TECHNICAL PAPER

MATHEMATICAL MODEL TO ESTIMATE OF THE DETERIORATION OF WOODEN POLES IN CONTACT WITH SOIL USED IN RURAL AREAS[1]

JULIO C. MOLINA[2], CARLITO CALIL JÚNIOR[3], ROBERTO R. DE FREITAS[4]

ABSTRACT: In São Paulo State, mainly in rural areas, the utilization of wooden poles is observed for different purposes. In this context, wood in contact with the ground presents faster deterioration, which is generally associated to environmental factors and, especially to the presence of fungi and insects. With the use of mathematical models, the useful life of wooden structures can be predicted by obtaining "climatic indexes" to indicate, comparatively among the areas studied, which have more or less tendency to fungi and insects attacks. In this work, by using climatological data of several cities at São Paulo State, a simplified mathematical model was obtained to measure the aggressiveness of the wood in contact with the soil.

KEYWORDS: durability of wood, decay of wood, wooden poles.

MODELO MATEMÁTICO PARA ESTIMATIVA DA DETERIORAÇÃO DE POSTES DE MADEIRA EM CONTATO COM O SOLO USADOS EM ÁREAS RURAIS

RESUMO: No Estado de São Paulo, principalmente em áreas rurais, é notável a utilização de postes roliços de madeira para diversas finalidades. Neste contexto, observa-se que a madeira, em contato com o solo, deteriora-se mais rapidamente, e essa deterioração está geralmente associada aos fatores ambientais e, principalmente, à presença de insetos e fungos. Com o auxílio de modelos matemáticos, pode ser prevista a vida útil das estruturas de madeira pela obtenção de "índices climáticos", que indicam comparativamente, entre as regiões estudadas, quais possuem maiores e menores propensões ao ataque de fungos e insetos. Neste trabalho, utilizando dados climatológicos de várias cidades do Estado de São Paulo, foi obtido um modelo matemático simplificado de agressividade à madeira em contato com o solo.

PALAVRAS-CHAVE: durabilidade da madeira, apodrecimento da madeira, postes de madeira.

INTRODUCTION

According to FIORELLI et al. (2008), treated logs have been increasingly used in rustic construction, composition of poles, as well as in agricultural sheds. The reforestation species most used as logs are pine and eucalyptus (MOLINA et al., 2009). In addition, natural logs undergo deterioration by rotting in the region that is in contact with the ground, an area called "upwelling region." It is worth mentioning that no material is inherently durable when subjected to environmental actions, and the biological nature of wood makes it susceptible to fungus and insect attacks. However, if the wood is treated, not only it becomes resistant to decomposing organisms, but also to fire, (FONTE & CALIL JUNIOR, 2007). In this context, it is also important to mention that rotting fungi and bacteria are probably one of the wood degradation forms that most commonly leads to extensive material destruction and consequent loss of resistance (HAYGREEN & BOWYER, 1985). However, wood degradation can be evaluated through mathematical models for which equations are proposed to verify the reduction of its properties. There are also kinetic models that consider wood decay properties due to oxidative processes in terrestrial and aquatic environments (APRILE et al., 1999). On the other hand, there are also models for assessing deterioration of

---

[1] Tese de doutorado do terceiro autor que teve apoio financeiro da CPFL.
[2] Pós-Doutorando, Departamento de Engenharia de Estruturas, EESC/USP, juliocm@sc.usp.br.
[3] Professor Titular, Departamento de Engenharia de Estruturas, EESC/USP, calil@sc.usp.br.
[4] Professor das Faculdades Integradas Dom Pedro II, robertorfreitas@terra.com.br.
Recebido pelo Conselho Editorial em: 6-7-2010
Aprovado pelo Conselho Editorial em: 19-6-2011

wooden poles above the soil (SCHEFFER, 1971). This work aims to obtain a simplified mathematical model of aggression for wood in contact with the ground, using weather data provided by IAC – Instituto Agronômico de Campinas, in several cities of São Paulo State, Brazil.

Leicester's model

LEICESTER et al. (2003) proposed a mathematical model to verify the decomposing of wood in contact with soil, based on monitoring small poles for over 30 years in Australia. The model considers the existence of a lag time to beginning of the rotting process, which, after its onset, evolves at a constant speed ("r" ratio); a new start time may occur, with the establishment of a constant decay with maintenance of performance (Figure 1).

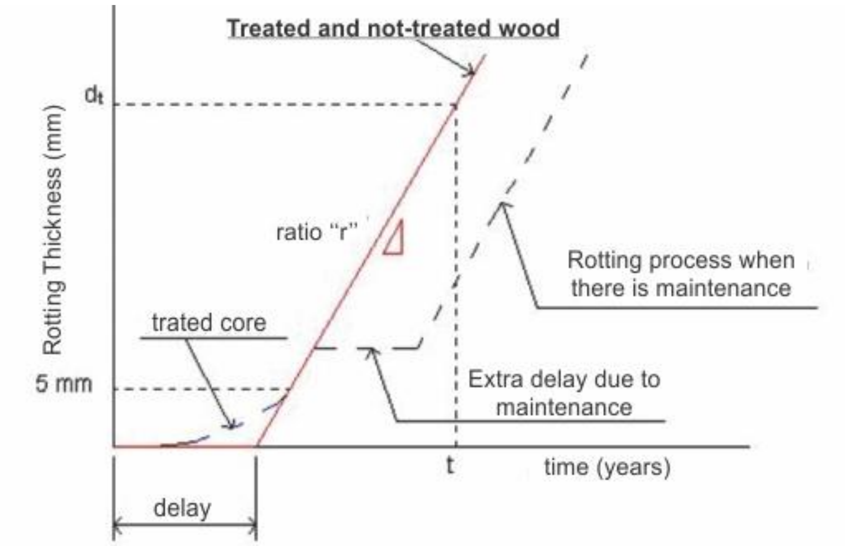

FIGURE 1. Idealized decay relatio.

This model is used to determine the "Climatic Index" - I_{ig}, which depends on the functions $f(R_{mean})$ and $g(T_{mean})$, which are dependent on "Average Annual Precipitation" - R_{mean} and "Average Annual Temperature" - T_{mean}, respectively, being N_{dm} the number of dry months per year, defined as a dry month those which the average rainfall is less than or equal to 5 mm (Equations 1-5).

$$I_{ig} = f(R_{mean})^{0,3} \times g(T_{mean})^{0,2} \quad (1)$$

$$f(R_{mean}) = \begin{cases} 0 & \text{If } R_{mean} \leq 250 \text{ mm or } N_{dm} > 6 \\ f_0(R_{mean}) \times \left(1 - \frac{N_{dm}}{6}\right) & \text{If } R_{mean} > 250 \text{ mm and } 0 \leq N_{dm} \leq 6 \end{cases} \quad (2)$$

$$f_0(R_{mean}) = 10 \times [1 - e^{-0,001(R_{mean}-250)}] \quad (3)$$

$$g(T_{mean}) = \begin{cases} 0 & \text{If } T_{mean} \leq 5ºC \\ -1 + 0,2 \times T_{mean} & \text{If } 5 < T_{mean} \leq 20ºC \\ -25 + 1,4 \times T_{mean} & \text{If } T_{mean} > 20ºC \end{cases} \quad (4)$$

LEICESTER (2001) considers the influence of wood types present in a structural element, as well as the speed of decay for different types of wood (Figure 2).

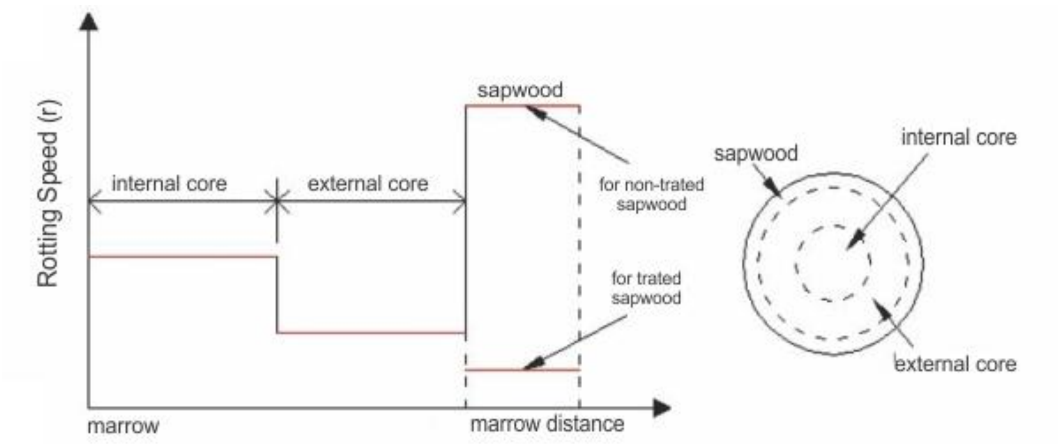

FIGURE 2. Wood relative decay.

To determine the decomposing initiation time of the process (lag) and the speed of decay (r), mathematical equations (equations 5-9) are adopted along with tabulated parameters (Table 1).

External core

$$r_{un,\,heart,\,stake} = A \times I_{ig} \quad (5)$$

Internal Corte

$$lag_{un,\,core,\,stake} = 0,3 \times lag_{un,\,heart,\,stake} \quad (6)$$

$$r_{un,\,core,\,stake} = 3 \times r_{un,\,heart,\,stake} \quad (7)$$

Sapwood

$$lag_{un,\,sap,\,stake} = 0,5 \times lag_{un,\,heart,\,dc\,4,\,stake} \quad (8)$$

$$r_{un,\,sap,\,stake} = 2 \times r_{un,\,heart,\,dc\,4,\,stake} \quad (9)$$

where,

$r_{un,core,stake}$ - rate of decay of new, untreated wood in experimental poles;
$r_{un,heart,stake}$ - decay speed rate of untreated core in experimental poles;
$r_{un,sap,stake}$ - decay speed rate of untreated sapwood in experimental poles;
$r_{un,heart,dc4,stake}$ - decay speed rate of untreated external core of species of class 4 durability;
$lag_{un,core,stake}$ - initial time of decay of new, untreated wood in experimental poles;
$lag_{un,heart,stake}$ - initial time of decay of untreated core in experimental poles;
$lag_{un,sap,,stake}$ - initial time of decay of untreated sapwood in experimental poles, and
$lag_{un,heart,dc4,stake}$ - initial time of decay of external core of species of class 4 durability.

TABLE 1. Parameters of decay of untreated external core of wood.

Durability Class (AS 5604-2005)	A	Initial Time $lag_{un,heart,stake}$ (years)
Class 1	0.20	6
Class 2	0.55	4
Class 3	0.80	2
Class 4	1.85	1

MATERIAL AND METHODS

In the present study, a simplified mathematical model was obtained to describe the decaying wood stakes in contact with the ground. This study took into account a total of 113 municipalities in the State of São Paulo, Brazil seeking to encompass locations that were representative across the whole state. Thus, we considered coastal towns and also inner cities in the State. Climate data was provided by IAC - Instituto Agronômico de Campinas, and used to determine the values of I_{ig}, according to the initial model proposed by LEICESTER (2001), and subsequently, to calculate $I_{ig;simplified}$, according to the simplified model proposed in this work. It is worth mentioning that although data from 113 meteorological stations located in various São Paulo State municipalities, determination of I_{ig} and $I_{ig;simplified}$ values was performed only for stations that had a minimum record period of five years until the collection date. For this reason 11 weather stations were excluded from the study. This decision avoided the analysis of values that were not very representative in terms of annual variations in climate. Moreover, in order to determine whether the cities classified by the regions of decay (Table 5) had populations of temperature, precipitation and different dry months, F-test (Snedecor distribution) was applied to the variables, dividing them into two populations; I_{ig} lower than 2.50 (I_{ig} <2.50) and I_{ig} higher than 2.50 (I_{ig} > 2.50). F-test was carried out at a significance level of 5% ($\alpha = 0.05$).

RESULTS AND DISCUSSION

The descriptive statistics of climate data of the municipalities studied is presented for temperature, annual rainfall and dry months (Table 2).

TABLE 2. Statistics of climate data.

Statistics	Temperature (°C)	Annual Precipitation (mm)	N_{dm} - dry months
Mean	22.6	1446	0.8
Minimum	15.1	1165	0.0
Maximum	25.7	2514	1.9
Amplitude	10.6	1349	1.9

The absolute frequency distributions are given as a function of temperature, annual rainfall and dry months from histograms with normal distribution curve (Figures 3-5).

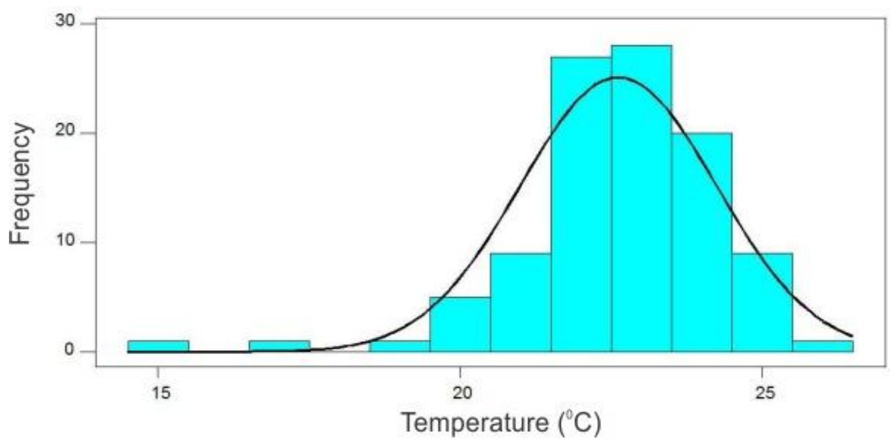

FIGURE 3. Histogram of absolute frequency of the average temperatures in the municipalities of the state of São Paulo.

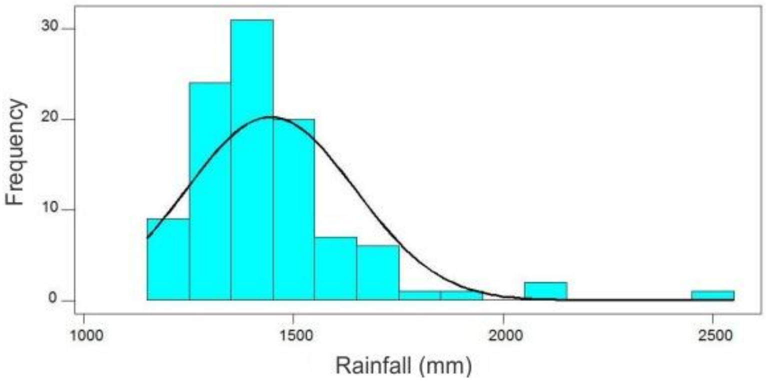

FIGURE 4. Histogram of absolute frequency of the annual precipitations in the municipalities of the state of São Paulo.

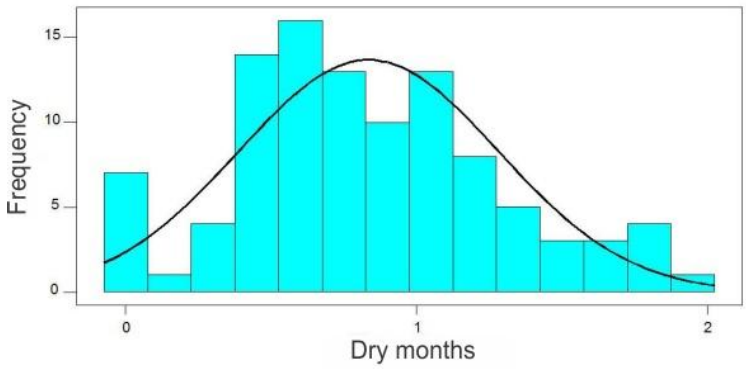

FIGURE 5. Histogram of absolute frequency of the dry months in the municipalities of the state of São Paulo.

Application of Leicester Model

Descriptive statistics (Table 3) was carried out for the values obtained with the application of climate data applied to the initial Leicester model, available in LEICESTER et al. (2003).

TABLE 3. Statistics of the climate data.

Statistics	I_{ig}
Mean	2.48
Minimum	2.04
Maximum	2.85
Amplitude	0.81

Considering the class of aggressiveness of the initial model, we obtained the distribution of municipalities in relation to this classification (Table 4). The descriptive statistics for variables of the populations of I_{ig} <2.50 and I_{ig} > 2.50 were also obtained (Table 5).

TABLE 4. Representative Climate Index of four aggressiveness categories.

Rotting Zone	Representative I_{ig}	Number of Municipalities
A	0.5	0
B	1.5	0
C	2.5	49
D	3.0	53

TABLE 5. Descriptive statistics for the variables of I_{ig} population.

Statistics	Temperature (°C)		Precipitation (mm)		N_{dm} - dry months	
	$I_{ig<2.50}$	$I_{ig>2.50}$	$I_{ig<2.50}$	$I_{ig>2.50}$	$I_{ig<2.50}$	$I_{ig>2.50}$
Mean	21.5	23.6	1405	1483	0.87	0.80
Minimum	15.1	21.5	1165	1174	0.25	0.00
Maximum	24.1	25.7	1726	2514	1.88	1.75

F-Test for temperature

H_0: the variance of temperatures for $I_{ig<2.50}$ and $I_{ig>2.50}$ are similar;

H_1 the variance of temperatures for $I_{ig<2.50}$ and $I_{ig>2.50}$ are not similar.

$F_{obtained}$: 2.845 $F_{critical}$: 1.596 P-Value: 0.0001

Conclusion: reject H_0

F-Test for precipitation

H_0: the variance of precipitation for $I_{ig<2.50}$ and $I_{ig>2.50}$ are similar;

H_1: the variance of precipitation for $I_{ig<2.50}$ and $I_{ig>2.50}$ are not similar.

$F_{obtained}$: 3.307 $F_{critical}$: 1.604 P-Value: 0.000025

Conclusion: reject H_0

F-Test for dry months

H_0: the variance of dry months for $I_{ig<2.50}$ and $I_{ig>2.50}$ are similar;

H_1: the variance of dry months for $I_{ig<2.50}$ and $I_{ig>2.50}$ are not similar.

$F_{obtained}$: 1.220 $F_{critical}$: 1.604 P-Value: 0.244

Conclusion: not reject H_0

There is no statistical evidence that the populations of temperature and precipitation are the equivalent for I_{ig} <2.50 and I_{ig} > 2.50. However, there is statistical evidence that the populations of dry months for I_{ig}<2.50 and I_{ig}> 2.50 are comparable. Therefore, one can conclude that the variable N_{dm} (dry months) is not for this data set in analysis a significant variable contributing to the determination of I_{ig}.

Proposition of the simplified model

The simplification proposed herein is the removal of the variable " N_{dm} - dry months", which is the most difficult to obtain. This proposition is justified, as when carrying out the F-test for this variable for the population of I_{ig}<2.50 and I_{ig}>2.50, no evidence has been obtained about the statistical difference between these data sets. Thus, the simplification of the model started with only the removal of the variable N_{dm}. The first model to be used is given below:

Simplified Leicester Model

$$I_{ig:simplificado} = f(R_{mean})^{0,3} \times g(T_{mean})^{0,2} \qquad (10)$$

$$f(R_{mean}) = \begin{cases} 0 & \text{If } R_{mean} \leq 250 \text{ mm} \\ f_0(R_{mean}) & \text{If } R_{mean} > 250 \text{ mm} \end{cases} \qquad (11)$$

$$f_0(R_{mean}) = 10 \times [1 - e^{-0,001(R_{mean}-250)}] \qquad (12)$$

$$g\,(T_{mean}) = \begin{cases} 0 & \text{If } T_{mean} \le 5ºC \\ -1 + 0,2 \times T_{mean} & \text{If } 5 < T_{mean} \le 20ºC \\ -25 + 1,4 \times T_{mean} & \text{If } T_{mean} > 20ºC \end{cases} \qquad (13)$$

It was compared the descriptive statistics for th I_{ig} and $I_{ig;\ simplified}$ (Table 6).

TABLE 6. Descriptic statistics of I_{ig} AND $I_{ig;simplified}$.

Statistics	I_{ig}	$I_{ig;\ simplified}$
Mean	2.48	2.60
Minimum	2.04	2.12
Maximum	2.85	2.86
Amplitude	0.81	0.74

The dispersion of I_{ig} and $I_{ig;\ simplified}$ values was also compared (Figure 6). One can observe in this case a positive displacement (increased values) of the population of data as well as the average.

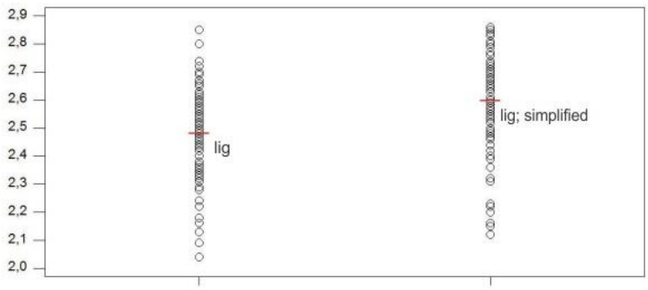

FIGURE 6. Populations of I_{ig} and $I_{ig:simplified}$.

To validate the simplification proposed, it was necessary to observe whether there was correlation between the values of the current model and the simplified model, considering the linear regression and the regression of residuals for I_{ig} and $I_{ig;\ simplified}$, respectively (Figures 7-8). It was observed that the r^2 value - coefficient of determination - for this regression was 83.3%. According to ANDERSON et al. (2002), the coefficient of determination r^2 can be expressed as a percentage of the sum of squares that can be explained by the regression proposed, ranging from 0 to 100%.

It can be observed (Figure 7) that until about $I_{ig;\ simplified}$ of 2.50, there was no considerable dispersion of values around the regression line. However, above 2.5, data dispersion around the regression line was high. Until $I_{ig;\ simplified}$ values between 2.50, the values of $I_{ig;\ simplified}$ of 2.50 and I_{ig} were more similar.

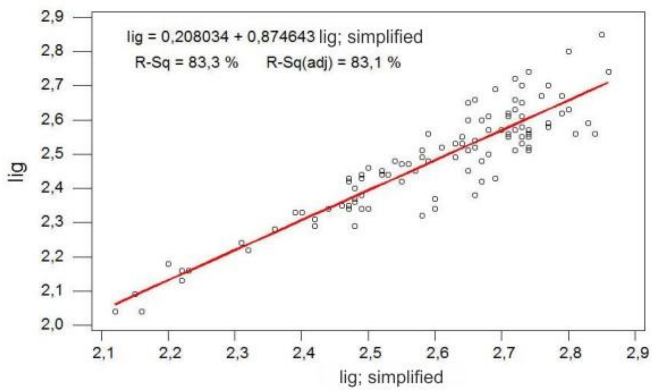

FIGURE 7. Regression I_{ig} vs. $I_{ig;simplified}$.

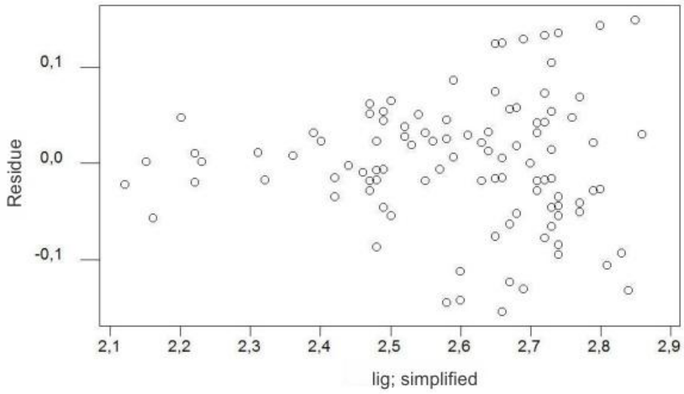

FIGURE 8. Residues vs. $I_{ig;simplified}$.

It is observed that the correlation between I_{ig} and $I_{ig;\ simplified}$ has no independence of errors due to the $I_{ig;\ simplified}$ function. This feature can be explained by considering that for the same value of the reduction factor (1 - N_{dm}/6), the difference between the values of I_{ig} and $I_{ig;\ simplified}$ increases proportionally to the second variable. Adopting the same aggressiveness classification as used by LEICESTER (2001), we obtained the distribution of $I_{ig;\ simplified}$ (Table 7). We also present descriptive statistics for the populations of $I_{ig;\ simplified}$ (Table 8).

TABLE 7. Climate index (representative) of four aggressiveness classes.

Rotting Zone	Representative $I_{ig;\ simplified}$	Number of Municipalities
A	0.5	0
B	1.5	0
C	2.5	28
D	3.0	74

TABLE 8. Descriptive statistics of the parameters of the populations of $I_{ig;simplified}$.

Statistics	Temperature (°C)		Precipitation (mm)	
	$I_{ig;\ simplified}$ <2.50	$I_{ig;\ simplified}$ >2.50	$I_{ig;\ simplified}$ <2.50	$I_{ig;\ simplified}$ >2.50
Mean	20.8	23.3	1393	1465
Minimum	15.1	21.3	1167	1165
Maximum	22.2	25.7	1726	2514

We carried out the F-test to identify whether it is possible to consider that the two populations I_{ig} and $I_{ig;\ simplified}$ are similar. Thus, for $\alpha = 0.05$ we have:

F-test I_{ig} and $I_{ig;\ simplified}$

H_0: the variances of I_{ig} and $I_{ig;\ simplified}$ are similar;

H_1: the variances of I_{ig} and $I_{ig;\ simplified}$ are not similar.

F_{obtido}: 1.087 $F_{crítico}$: 1.389 P-Value: 0.338

Conclusion: not reject H_0

From the test above, we verify that there is statistical evidence that the populations I_{ig} and $I_{ig;\ simplified}$ are equivalent.

According to the previous procedure, F-test was performed between the populations of temperature and precipitation, to verify whether the populations of these parameters $I_{ig;\ simplified}$ differ by dividing them again into two populations: municipalities with $I_{ig;\ simplified}$ lower than 2.50 ($I_{ig;}$

simplified <2.50) and municipalities with $I_{ig;\ simplified}$ greater than 2.50 ($I_{ig;\ simplified} > 2.50$). Thus for a significance level of 5% ($\alpha = 0.05$) we have:

F-Test for temperature

H_0: the variances of temperatures for $I_{ig;\ simplified\ <2.50}$ and $I_{ig;\ simplified\ >2.50}$ are similar;

H_1: the variances of temperatures for $I_{ig;\ simplified\ <2.50}$ and $I_{ig;\ simplified\ >2.50}$ are not similar.

$F_{obtained}$: 2.517 $F_{critical}$: 1.639 P-Value: 0.001

Conclusion: reject H_0

F-Test for precipitation

H_0: the variance of precipitation for $I_{ig;\ simplified\ <2.50}$ and $I_{ig;\ simplified\ >2.50}$ are similar;

H_1: the variance of precipitation for $I_{ig;\ simplified\ <2.50}$ and $I_{ig;\ simplified\ >2.50}$ are not similar.

$F_{obtained}$: 2.062 $F_{critical}$: 1.766 P-Value: 0.019

Conclusion: reject H_0

It was observed that there is no statistical evidence that the populations of temperature and precipitation are similar to the population $I_{ig;\ simplified} < 2.50$ and $I_{ig;\ simplified} > 2.50$. In conclusion, in this case the removal of the N_{dm} variable from the model proposed by Leicester does not influence the variables temperature and precipitation in determining the aggressiveness index, as the population values of these variables remain different for $I_{ig;\ simplified} < 2.50$ and $I_{ig;\ simplified} > 2.50$ for the data set studied.

Regression Analyses

Linear regression between I_{ig} and $I_{ig;\ simplified}$ values for the top ten most aggressive municipalities according to the I_{ig}, shows a low coefficient of determination, $r^2 = 36.6\%$ (Figure 9).

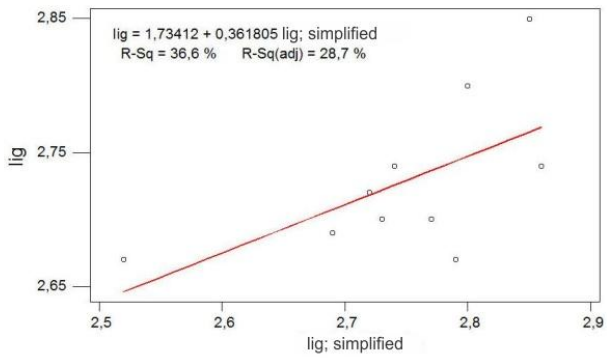

FIGURE 9. Regression between I_{ig} and $I_{ig;\ simplified}$ for the municipalities with highest I_{ig} values.

However, by making a linear regression between the I_{ig} and $I_{ig;\ simplified}$ values for the ten municipalities with the lowest I_{ig}, a high coefficient of determination, $r^2 = 95.5\%$ is obtained (Figure 10).

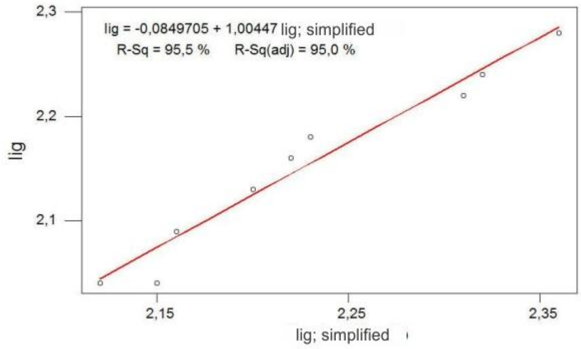

FIGURE 10. Regression of the I_{ig} and $I_{ig;simplified}$ for the municipalities with the least values of I_{ig}.

Considering a linear equation:

$$y = ax + b \qquad (14)$$

For the values of the x-axis to be equal to the y-axis, it is necessary that the linear coefficient (b) to be zero and the value of the angular coefficient (a) of the line to equal to 1 (equation 15). In other words, if the I_{ig} and $I_{ig;\ simplified}$ values are numerically equal to the slope, it should be equal to 1 and the linear coefficient be equal to zero.

$$y = 1 \cdot x + 0 \qquad (15)$$

Thus, the higher the value in module for the linear coefficient (b) and the slope (a), the greater the distance from the identity line (y = x). From the comparison (Table 9) of the values of linear and angular coefficients of the linear regression performed to observe the values on which passages were more similar, it was found that the coefficient values were very close to the values for the identity line only for regression low I_{ig} values. This means that the difference between I_{ig} and $I_{ig;\ simplified}$ was virtually constant in this case, and this correlation was closest to a straight line parallel to the identity, and thus it was adopted. The other regressions performed were not close to be the identity line (Figure 11). The error between the parallel lines in this case was estimated by the regression equation (equation 16).

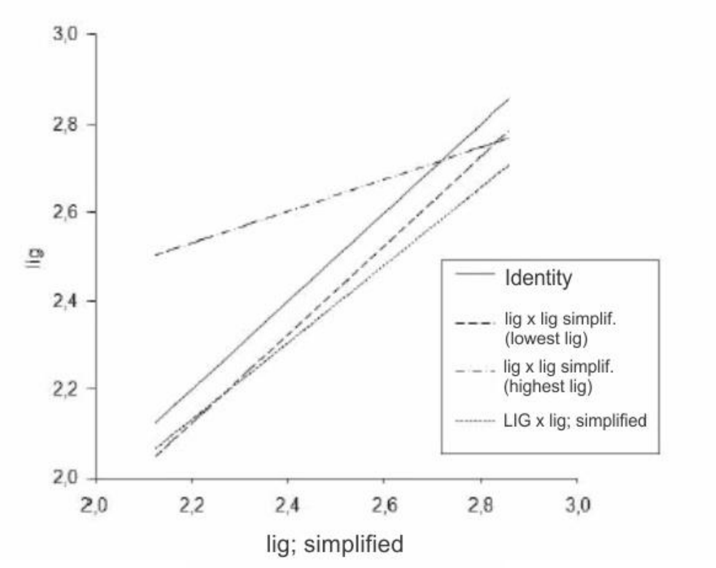

FIGURE 11. Difference between the regressions considered.

TABLE 9. Coefficient values of the regressions I_{ig} x $I_{ig;simplified}$.

Regression	Coefficient		r^2
	Angular (a)	Linear (b)	
I_{ig} x $I_{ig;\ simplified}$ (Figura 7)	0.874643	0.208034	83.3%
I_{ig} x $I_{ig;\ simplified}$ (highest I_{ig})	0.3621805	1.73412	36.6%
I_{ig} x $I_{ig;\ simplified}$ (lowest I_{ig})	1.00447	- 0.0849705	95.5%

The populations of I_{ig} and $I_{ig;\ simplified}$ are not significantly different after the removal of the variable N_{dm} (dry months). However, the higher the I_{ig} value, the greater the difference between I_{ig} and $I_{ig;\ simplified}$ values obtained. We applied the linear regression (equation 15) for the ten lowest I_{ig} values (Figure 11) and their respective $I_{ig;\ simplified}$, to all $I_{ig;\ simplified}$ values in order to obtain $I_{ig'}$ for all cities considered in analysis. Thus, it was possible to obtain the estimated error in this case.

$$I'_{ig} = 1,00447 \text{ x } I_{ig;simplified} - 0,0849705 \qquad (16)$$

Subtracting the $I_{ig'}$ value from $I_{ig,}$ the error estimate (E) is obtained (equation 17). The value of average error (E_m) estimation was then determined (equation 18).

$$E = I_{ig} - I'_{Ig} \tag{17}$$

$$E_m = \sum_{i=1}^{n} \frac{I_{ig} - I'_{Ig}}{n} \tag{18}$$

The value of mean error (E_m) was -0.0438074, in this case. We then obtained the final model adjusted to the data of São Paulo State (equation 16), which will be called the Climate Index of the State of Sao Paulo for decaying of wood in contact with the ground.

$$I_{LL-SP} = 1,00447 \times I_{ig:simplified} - 0,0849705 - 0,0438074 \tag{19}$$

$$I_{LL-SP} = 1,00447 \times I_{ig:simplified} - 0,12878 \tag{20}$$

Thus, two models are proposed, the simplified model (equation 21), which was shown to have little variation with respect to the initial Leicester model, and the adjusted model to the State of São Paulo (equation 22). The comparison of the results (Table 10) obtained for each of the models did not show major differences.

$$I_{ig:simplified} = f(R_{mean})^{0,3} \times g(T_{mean})^{0,2} \tag{21}$$

$$I_{LL} = 1,00447 \times f(R_{mean})^{0,3} \times g(T_{mean})^{0,2} - 0,12878 \tag{22}$$

$$f(R_{mean}) = \begin{cases} 0 & \text{If } R_{mean} \leq 250 \text{ mm} \\ f_0(R_{mean}) & \text{If } R_{mean} > 250 \text{ mm} \end{cases} \tag{23}$$

$$f_0(R_{mean}) = 10 \times [1 - e^{-0,001(R_{mean} - 250)}] \tag{24}$$

$$g(T_{mean}) = \begin{cases} 0 & \text{If } T_{mean} \leq 5^{o}C \\ -1 + 0,2 \times T_{mean} & \text{If } 5 < T_{mean} \leq 20^{o}C \\ -25 + 1,4 \times T_{mean} & \text{If } T_{mean} > 20^{o}C \end{cases} \tag{25}$$

TABLE 10. Comparation of I_{ig}, $I_{ig;simplified}$ and I_{LL} values.

Municipalities	I_{ig}	$I_{ig, simplified}$	I_{LL}	Municipalities	I_{ig}	$I_{ig, simplified}$	I_{LL}
Araçatuba	2.63	2.80	2.68	Itapeva	2.46	2.50	2.38
Barretos	2.56	2.84	2.72	Lins	2.59	2.77	2.65
Bauru	2.56	2.71	2.59	Matão	2.52	2.66	2.54
Campinas	2.45	2.57	2.45	Penápolis	2.62	2.79	2.67
Campos do Jordão	2.04	2.12	2.00	São José do Rio Preto	2.59	2.83	2.71
Capão Bonito	2.16	2.23	2.11	Ubatuba	2.85	2.85	2.73
Itapetininga	2.33	2.39	2.27	Valparaiso	2.55	2.74	2.62

CONCLUSIONS

By applying the initial model of degradation of wood in contact with the ground I_{ig}, and performing the analysis of the variables "Temperature", "Precipitation" and "Dry Months" for populations of $I_{ig} < 2.50$ and $I_{ig} > 2.50$, we concluded that there were no statistical evidence of difference between these two populations for the variable "dry months". In order to simplify the initial model, and to determine $I_{ig;\ simplified}$ values, we compared the population of these values with the I_{ig} population, but this did not achieving statistical significance, indicating that there is difference between these two populations of climatic indices. The best regression between I_{ig} and $I_{ig;\ simplified}$ was that carried out with the lowest ten I_{ig} values and their $I_{ig;\ simplified}$, which is the closest to the identity line. Through this regression, it was possible to propose a final adjusted model of climate index for decaying wood in contact with the ground, the $I_{LL\text{-}SP}$. This model was adjusted to data originated from the State of São Paulo, which did not require the variable N_{dm} (dry months) to obtain values very close to the initial values obtained with the Leicester Model. So, two alternative models are possible to the initial Leicester model: the $I_{ig;\ simplified}$ and the $I_{LL\text{-}SP}$. Therefore, for data analysis, an appropriate simplification of the Leicester model can be considered.

ACKNOWLEDGEMENTS

We thank IAC - Instituto Agronômico de Campinas, an agency belonging to the Department of Agriculture and Food Supply of the State of São Paulo, for providing the climate data.

REFERENCES

ANDERSON, D.R.; SWEENEY, D.J.; WILLIAMS, T.A. *Estatística aplicada à administração e à economia*. Tradução de Luiz Sérgio de Castro Paiva. 2.ed. São Paulo: Ed. Pioneira, 2002. p. 439-509, 2002.

APRILE, F.M.; DELITTI, W.B.C.; BIANCHINI JR., I. Proposta de modelo cinético da degradação de laminados de madeiras em ambientes aquático e terrestre. *Revista Brasileira de Biologia*, Rio de Janeiro, v.59, n.3, ago. 1999.

FIORELLI, J.; INO, A.; DIAS, A.A. Sistema modular em madeira de reflorestamento e cobertura com telha ecológica. *Madeira: Arquitetura e Engenharia*, São Carlos, v.9, n.22, jan./jun. 2008.

FONTE, T.F.; CALIL JUNIOR, C. Pontes protendidas de madeira: alternativa técnico-econômica para vias rurais. *Engenharia Agrícola*, Jaboticabal, v.27, p.552-559, 2007.

HAYGREEN, J.G.; BOWYER J.L. Forest products and wood service – an introduction. Iowa: Iowa University, 1985. 495 p.

LEICESTER, R.H. *Engineered durability for timber construction*. Australia: CSIRO, 2001. p.2-12, 2001.

LEICESTER, R.H.; NGUYEN, C.H.M.N.; FOLIENTE, G.C.; MCKENZIE, C. An engineering model for the decay of timber in ground contact. In: PROCEEDINGS ANNUAL MEETING OF THE INTERNATIONAL RESEARCH GROUP ON WOOD PRESERVATION, 34., 2003, Stockholm.

MOLINA, J.C.; CALIL JUNIOR, C.; CARREIRA, M.R. Pullout strength of axially loaded steel rods bonded in glulam at a 450 angle to the grain. *Materials Research*, São Carlos, v.12, n.4, 2009.

SCHEFFER, T. C. A climate index for estimating potencial for decay in wood structures above ground. *Forest Products Journal*, Madison, v.1, n.10, 1971.