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Relationships between wood volume increments by stem analysis and water balance in the semi-arid interior of northeastern Brazil

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Abstract : In the semi-arid region of northeastern Brazil, drought deciduous thorny shrub forest which is locally called caatinga is widely spread. Using four trunks of *Clitoria cearensis* Hub., which is one of the caatinga tree species, stem analysis was applied to estimate annual wood volume increments. Regarding evaluation of water stress in this region, water storage in the soil was calculated by the Thornthwaite and Mather's method, and the annual amount was estimated by the variable timing year method. As a result, it was found that the wood volume growth was dependent on seasonal cycles between the rainy and dry seasons. In such a region, temperature is not a decisive factor for plant growth, wood volume growth is dependent on how long soil moisture was successively retained. The species used in this study is one of the pioneer species in the plant succession process of the caatinga forest. Trees in this group quickly react to annual changes of effective amounts of water, and the increments are also large, but have small tolerance of aridity. Therefore, it is thought that the fluctuation of wood volume increment of *Clitoria cearensis* Hub. is directly influenced by the semi-arid climate of northeastern Brazil. If the same analysis is applied to other species in different succession stages, it becomes possible to evaluate total increments of caatinga stand in a unit area.

Key words : annual wood volume increments, stem analysis, water balance, semi-arid climate, caatinga forest, northeastern Brazil

Introduction

Previously, the relationship between growth of trees and an outside factor, particularly, climatic environment has been investigated. They were conducted in one dimensional scale using tree-ring width, two dimensional scale such as cell growth by image analysis, and a density of growth ring in each year by soft x-ray. These methods and the results are summarized in detail by Schweingrüber (1983) and Hughes, *et al.* (1982) . Old stumps were frequently used because the purpose of this kind of study is to reconstruct past

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climate. Therefore, most of them were studied in the one dimensional scale such as length and width.

On the other hand, the studies on the annual wood volume increments have been done mainly on the valuable tree species. The purpose is to produce as many trees of good quality as possible. The stem analysis method has been used in a forest mensuration from the past (Fritts, 1976, Osumi, 1983).

In this study, this wood volume calculation is to be applied on caatinga trees in the semi-arid inland area of northeastern Brazil. The relationships are to be examined between the wood volume increments and water balance both of which are regarded as one of the representative indices of semi-arid climate in this area.

Water balance in northeastern Brazil

As shown in Fig. 1, the inland area of northeastern Brazil is the typical semi-arid region. Annual mean of precipitation is less than 600 mm and in reverse, annual mean of potential evapotranspiration exceeds 1500 mm. Therefore, it is frequent that the annual total water deficit is greater than 1000 mm. Moreover, the variability of annual precipitation in this region is greater than 50 %, and the arrival of the wet season greatly varies year by year (Fig. 2). Therefore, both hypertrophic and extention growth of trees composing the caatinga forest are dependent on such severe aridity and unstable arrival of the wet season.

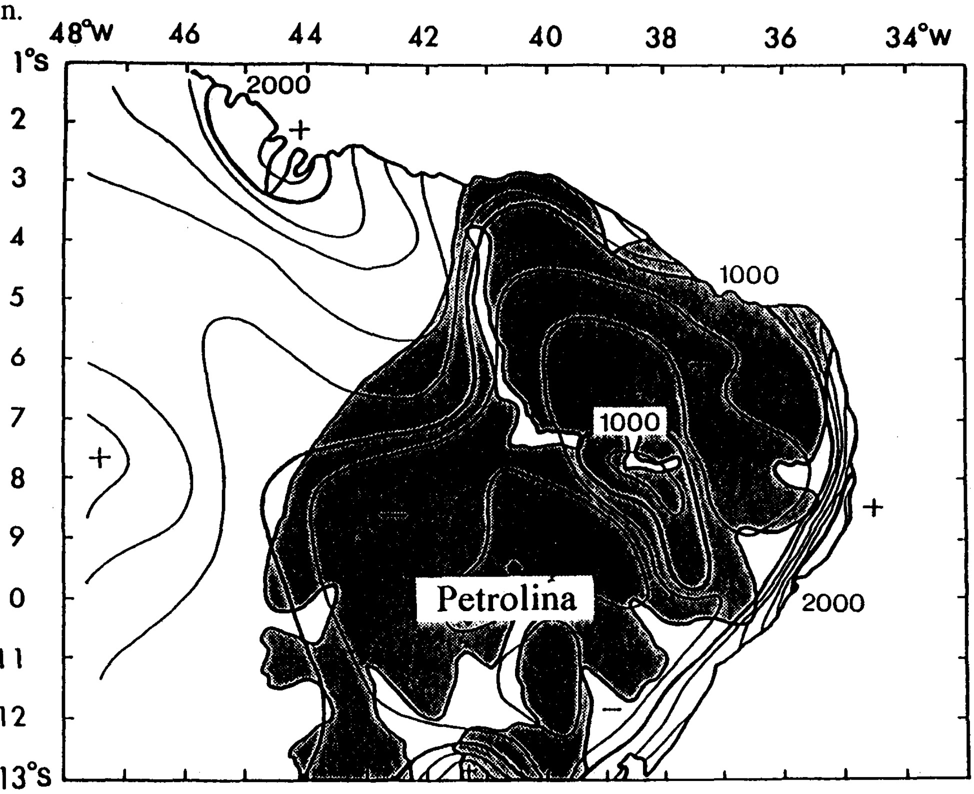

Fig. 1 Distribution of annual mean precipitation of northeastern Brazil. Iso-line of 1000 mm coincides with the distribution of caatinga vegetation shown in dotted area.

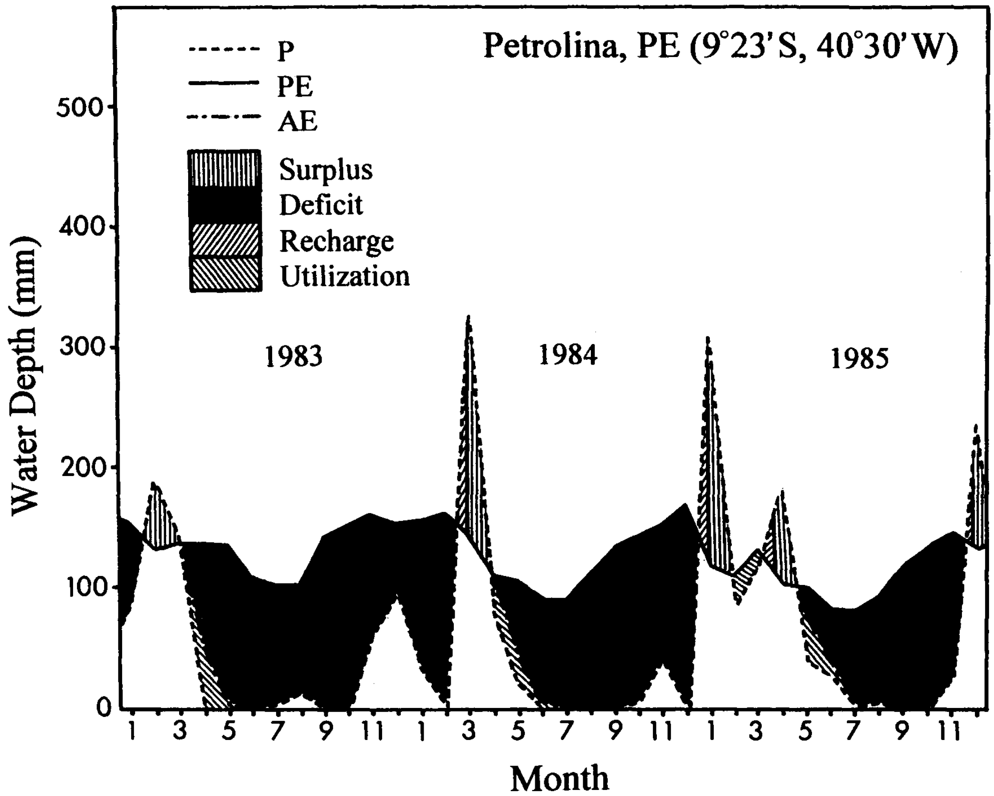

Fig. 2 Time series of water balance components in Petrolina from 1983 to 1985.

Because of the effects of water stress on the growth of trees being so great in the semi-arid region, it is necessary to calculate water balance in which evapotranspiration and run-off into the ground surface are eliminated from precipitation. Fig. 2 shows the time series of water balance in Petrolina, Pernambuco state from 1983 to 1985 calculated by the Thornthwaite and Mather's method inviced in 1955. In this calculation, soil moisture retention was fixed to 50 mm/m (as regards to the reason why water holding capacity was fixed at 50 mm/m, refer to Tsuchiya, 1990). It is found that caatinga trees can grow only when the soil moisture exists in the short wet season.

Materials and methods

1. Sample preparation

Clitoria cearensis Hub. (local name is Faveira) was used for the wood volume calculation. This species grows quickly and has clear tree-ring boundaries. Therefore, it was thought to be appropriate for the stem analysis. In addition, *Clitoria cearensis* Hub. has a keen sensitivity to water conditions, and the tolerance of aridity is small. The growth greatly depends on the annual fluctuation of water storage. From the viewpoint of plant succession, it is regarded as one of the pioneer species, because it begins growing prior to other species after clear-cutting.

Transection cores were obtained in Petrolina in 1990. In order to calculate the wood volume by stem analysis, cores were sampled at 1 m interval from the root zone to the top of the trees. Totally, twenty two transection samples with thickness of 10 cm were prepared from four individuals. After grinding them by sandpaper and carborundum, the tree-ring width of each sample were measured from the pith to the bark by a microscope by Nikon Co., Ltd. with an accuracy of 0.001 mm.

2. Wood volume calculation

As an example among four stems, Figure.3 shows the relationship between tree height (m) and the radius (cm) of the transection samples. Tree height is indicated along the horizontal line, and the radius is shown along the vertical line. Annual change of both the hypertrophic and the extension growth of this stem can easily be found from this figure. However, estimated values are used on the dotted lines in some portions, because it is difficult to accurately grasp the annual change of tree height.

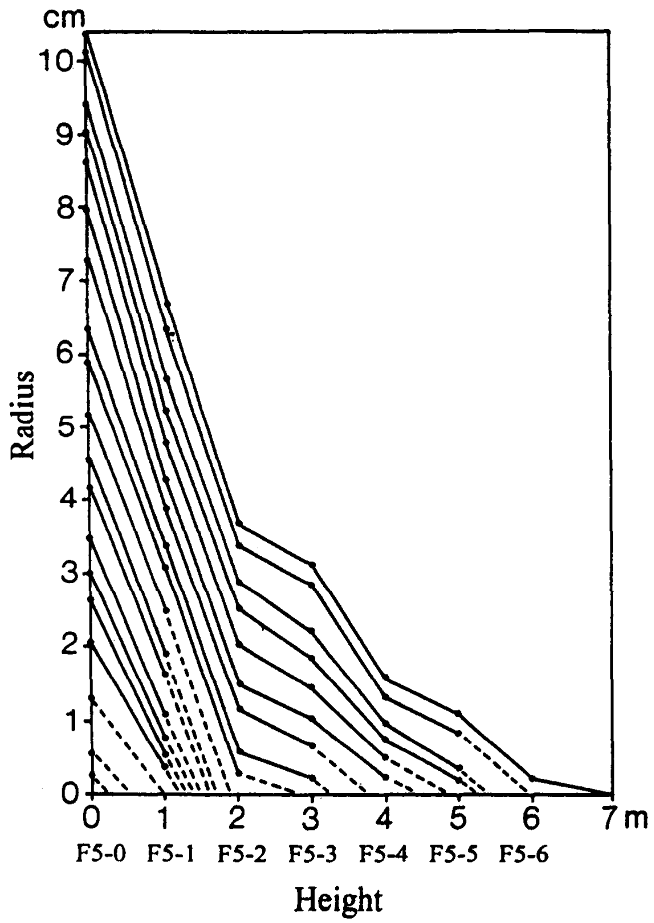

Fig. 3 Relationship between tree height and radius of transection samples. Dotted line means it is an estimated tree-ring boundary.

Regarding the stem as a cone shaped truncated body and excluding the volume of branches, annual volume increment was calculated by means of sectional measurement of volume.

Supposing that the gradient is indicated as "a", and the intercept is indicated as "b" when the coordinates of the tree-ring boundaries in the same year in a given sample and a sample just below it are expressed (x_1, y_1), (x_2, y_2), each value is calculated from a formula linking the two points as follows:

$$a = (y_2 - y_1)/(x_2 - x_1) \quad (1)$$
$$b = (x_2y_1 - x_1y_2)/(x_2 - x_1) \quad (2)$$

In the same way, the gradient (c) and the intercept (d) linking two boundaries before one year are indicated as follows:

$$c = (y_4 - y_3)/(x_2 - x_1) \quad (3)$$
$$d = (x_2y_3 - x_1y_4)/(x_2 - x_1) \quad (4)$$

From these values, the volume of one truncated cone for one year can be calculated, making use of a formula of solid revolution as follows:

$$V_1 = \int_0^x (\pi\,(ax + b)^2 - \pi\,(cx + d)^2)\,dx \quad (5)$$

Here, supposing π equals 3, and x equals 1 (m), equation (5) is re-written as follows:

$$V_1 = (a^2 - c^2) + 3(ab - cd) + (b^2 - d^2) \quad (6)$$

Therefore, adding up the value of V from the bottom to the top, the one year periodic increment of this stem can be calculated.

$$V_{1989} = V_1 + V_2 + \cdot\cdot\cdot\cdot\cdot + V_n \quad (7)$$

Results from the comparison between annual wood volume increment and water storage

The annual change of volume increments of one representative stem was calculated by the above-mentioned procedure. However, it was found that this time series was drawn in a shape of a growth curve. Because the age of each stem is different, it is not capable of comparing the time series directly with the water balance component (Fig. 4).

After eliminating the difference of age from the real time series, and normalizing them so that the average may be zero, and the standard deviation may be one, the time series

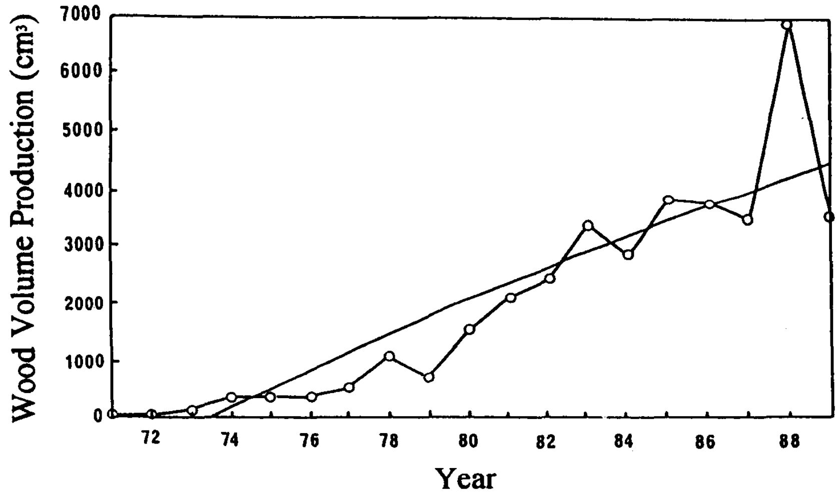

Fig. 4 Annual wood volume increment of *Clitoria cearensis* Hub.

were re-drawn in the upper part of Fig. 5.

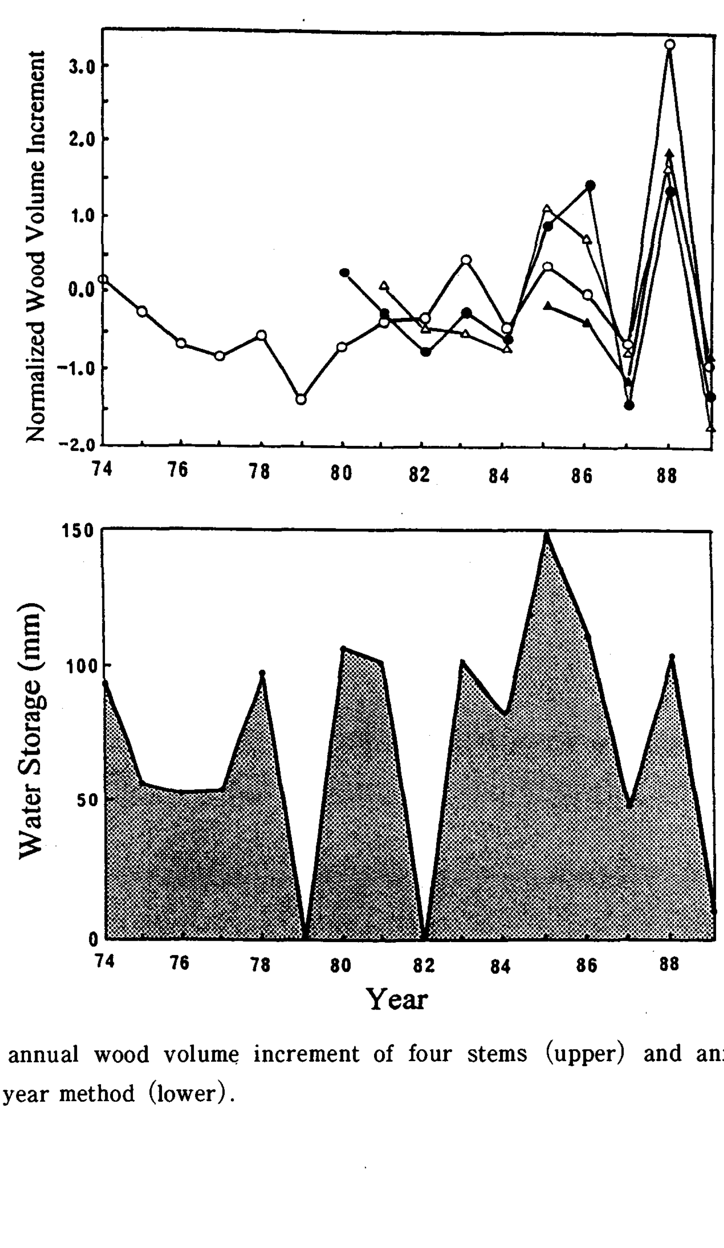

Fig. 5 Normalized annual wood volume increment of four stems (upper) and annual water storage by the variable timing year method (lower).

Also, the annual change of water storage in Petrolina was shown in the lower part of the same figure. This annual amount of water storage was calculated by summing up the monthly water storage using the variable timing year method so as not to divide a continuing wet season (concerning this method, refer to Tsuchiya, 1990).

Comparing them, every sample shows similar changing patterns, and they quite resemble the changing pattern of water storage. Conversely, this fact suggests that the former is dominated by the latter.

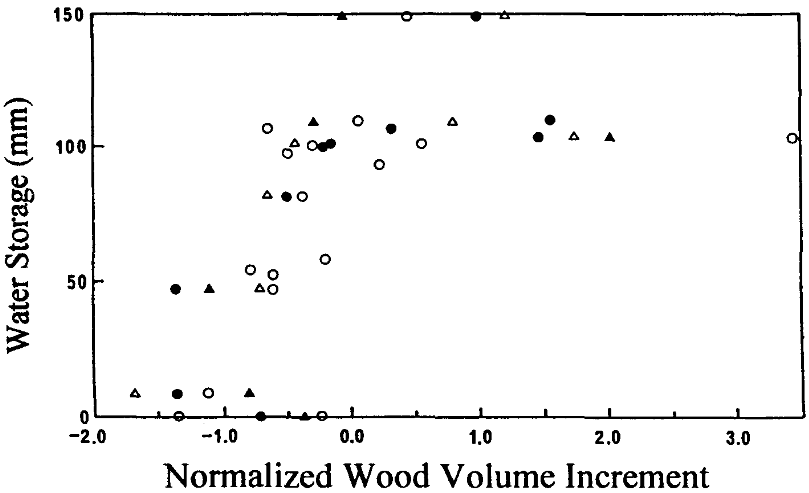

Fig. 6 Relationship between normalized wood volume increment and annual water storage.

Next, the relationship between them was investigated in Fig. 6. From this figure, it is found that the volume increments of *Clitoria cearensis* Hub. are generally restrained when the water storage is small. On the other hand, it performs photosynthesis well and the wood volume increments increase when the water storage is large. However, the relationship becomes indistinct when the annual water storage is greater than 100 mm.

Discussion

Nishizawa, *et al.* (1993) classified sixteen caatinga tree species, which are widely seen in the caatinga forest, into three groups, using tree core samples of 259 pieces (Fig. 7).

The x-axis shows the gradient of a regression equation between the relative growth ring width (R. G. R. W.) and annual water storage by the variable timing year method (R. G. R. W. was introduced from the ratio between each tree-ring width and the radius along the measured direction). This value indicates the different degree of response to available water amount among tree species. The y-axis shows the annual water deficit by the variable timing year method in the case that the hypertrophic growth does not occur at all (here, this value was converted into such a value that the R. G. R. W. of every species uniformly became 0.1 when the water deficit was zero in order to revise the difference among species). This value indicates the difference in tolerance of aridity among tree species.

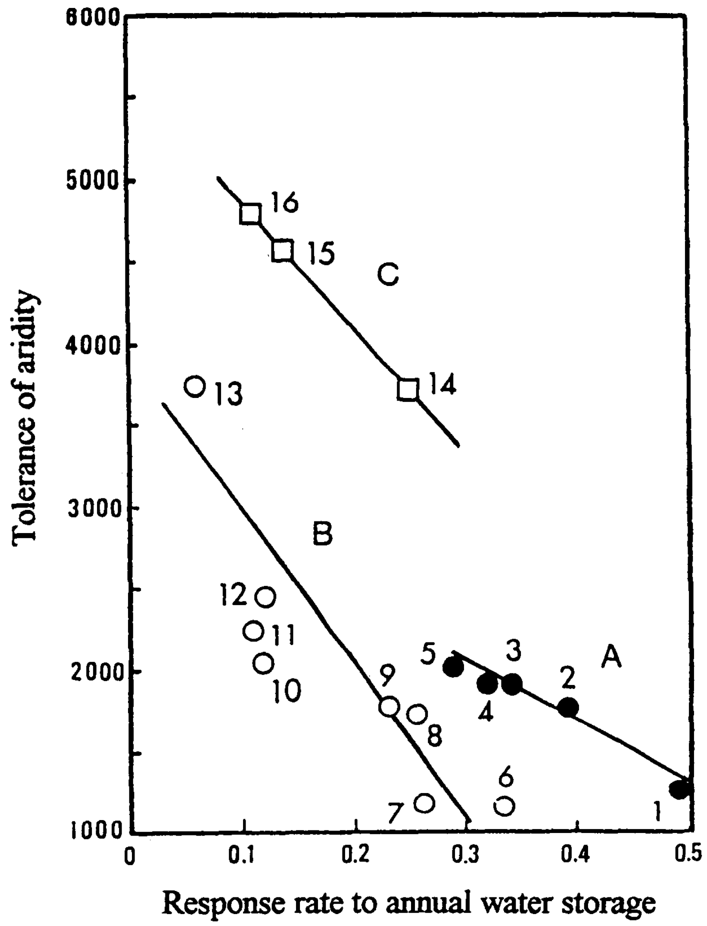

Fig. 7 Classification of sixteen tree species in the caatinga stand (after Nishizawa, T., Tsuchiya, A. and Pinto, M. M. V., 1993). *Clitoria cearensis* Hub. belongs to group A (No. 2).

According to this figure, *Clitoria cearensis* Hub. (No. 2) belongs to group A. Tree species in this group have characteristics of small tolerance in aridity and large response rate to water conditions.

What is more interesting is the results from the floristic composition in some quadrate areas. That is to say, group A corresponds to the pioneer species in the caatinga forest, group B, the dominant species in the present stage of plant succession, and group C, the permanent species (Tsuchiya, 1991).

Collating these results with the wood volume increments, the following can be estimated. The pioneer species such as *Clitoria cearensis* Hub. is the first group that begins growth after the caatinga is made naked for some reasons such as an artificial burning or deforestation. Its increments are large and fast, depending greatly on the water conditions. However, tree species of group B gradually predominates in the caatinga. Then group A begins to decline. Although the increments become smaller, it becomes harder to be influenced by the annual fluctuation of water stress by the change of dominant species from group A to group B. It is difficult to find the caatinga where tree species of group C predominates because the lumber is utilized by its inhabitants. However, this group can perform constant growth although its increments are small, not being influenced by annual climatic variation.

In short, tree species with a strong and a weak tolerance of aridity coexist in the caatinga forest. If the volume increments of various species are investigated and the floristic composition is surveyed in many areas with different degree of aridity, it may be possible to compare annual net-production of wood volume among the areas. There is no doubt that the result will contribute toward examining the degree of desertification in northeastern Brazil.

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