detail by Felfili *et al.* (2007).

According to Felfili *et al.* (2007), *Acacia tenuifolia* (L.) Willd. is a fast growing pioneer tree species common in this forest type. It occurs with high density and frequency in the studied site. Twenty *A. tenuifolia* trees with stem diameters at breast height (DBH, 1.30 m above soil) ranging from 6 to 16 cm were randomly selected in a variety of positions in the forest. In December 2007, the two kinds of dendrometer bands were set up around the trunk (DBH) of each tree:

(1) an industrial dendrometer band ("Series 5 manual band dendrometers", Forestry Suppliers Inc., USA) consisting of one stainless steel band (0.05 mm thick and 3.20 mm wide) placed around the trunk and attached to one brass body with one hinge, one stainless steel spring (15.0 mm range, 4.5 mm outside diameter and 0.5 mm wire diameter) and one movable inner tube with two metric Vernier (millimeter) scales (see Fig. 1). The brass body was fixed on the trunk with two steel screws, inserted ca. 30.0 mm deep into the trunk. One scale was fixed on the movable inner tube of the brass body, and the other was attached to the band and moved as the tree expanded and contracted, being able to measure very small changes in the length of the band;

(2) a homemade dendrometer band, constructed according to Keeland & Young (2006), consisting of one stainless steel band (0.1 mm thick and 15.0 mm wide) placed around the trunk, with one end passed through a collar and then connected back to itself with a stainless steel spring (38.0 mm range, 6.35 mm outside diameter and 0.65 mm wire diameter) (see Fig. 1). A scratch was made across the band at the edge of the collar away from the free-running end of the band. As the tree expanded or contracted, the scratch moved away from the collar, allowing measurements of very small changes in the length of the band. Both bands and springs of the homemade dendrometers were made with ASI 304 stainless steel alloy bought from Brazilian companies.

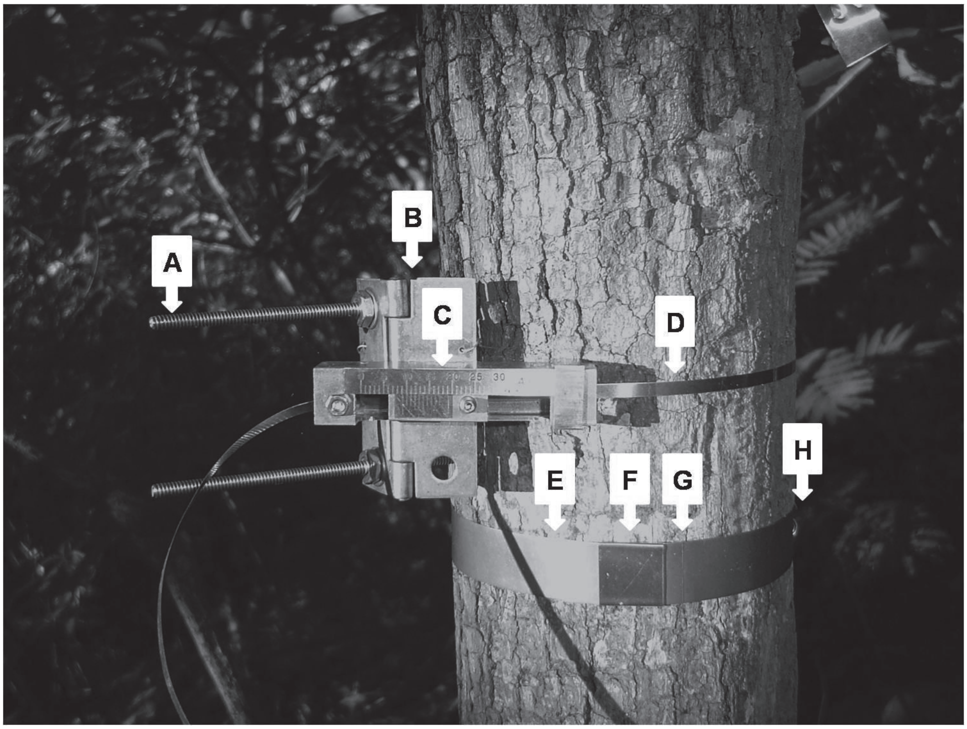

Figure 1. Aspects of dendrometer bands used in this study. Industrial dendrometer (above): (a) steel screws to fix the (b) brass body to the trunk; (c) inner tube with milimetric scales; (d) stainless steel band. Homemade dendrometer (bellow): (e) stainless steel band; (f) collar; (g) scratch parallel to the collar; (h) stainless steel spring.

The surface of the trunk where the dendrometers were installed was smoothed using a coarse sandpaper, to make sure that the bands were extended around the stem in a uniform manner and the bark did not interfere with the radial growth (Keeland & Sharitz 1993). As suggested by Keeland & Young (2006), the dendrometers were installed in the middle of the growing season (December 2007, rainy season), two months prior to the initiation of the measurements (February 2008), to allow settlement of the bands onto the tree trunks.

A digital caliper (± 0.03 mm precision) was used to measure the growth (expansion or contraction) of tree trunk in both dendrometers types. Although the industrial dendrometer had a metric (Vernier) scale, we use the digital caliper to standardize measurements. These measurements were taken every month, always between the 20^{th} and 25^{th} day and between 8 am and 11 am, from February 2008 to January 2009.

Correlation analysis was used to compare the monthly growth measurements of the two types of dendrometers and the differences were tested for statistical significance by a paired-comparisons *t*-test, after the data was tested for normality by the Chi-square test (χ^2, $P > 0{,}05$). Analyses were performed with PAST version 1.81 software (Hammer *et al.* 2008).

A comparison of the costs of the two dendrometers types was made based on prices of the imported industrial dendrometer and of the components of the national homemade dendrometer, including freight fees, according to surveys conducted at the start of the project (April 2007).

Results and discussion

Monthly measurements of the industrial and homemade dendrometers bands were very similar along the studied period (Fig. 2), and, thus, were highly correlated ($r \geq 0.930$, $P < 0.01$, Table 1). The *t*-test paired-comparison revealed no significant differences between measurements of the dendrometer types ($P \geq 0.55$, Table 1). Therefore, homemade dendrometer bands provided the same precise measurements as the industrial ones.

Other important aspects of the homemade dendrometer need to be emphasized: First, the absence of some damage to the tree trunks, which was observed using the industrial dendrometer bands (Fig. 3). The insertion of the screws of the industrial dendrometers into the trunk caused cracks in the bark and resin to exude through the screws holes (Fig. 3A and 3B). Trees growing in seasonal forests develop physiological strategies to retain water in their trunk during the wet seasons, to support the water stress during dry seasons (Borchert 1994, 1999; Eamus, 1999), and this type of damage may disturb this retention and could even lead to tree death.

Second, the homemade dendrometers were easily manipulated and installed in the field. Their 0.10 mm thick steel

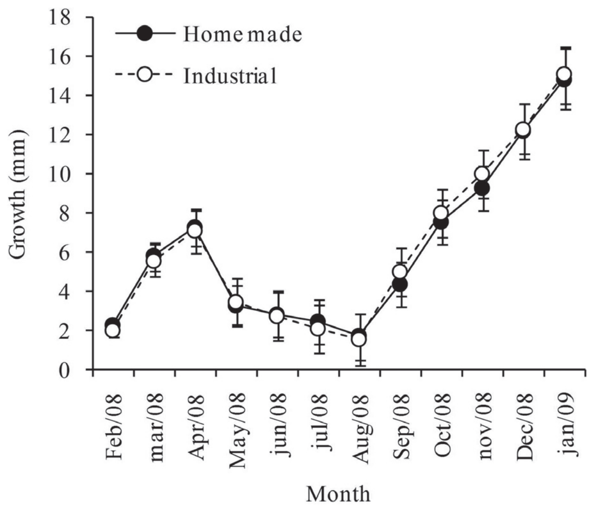

Figure 2. Means (± SE) of tree growth measurements in *Acacia tenuifolia* (L.) Willd. made with the industrial and homemade dendrometer bands from February 2008 to January 2009.

Table 1. Correlation (*r*) and paired *t*-test (*t*) analysis of monthly growth measurements in *Acacia tenuifolia* (L.) Willd. by the industrial and homemade dendrometer bands. *Mean with SE in parentheses; **All values with statistical significance ($P < 0.01$); ***All values without statistical significance ($P > 0.50$).

	Growth* (mm)			
Month/Year	Homemade	Industrial	r^{**}	t^{***}
Feb/2008	2.31 (0.33)	2.03 (0.35)	0.930	-1.797
Mar/2008	5.80 (0.70)	5.58 (0.83)	0.961	-0.855
Apr/2008	7.30 (0.94)	7.06 (1.11)	0.964	-0.751
May/2008	3.30 (1.05)	3.48 (1.21)	0.945	0.357
Jun/2008	2.84 (1.10)	2.79 (1.23)	0.954	-0.138
Jul/2008	2.49 (1.13)	2.13 (1.24)	0.961	-0.315
Aug/2008	1.72 (1.19)	1.53 (1.31)	0.962	-0.530
Sep/2008	4.38 (1.12)	5.04 (1.21)	0.953	1.771
Oct/2008	7.56 (1.13)	8.02 (1.25)	0.936	1.040
Nov/2008	9.99 (1.24)	9.25 (1.14)	0.950	1.912
Dec/2008	12.19 (1.25)	12.30 (1.41)	0.959	0.284
Jan/2008	14.84 (1.54)	15.03 (1.42)	0.968	0.489

Figure 3. Damage caused by the industrial dendrometer screws to the trunks of *Acacia tenuifolia* (L.) Willd.: (A) resin exuding during the wet season and (B) cracks during the following dry season.

bands could be cut with common scissor to the desirable size, and the hole in the band to install the spring could be opened with a common paper hole punch. These accessories are cheap and available in many stores, contrary to professional metal scissors and punches used worldwide (Keeland & Young 2006).

Third and finally, homemade dendrometer bands had a low cost (U$ 3.00 to 6.90) compared to the imported industrial ones (U$ 47.95 to 67.50). In summary, our analyses showed that the same accurate growth measurements provided by the industrial dendrometer bands (considering this dendrometer type as a control) could be obtained with the national homemade dendrometer bands, but these latter were 10 to 15 times cheaper.

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