

**Preservation of the *Guadua angustifolia* Kunth by submersion
in aqueous boron solutions: The influence of temperature,
concentration and duration of submersion in aqueous boron
solutions on the effectiveness of the preservation of Colombian
bamboo (*Guadua angustifolia* Kunth)**

Tito Morales Pinzón

Facultad de Ciencias Ambientales, Universidad Tecnológica de Pereira, Risaralda, Colombia
Tito@utp.edu.co

and

Michael Tistl

Agro Bamboo de Colombia, A.A. 355, Pereira, Risaralda, Colombia
Mitistl@yahoo.com

ABSTRACT

In the Colombian Coffee Region, the effectiveness of the chemical preservation of *Guadua angustifolia* Kunth using the submersion in a boron solution was investigated. Samples between 50 and 60 cm of length with different diameters and wall thickness were used with and without clump-curing. They were submerged in three different boron concentrations with a relation of borax:boric acid of 1:2, using different submersion times (3 to 5 days) and different temperatures (20 to 80 C).

The quality of the preservation is controlled significantly by the initial moisture content of a sample, the specific weight, the concentration of the solution, the submersion time, and the temperature of the solution.

Mathematical models were created to control the concentration of the solution and for the determination of the retention and the penetration of boron compounds into guadua using the submersion technique.

INTRODUCTION

Historically, bamboo has been used in Northern South America, and especially in some regions of Colombia, as an essential material for construction. The so called “bahereque” technique combined timber and the local bamboo (*Guadua angustifolia* Kunth, in the following “guadua”) as structural elements for buildings.

Traditionally, the preservation of the guadua is made by special cutting- and harvest-methods. Especially in the Colombian Coffee Region, the bamboo is cut during the

wane of the moon and before sunrise. The culms are left in vertical position at their sites during some weeks (clump-curing). On one side, the ongoing photosynthesis processes of the leaves reduces water and carbohydrates which are stored in the culms, and on the other side, a part of the sugars is fermented within the culms (Spanish: “*vinagrado*”), reducing so the attractiveness for later borer attack. After two or three weeks, the leaves dried and the guadua culms can be harvested and prepared for their final use (Moran 2003). Montoya (2002) showed that this method, in deed, reduces significantly the later attack by borers.

However, for modern constructions and long time use, this technique is not sufficient and an additional preservation with chemicals is required (Liese 2004, Liese and Kumar 2003). Modern preservation methods for timber offer a wide range of techniques and technical requirements (JUNAC 1988, Vaca de Fuentes 1998). After the 1999 disastrous earthquake in the Colombian Coffee Region, reconstruction caused an increasing demand of preserved guadua and the necessity of a practical and environmentally friendly preservation method. Nowadays, and based on very good empirical results, the majority of the Colombian bamboo producers submerge the culms, after clump-curing, in an aqueous boron solutions, generally applying a combination of boric acid and borax in a relation of 1:1 and in concentrations of 4 to 5%. To permit the diffusion of the protecting boron compounds, all nodal walls are axially perforated and the culms are submerged in the aqueous boron solution during five days (soaking). In Colombia, this method has shown good preservation results and easy applicability in rural areas. The increasing export of bamboo poles to markets in USA and EU during the last years makes a controlled quality of preservation necessary.

The interest of the actual study is to demonstrate the diffusion effectiveness, to quantify the penetration of the boron solution in function of temperature, concentration of the solution and duration of submersion and to quantify the effective retention of boron salts within the timber as an indicator for preservation quality.

MATERIALS AND METHODS

A factorial experiment with two factors and tree levels (design 3²) was designed with two blocs called “site 1” (Nápoles Farm, Montenegro, Quindío) and “site 2” (Botanical Garden, Universidad Tecnológica de Pereira), where samples with average diameters of 8.3 and 14.5 cm were taken.

The concentration of the solution (0.45, 0.90 and 1.35 wt. % of boron, calculated on the base of a mixture of borax and boric acid 1:2) and the duration of submersion (3, 4 and 5 days) were defined as factors. As response variables, the penetration and the retention of boron were measured and as co variables, the moisture contents before submersion as well as the specific weight of the samples. The experimental unity corresponds to samples of the basal (*basa*) and the middle part (middle) of adult guadua of more than three years, 50-60 cm in length with at least two internodal sections.

To observe the influence of temperature of the preservative solution, a unifactorial experiment with four levels was designed (20, 30, 40 y 80 C). As response variables, the penetration and the retention of boron were measured and as co variables, the moisture content before submersion as well as the specific weight of the samples. The

experimental unity corresponds to samples of the basal part of adult guadua of more than three years, 60 cm in length with at least two internodal sections (from site 2).

The samples for the evaluation of penetration and retention of boron salts were taken in the middle of the nodes (curcuma coloring method), and quantitatively by the azometina H-method at the Technical University of Pereira.

RESULTS AND DISCUSION

Effects of boron compounds in aqueous solutions

Borax and boric acid are commercialized in form of water-soluble salts. Meanwhile increasing borax contents changes the pH of an aqueous solution toward alkaline values, the addition of boric acid shifts the pH toward acidic values (Fig. 1). This explains the necessity of both compounds to maintain pH neutral.

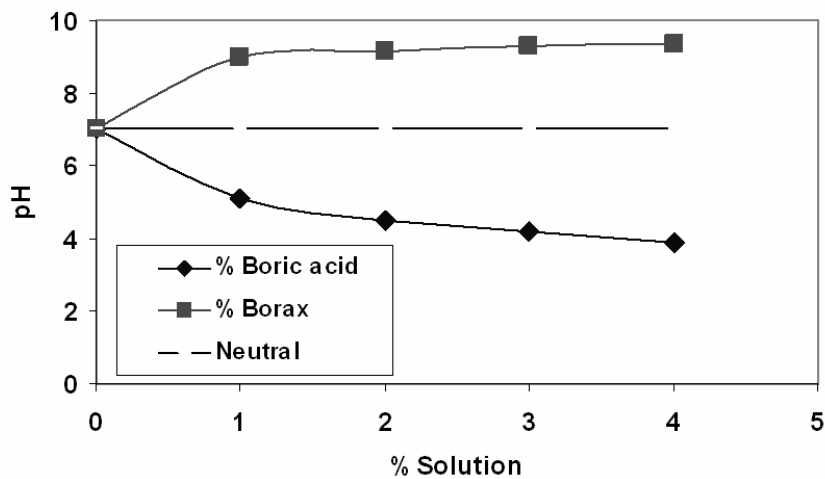


Fig. 1: Influence of borax and boric acid concentration on the pH of an aqueous solution.

The solubility of both salts increases drastically with increasing temperature (Fig. 2). However, the increase of solubility of borax at up to 60 C is low as compared to the temperature interval 60-100 C. Higher solubility in the lower temperature range would have been more favorable for practical uses. The dissociation of borax is at 100 C nearly 2.000 g/l compared to 250 g/l boric acid. The higher solubility of borax as compared to boric acid means that the preservation effect is caused principally by dissolved borax.

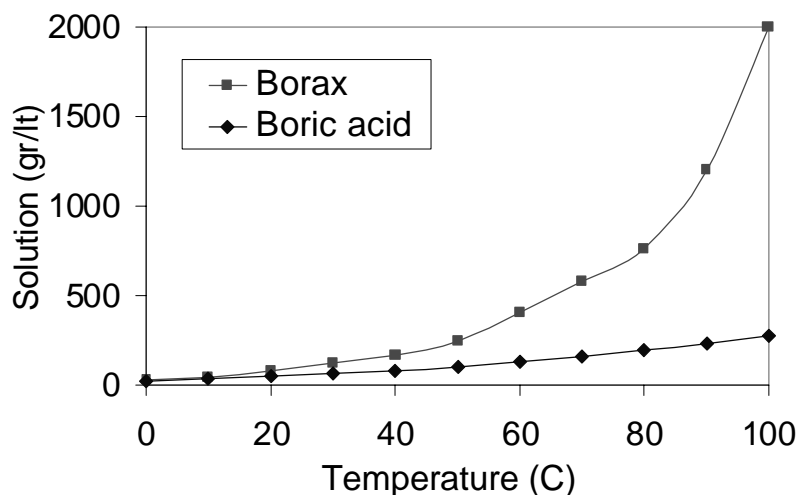


Fig. 2: Solubility of borax and boric acid in function of the temperature of an aqueous solution.

To control the salinity and therefore the quality of the preservation solution, it is possible to measure the conductivity of the solution at neutral pH as the conductivity is a linear function of the dissolved ions (Fig. 3). A 2% borax solution is characterized by a mean conductivity of 6800 $\mu\text{S}/\text{cm}$ meanwhile a 4% solution has 11500 $\mu\text{S}/\text{cm}$ (at 23 ± 1 C). These differences are great enough to utilize the conductivity as a practical indicator for the borax content or quality of the solution as described by the formulas:

- 1.) % Borax = (Conductivity-315)/2929 or
- 2.) Conductivity ($\mu\text{S}/\text{cm}$) = 315+2929 x Borax (%)
- 3.) % Solution (relation 1:2) = % Borax + % Boric Acid

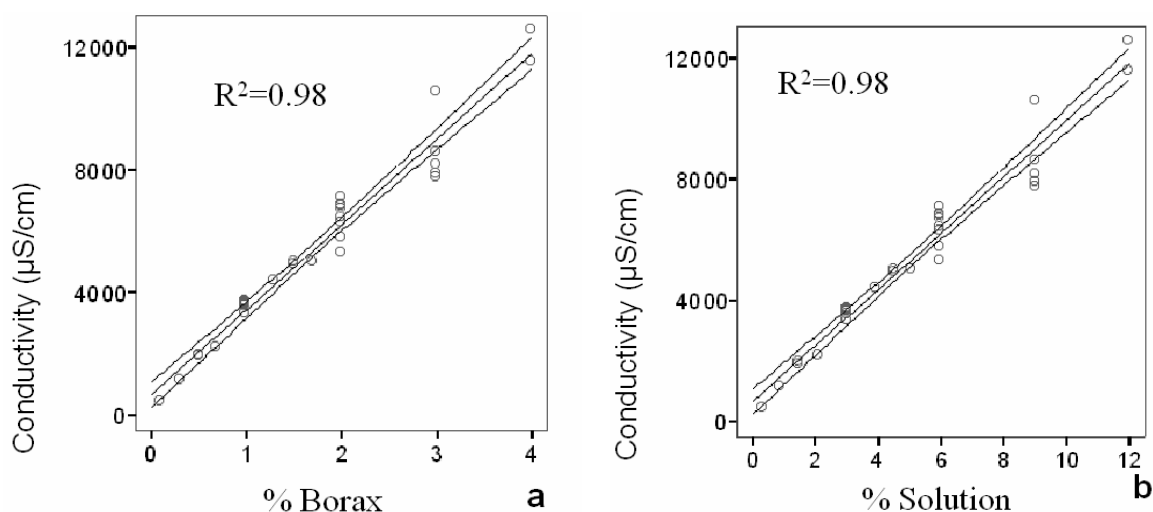


Fig. 3: Conductivity of an aqueous solution in function of its boron concentration as described by formula 2 (a) and its solution concentration as described by formula 3 (b) at 23 ± 1 C.

Penetration and retention of boron salts

The concentration of the preservation solution and the submersion time are two of the most important variables with strong influence on the final retention of boron salts of a sample.

Most of the samples showed a total penetration of boron compounds with a stronger boron concentration in the inner wall side. The concentration of the boron solution shows a significant influence on the diffusion and retention with 3.3 kg/m³ BAE (boric acid equivalent) in a 3% solution and 6.9 kg/m³ BAE in a 9% concentration (Table 1).

Table 1. Boron content of preserved guadua in function of different concentrations of the solution and different submersion time

Concentration	Submersion time (days)			Total
	3	4	5	

(% of boron)				
0.5	1.6±0.4	3.7±1.1	4.7±2.2	3.3±0.8 (c)
0.9	4.9±1.4	6.1±2.0	6.1±1.7	5.7±0.9 (b)
1.4	6.6±1.7	6.9±2.1	7.1±1.8	6.9±1.0 (a)
Total	4.4±0.9	5.6±1.0	6.0±1.1	

Mean±standard error of the mean, based in 6 samples per treatment (n=54). Different letters mean significant differences in concentration (Tukey-test p<0.05).

Due to the anatomic heterogeneity of guadua (Gritsch *et al.* 2004), with different moisture contents and different densities (both depend on the relative amount of parenchyma tissue), the penetration and retention of boron compounds is as well heterogeneous. Londoño *et al.* (2002) report a range of parenchyma tissue of 63% in basal and 36% in apical parts of *Guadua Angustifolia* that corresponds to a range of specific weight from 0.36-0.99 g/cm³ (Camargo 2006). Parenchyma tissue permits better diffusion of the preservative solution. On the other hand, borers preferably attack parenchyma rich parts of the bamboo as they serve as storage for starch grains (Liese 2004). Therefore, the preservation reaches the parts where it is precisely required.

Penetration acts at the ends of a guadua pole along the metaxylem vessels of the vascular bundles, while, in the interior of a pole, diffusion processes through the inner wall-layer dominate. Guaduas without perforated inner nodal walls showed clearly lower retention values of 0.3 BAE at 20 C and 1,1 BAE at 80 C while samples with perforated nodal walls show retention values of 3.9 BAE and 15.2 BAE at the respective temperatures (Table 2).

Table 2. Boron concentration of preserved guadua with and without ruptured nodal walls at different temperatures.

Treatment	20 C	80 C
With ruptured	3.9±1.2 (b)	15.2±1.7 (a)
Without ruptured	0.3±0.1 (d)	1.1±0.4 (c)

Mean±standard error of the mean, based in 4 samples per treatment (n=16). Different letters mean significant differences in concentration (Tukey-test p<0.05).

The outer wall, with its watertight, silica rich layer (cortex), is practically not penetrated by the boron compounds.

Our investigations showed that there exists longitudinal penetration, but it is negligible as compared to the penetration through the inner wall. Therefore, the perforation of the inner nodal walls or two perforations at each node are fundamental for a good preservation without using pressure techniques like “Boucherie”.

Mature guadua, as harvested at an age of 5-7 years and used for the present investigation, has moisture contents of 80-120%. After three weeks of clump-curing, the moisture content is still about 40-80%. Under this condition, the culms are submerged in the preservation solution.

In samples with more than 80% moisture content, penetration of the boron solution was not complete (100%), while in samples with moisture content less than 80%, the penetration was complete. However, in the present study, we did not investigate the lower limits of moisture content. Liese (2004) notes, that with further drying, the

bamboo tissue becomes quite refractory and penetration will depend mainly on the limited internal capillary forces.

In our linear regression model, 46% of the variability in retention of boron salts may be explained by moisture content and specific weight, while individual effects show 17% and 25% of variability (Fig. 4).

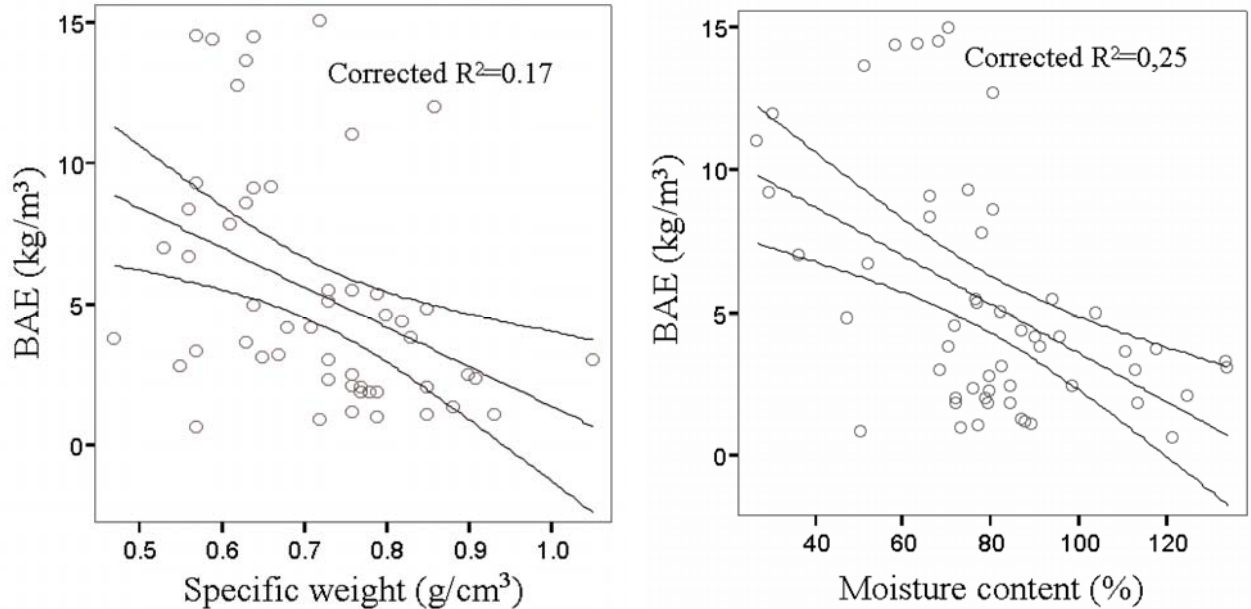


Fig. 4: Relation between specific weight, moisture content and penetration.

CONCLUSIONS

As the conductivity is a direct function of the dissociated ions of borax, the concentration of the preserving solution can be measured easily by the conductivity and the pH of the solution. For practical uses it is recommended to maintain the pH neutral.

The retention of boron compounds depends strongly on the concentration of the solution, on the specific weight of the guadua, on the moisture content of the guadua and on the duration of submersion. Each of the four parameters may strongly influence the quality of protection in soaking treatment.

The concentration of the boron solution showed good results in the range of 3-9% but a 4-5% solution seems sufficient for a good preservation. In practical application, higher concentrations may produce a thin crystal film on the pole's surface during drying (verb. comm. Joerg Stamm). At increased temperature, the solution dissolves significantly more borax and favors the penetration of the boron compounds. Shorter submersion times could be the consequence, but the higher costs for heating up the solution has to be compared with the advantage of shorter submersion times.

The specific weight of the guadua is a natural parameter that may depend on growing conditions or site quality but it is present also within a single guadua pole. A good

selection of the material before submersion is required to achieve a uniform preservation.

The moisture content of the guadua at the time of submersion should be less than 80%. For a uniform preservation, groups of culms from one site and with the same harvesting and drying history should be treated.

Submersion time depends strongly on the other three parameters. According to the parameters used in this study, a submersion during four to five days seems recommendable.

The retention of boron compounds is not uniformly as it depends strongly on the specific weight of the guadua. The natural heterogeneity from lower dense inner walls to higher dense outer walls and from lower dense lower parts to higher dense upper parts makes the homogeneous retention of salts impossible. Therefore, a minimum limit of BAE should be defined to guarantee the preservation quality. Control sampling should be made at the parts with lowest parenchyma content i.e. highest specific weight.

However, all analysis made in this study have shown that the retention of 1-4 kg BAE, which is reached by the actually applied soaking method, is sufficient to guarantee a good protection of the guadua.

ACKNOWLEDGEMENTS

The present study was realized with financial support provided by the German Technical Cooperation Agency (GTZ), the Centro de Investigaciones y Estudios en Biodiversidad y Recursos Genéticos (CIEBREG), the Technological University of Pereira (UTP) and it's Faculty of Environmental Sciences. We thank Dr. Walter Liese and Joerg Stamm for their constructive comments on the manuscript.

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