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# MODELING OF WATER INFILTRATION IN SOIL CULTIVATED WITH EUCALYPTUS AND PASTURE[1]

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**ABSTRACT -** The rio Doce river basin has great silvicultural potential, areas cultivated with pasture are converted to forest plantations. Physical processes in the soil, especially the infiltration water, are very dependent on the type and management of its coverage. The objective of the present study was to evaluate the differences between rates of water infiltration in soils submitted to eucalyptus plantations and pasture and adjust empirical models of infiltration. The experiment was conducted at four sites in the Rio Doce river basin, MG, Brazil, where two were planted with eucalyptus and two with pasture. Five infiltration tests using the concentric rings method were performed in each area. Results show that the soils infiltration rate with eucalyptus plantations were higher than those found in soils from pasture areas, with stable infiltration rates of 78 and 165 mm $h^{-1}$ in eucalyptus and 47 and 50 mm $h^{-1}$ in pasture. The model of Horton indicated the highest adjusted confidence index for the four sites analyzed.

**Keywords**: Rio Doce river basin. Horton. Kostiakov-Lewis. Philip.

## MODELAGEM DA INFILTRAÇÃO DA ÁGUA EM SOLOS CULTIVADOS COM EUCALIPTO E PASTAGEM

**RESUMO -** A bacia hidrográfica do rio doce tem grande aptidão silvicultural, áreas cultivadas com pastagem são convertidas em plantios florestais. Os processos físicos do solo, em especial a infiltração da água, são de grande dependência do tipo e manejo da sua cobertura. O objetivo desse trabalho foi avaliar as diferenças entre as taxas de infiltração de água nos solos sob plantios florestais de eucalipto e pastagem e ajustar modelos empíricos de infiltração. O experimento foi realizado em quatro sítios da bacia hidrográfica do rio Doce-MG, dois cultivados com eucalipto e dois com pastagem. Cinco ensaios de infiltração pelo método dos anéis concêntricos foram realizados em cada área. Os resultados mostram que os valores de taxa de infiltração nos solos sob plantios de eucalipto foram superiores aqueles encontrados nos solos sob pastagem, com valores de taxa de infiltração estável de 78 e 165 mm $h^{-1}$ no eucalipto e 47 e 50 mm $h^{-1}$ na pastagem. O modelo de Horton apresentou os maiores valores de índice de confiança ajustado para os quatro sítios analisados.

**Palavras-chave**: Bacia do rio Doce. Horton. Kostiakov-Lewis. Philip.

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## INTRODUCTION

More than twenty million hectares of the lands cultivated with forest plantations on the planet are eucalyptus forests (GIT FORESTRY CONSULTING'S BLOG, 2010). In Brazil alone, the area planted today is approximately four and a half million hectares, equivalent to one half percent of the national territory.

The forest sector in the Rio Doce river basin is well developed, where large companies in the energy and cellulose industry are encountered. Because the majority of the land occupation in the basin is for grazing and is mostly degraded, it is expected that there be a significant changes in soil use from this coverage for eucalyptus forests. According to research conducted by the Technological Foundation Center of Minas Gerais - CETEC, 95% of river basin lands consist of pastures and clearings.

Some characteristics and physical processes of soil, particularly the infiltration of water, are related to the type of soil coverage and management, among other factors (MARTINS et al., 2003; WARD; TRIMBLE, 2004; SILVA, et al, 2008; GERMER et al., 2010). Several studies have shown that water infiltration of soil in areas of forest, including eucalyptus, are greater than under other types of coverage, especially pasture (PANACHUKI et al., 2006; ANTONELI; THOMAS, 2009; MENDONÇA et al., 2009; PINHEIRO et al., 2009; SILVA et al., 2011). Forest coverage decreases the kinetic energy of rain drops, improving the physical characteristics of the soil, and increasing infiltration rate and residence time of water in the basin (TURNBULL et al., 2010).

Procedural and empirical models can be used to describe the process of soil water infiltration, presenting both advantages and disadvantages. Those simulating physical processes of greater complexity can be extrapolated to any condition, requiring an input parameter and a larger number of independent variables. As for empirical models, although they are simpler, they are site specific. The empirical models of Horton, Kostiakov-Lewis and Philip are widely used to describe the infiltration process. These present parameters that may be estimated from regression equations fit to infiltration data measured in the field.

Based on these facts, the objective of the preset study was to evaluate the effect of different coverages (eucalyptus and pasture) on water infiltration rates and assess the adequacy of the models of Horton, Kostiakov-Lewis and Philip to estimate the infiltration rate (Ti) and accumulated infiltration (I) of water in the soil.

## MATERIAL AND METHODS

The study was conducted at four different sites in the Rio Doce river basin, MG, Brazil, being two cultivated with eucalyptus forest and two of pasture. Plantations were composed of hybrid Eucalyptus *grandis* x *urophylla* at seven years old. In sites with pasture, forage (*Brachiaria decumbens*) was established after harrowing. For more than two decades the pasture has been used for the same purpose, grazing of dairy cattle.

The site of Belo Oriente is located at 19º18'S and 42º22'W in soil classified as typical Latosolic Dystrophic Haplic Cambisol with clayey texture (Table 1). Total average annual rainfall is 1163 mm, while average temperature and humidity are 25.2 °C and 65.2%, respectively.

**Table 1**. Textural analysis and physical characteristics of the four soils studied in the rio Doce river basin. Represents the mean values of five samples.

| Site | Land | Soil type | Depth m | Sand % | Silt % | Clay % | $d_s$ g $cm^{-3}$ | p (%) |
|---|---|---|---|---|---|---|---|---|
| Belo Oriente | Eucalyptus | CXbd | 0.2 - 1.0 | 32 | 12 | 56 | 1.10 | 53 |
| Antônio Dias | Eucalyptus | CXbd | 0.2 – 1.0 | 47 | 14 | 39 | 1.09 | 62 |
| Açucena | Pasture | CXbd | 0.1 – 0.3 | 48 | 10 | 43 | 1.40 | 35 |
| Peçanha | Pasture | LVd | 0.1 – 0.3 | 32 | 10 | 58 | 1.38 | 49 |

CXbd: Latosolic Dystrophic Haplic Cambisol; LVd: Red Latosol; ds: Density of the soil (volumetric ring method); dp: Density of the particles (volumetric balloon method); p: Porosity (1-dsdp-1)*100.

The site Antônio Dias, also cultivated with Eucalyptus, is located at 19º28'S and 42º49'W, near the village of Cocais das Estrelas in Latosolic Dystrophic Haplic Cambisol with sandy-loamy texture (Table 1). The total average annual precipitation for the region is 1281 mm, while average temperature and relative humidity are 20.3 ºC and 71.2%, respectively.

The site with pasture known as Acucena is located at 18°37'S and 42°33'W, near the city of Açucena in an area of Latosolic Dystrophic Haplic Cambisol with clay-sandy texture (Table 1). In this region the climatic conditions are identical to those of the eucalyptus plantation of Belo Oriente.

The second site with pasture, Peçanha, is located at 19°4'S and 42°21'W, near the city of Peçanha, in an area of typic distrophic Red Latosol with clayey texture (Table 1). Average total annual

rainfall and temperature are 1180 mm and 21 °C, respectively.

The Ti was measured by the concentric ring method as described by Forsythe (1975). Dimensions of the rings were 0.30 and 0.15 m in internal diameter, each measuring 0.30 m in height. They were introduced vertically and concentrically to a depth of 0.1 m in the soil.

Both rings were filled with water and with the aid of a graduated ruler, vertical infiltration of water into the cylinder was recorded at defined time (t) intervals. The volume of water in the outer ring was constantly renewed, maintaining the same hydraulic head throughout the process.

The stable infiltration rate ($Ti_e$) and the end of the test occurred after repetition of four consecutive readings of the same value. In all, five trials were conducted at each site during the same period of the year (november 24 to 28, 2010), with values of volumetric water content in the soil between 17 and 20%. Values of field capacity in Belo Oriente, Antônio Dias, Açucena and Peçanha were 23.8, 24.1, 29.0 and 35.0%, respectively. Assays were performed within a experimental plot 30 x 30 meters.

Construction of the curves for Ti and I at each site was performed from the plot of mean time values (of the five trials) *versus* infiltration rate or infiltrated depth.

With the infiltration rate obtained by the ring infiltrometer method, equations were adjusted to the infiltration rate versus time, according to empirical models developed by Horton, Kostiakov-Lewis and Philip, as described in equations 1, 2 and 3, below.

$$Ti = Ti_f + (Ti_i - Ti_e)e^{-\beta t} \quad (1)$$

$$Ti = \kappa\alpha\, t^{\alpha-1} + Ti_e \quad (2)$$

$$Ti = \beta + \frac{1}{2}\kappa t^{\frac{1}{2}} \quad (3)$$

where,
Ti – infiltration rate at a determined instant, mm $h^{-1}$;
$Ti_i$ – initial infiltration rate, mm $h^{-1}$;
$Ti_e$ – stable infiltration rate, mm $h^{-1}$;
t – infiltration time, h;
$\beta$, $k$ and $\alpha$ – statistically determined parameters based on measured values of infiltration and time.

These parameters were estimated by nonlinear regression. To assess the degree of fit of models the adjusted confidence index (c') was used, which is calculated by the product of the correlation coefficient (r) and adjusted concordance index (d') proposed by Legates e McCabe Jr. (1999), obtained from the equation below.

$$d' = 1 - \frac{\sum_{i=1}^{j}\left|O_i - E_i\right|}{\sum_{i=1}^{j}\left(\left|E_i - \overline{O_i}\right| + \left|O_i - \overline{O_i}\right|\right)} \quad (4)$$

where j is the number of observations, $O_i$ the value measured in the field, $\bar{O}_i$ the average of the measured values and $E_i$ the value estimated by the model.

## RESULTS AND DISCUSSION

The parameters of the models and the simulated curves of Ti and I as a function of time are indicated in Table 2 and Figure 1. In addition to the average experimental value found with standard deviations of 14, 100, 2 and 17 mm for the sites of Belo Oriente, Antonio Dias, Acucena and Peçanha, respectively. Table 3 shows the c' values encountered between the measured and simulated values.

In general, the highest values of Tie were found in sites cultivated with eucalyptus forest, with stable values of 78 and 165 mm $h^{-1}$, respectively, for Belo Oriente and Antônio Dias.

Differences were observed in sites with pasture. In Açucena, for example, with the same soil type as the site Belo Oriente, value of Tie was 47 mm $h^{-1}$. In the other site with pasture, Peçanha, values of the infiltration rate were slightly higher but not greater than those encountered in sites with eucalyptus. In pastures, compaction due to cattle trampling causes a reduction in infiltration, increased runoff and increased soil erosion (THOMAZ, 2007).

It is noteworthy that measured infiltration showed to be highly dependent on the method used for its determination. Several studies have shown that the values of Ti determined by the ring infiltrometer method are greater than those obtained by other methods (COELHO at al., 2000; POTT; MARIA, 2003).

The models of Horton and Philip were capable of properly estimating the water infiltration process in different soil types and uses, different from the Kostiakov-Lewis model, which in three of the four sites overestimated the values of accumulated infiltration (Figure 1). The same behavior was observed in the study of TOMASINI et al. (2010), where the values of Ti and I in areas cultivated with sugar cane were overestimated by this model. Graphical analysis of the c' values showed that the model of Horton provided the best results for all four situations, without overestimating the values of Ti and presenting c' always greater than 0.70.

**Table 2**. Values of infiltration rate and parameters adjusted to the models of Horton, Kostiakov-Lewis and Philp in the different soils evaluated in the rio Doce river basin.

| Site | Tie | Horton | Kostiakov-Lewis | | Philip | |
|---|---|---|---|---|---|---|
| | mm $h^{-1}$ | B | α | K | β | k |
| Belo Oriente | 78±14 a | 0.1403 | 0.4646 | 11.0539 | 78.4576 | 246.9496 |
| Antônio Dias | 165±100 b | 0.0978 | 0.4847 | 8.8774 | 16.6048 | 167.4475 |
| Açucena | 47±2 a | 0.2611 | 0.6188 | 10.4724 | 25.6783 | 277.7876 |
| Peçanha | 50±17 a | 0.2487 | 0.5464 | 10.9 | 30.5996 | 280.8687 |

Mean values ± standard error; Means followed by same letter do not differ among themselves by Tukey test at 5% probability.

**Table 3**. Values of the adjusted confidence index (c') for the models of Horton, Kostiakov-Lewis and Philip in the different soil used in the Rio Doce river basin.

| Site | Horton | Kostiakov-Lewis | Philip |
|---|---|---|---|
| | c' | c' | c' |
| Belo Oriente | 0.83 | 0.53 | 0.85 |
| Antônio Dias | 0.71 | 0.43 | 0.49 |
| Açucena | 0.85 | 0.53 | 0.87 |
| Peçanha | 0.80 | 0.61 | 0.81 |

The lowest values of c' encountered for the site Antônio Dias are related to the large standard deviation (100 mm) encountered during the experimental tests.

The elevated Ti values in the areas with eucalyptus show the efficiency of this type of coverage to conserve and maintain water in soils. For eucalyptus in Antônio Dias for example, after 40 minutes total infiltrated water was approximately 140 mm, well above that found in other sites (Figure 1). The deep root system, the extensive layer of litter and high levels of organic matter found in forest plantations are the main factors responsible for these high infiltration values (GERMER et al., 2010). The results of this study were similar to those found by other researchers, where the values of Ti were also higher in areas of eucalyptus forest (PANACHUKI et al., 2006; ANTONELI; THOMAS, 2009), proving that the process of soil water infiltration is strongly influenced by the coverage type, among other factors.

Despite the same land use, the site Antônio Dias showed better results than Belo Oriente. In addition to coverage, it can be confirmed that the physical properties of soils also influenced infiltration (WARD; TRIMBLE, 2004). The high porosity and low bulk density of the soil (Table 1) were crucial to the high Ti values found at the Antônio Dias site. Lal e Shukla (2004) affirmed that these characteristics favor groundwater flow, especially in horizon A of the soil.

Another difference between these two sites with the same coverage is the soil texture. Soil of Antônio Dias is more sandy, which facilitates the movement of water between soil aggregates. On the other hand, Belo Oriente has a higher amount of clay in the soil, hindering the penetration of water in the topsoil.

The results also show that the adopted management in the pasture areas was not able to maintain and/or improve physical characteristics (Table 1), which caused decreases in the Ti, especially the Tie. Several studies have shown that infiltration decreases when vegetation is sparse (TURNBULL et al., 2010). Because the pastures analyzed are degraded, during much of the year they present a low leaf area index, leaving bare soils. However in sites with eucalyptus forest, the greater leaf area and the high dendrometric values (DBH and height) are responsible for roughly 15 to 25% of rainfall interception, reducing the direct contact of rainwater with the soil surface.

The high values of infiltration encountered, approximately 50% higher, possibly decreased runoff, preventing the occurrence of undesirable processes such as detachment of soil particles and consequent silting of waterways (TURNBULL et al., 2010).

All data indicates that if changing the land use in the river basin of the Rio Doce from pasture to eucalyptus, there will be improvements in soil processes and physical characteristics. It should be highlighted that the study was conducted in an area of planted forest where only manual silvicultural techniques were used which reduce soil compaction caused by tractors and forestry machines. It can be affirmed that when disregarding the total precipitation intercepted by forests and the higher values of transpiration, much of the incident rainfall will infiltrate into the soil, replenishing underground aquifers and increasing minimum flows during the dry season. Extremely important is the maintenance and conservation of natural resources in the region.

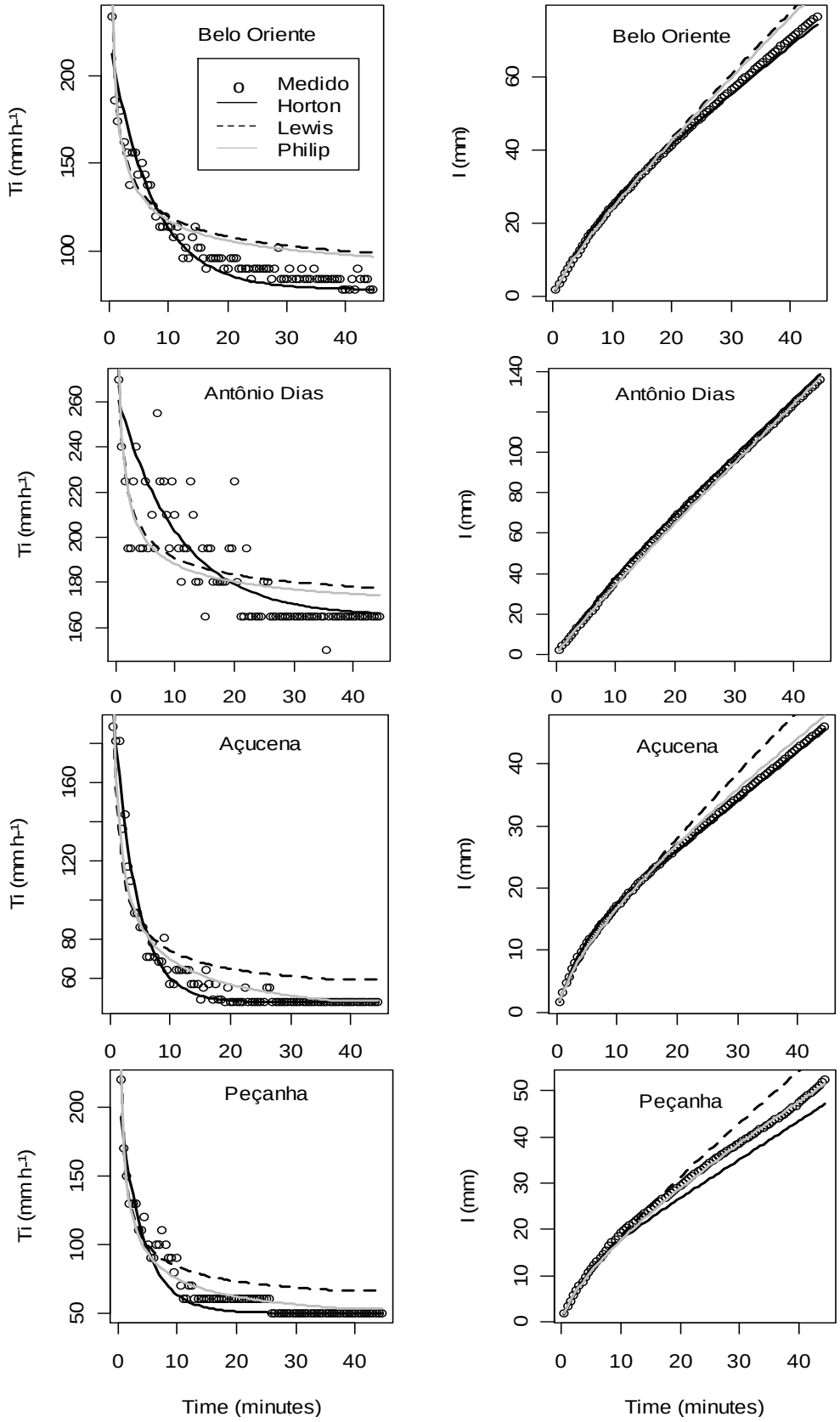


**Figure 1**. Infiltration rate (Ti) and accumulated infiltration (I) measured and estimated by the models of Horton, Kostiakov-Lewis and Philip in the four sites analyzed.

## CONCLUSIONS

From the results it can be concluded that the values of infiltration at the sites studied are directly related to the type of coverage and the physical characteristics of the soils;

In sites with Eucalyptus forests greater rates were observed with regards to soil water infiltration;

The model of Horton for soil water infiltration was that which fit best to the observed data.

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