ABSTRACT – With the purpose of comparing water consumption of plantations of Eucalyptus grandis, Pinus caribaea var. hondurensis, as well as natural vegetation of “Cerrado” (Brazilian savanna), using the soil water balance method, measurements of precipitation, soil water storage, and soil water potential have been taken during the two-year period of June 1981 through July 1983, in the Jequitinhonha valley, State of Minas Gerais, Brazil. The average annual results showed the following values for the water balance components of precipitation, total soil water loss, soil water drainage and capillary rise in adjacent plots and for a total soil profile of a depth of 180cm: E. grandis 1121 mm, 784 mm, 326 mm and 124 mm; P. caribaea: 1121 mm, 617 mm, 450 mm, 19.6 mm; “Cerrado”: 1121 mm, 569 mm, 556 mm, 4.3 mm. The differences in soil water consumption are discussed in comparison with results of similar studies. Differences in wood production are quite relevant, with Eucalyptus plantation presenting a volume, at 8 year age, of 366 m$^3$/ha, followed by pine, with 210 m$^3$/ha. As a comparison, average value for the “cerrado” vegetation are around 36 m$^3$/ha. The results, in general, show that the region present adequate soil water availability for forest growth, and also that the formation of forest plantations of Eucalyptus and Pinus in the region will not adversely affect the soil water regime.

INTRODUCTION

The Jequitinhonha valley stretches east-ward along the northeastern corner of the State of Minas Gerais, Brazil, comprising an approximate area of 85,000 km$^2$. It has been plagued by a continuous extractive exploitation of the native savanna vegetation for firewood and charcoal, as well as poor and overgrazed pasturelands.

With the advent of the Brazilian federal government incentive program for reforestation, and also as a consequence of the energy crisis of the seventies, this region
started to receive impetuous investments in reforestation with Eucalyptus species by several large forest companies, mainly for charcoal production. By 1981, it already presented the largest concentration of eucalypt plantation of the State of Minas Gerais (NEVES et alii, 1981).

The climate of the region is classed as moderate subtropical, sub-humid (GOLFARI et alii, 1978), and the average annual precipitation is around 1100 mm. The distribution of this annual total, however, is critical to forest growth, for practically all of it falls during the summer period of October through March (see Figure 1). The winter time (average annual temperature is around 20°C) is very dry, with the occurrence of water deficits during the months of May through September (Figure 1).

Therefore, the present study was installed with the purpose of providing a real insight in the suitability of the region for forest growth, in regards to water availability, based on the quantification of the soil water balance in field conditions. Given the widespread concern about environmental effects of large scale monoculture of tree species, the study was also intended to provide experimental evidence in relation to change of the original savanna cover to eucalypt plantation.

THE STUDY SITE

Figure 1 is the Thornthwaite average water balance for Grão Mogol, a Municipality in the Jequitinhonha valley where the experimental area is located, which depicts the already mentioned yearly distribution of water availability.
FIGURE 1 – Thornthwaite water balance for Grão Mogol, the Municipality of the study site in the Jequitinhonha valley (GOLFARI, 1975).
Natural vegetation in the region is the so called “cerradinho”, the Brazilian open savanna, characterized by well spaced low trees interspersed with shrubs in a surface covered with gramineous clumps (Figure 2).

Soils are very deep, medium textured, of very low fertility and highly acidic.

The experimental plots were located in an area belonging to Florestas Rio Doce S/A, a forest company subsidiary of Companhia Vale do Rio Doce.

FIGURE 2 – A view of the natural savanna vegetation of the study site. In the middle ground, the pair of tensiometers used for determination of soil water potential.

One plot was installed in the savanna (Figure 2). Adjacent to this area, two other plots were installed in forest plantations. One, in a 5-year old stand of Eucalyptus grandis plantation (Figure 3), and other in an also 5-year old stand of Pinus caribaea var. hondurensis. At the time of installation of the plots, the Eucalyptus stand presented an average height of 15 meters and an average d.b.h. of 12 centimeters, whereas for the pine stand the average height and d.b.h. were 9 meters and 11 centimeters, respectively.
FIGURE 3 – A view of the experimental plot installed under a 5-year old stand of *Eucalyptus grandis*.

**METHODS**

The soil water balance method (FEDERER, 1970), (WARD, 1971), (MciLLROY & DUNIN, 1982) was used for the estimation of the evapotranspiration in the studied savanna and forest plantation plots.

For a 2-meter deep soil profile in each plot, the general water balance equation applies:

\[ ET = P \pm Q \pm \Delta S - R \]

Where: ET = evapotranspiration  
\( P \) = precipitation  
\( Q \) = deep percolation  
\( R \) = surface runoff  
\( \Delta S \) = variation in soil water storage
Precipitation was measured in an open area adjacent to the forest plots using two non-recording raingauge.

Surface runoff was not measured. The plots were laid in flat terrain and surface runoff was thus assumed to be negligible in all cases.

Soil moisture was measured gravimetrically at a fortnight interval throughout the study period. In each plot, soil samples were taken with three replications at the depths of 30-, 60-, 90-, 120- and 180 cm. Bulk density determined for each of these layers in a soil trench dug in an adjacent open area was used for the calculation of the depth of water stored in the soil profile.

Deep percolation and capillary rise of water beyond the two-meter profile was estimated through Darcy’s equation. For this purpose, a pair of tensiometer was installed in each plot at the depths of 160 and 180 cm, which were read daily throughout the study period. Soil hydraulic conductivity was determined in an open area by the method developed by LIBARDI et alii (1980).

RESULTS AND DISCUSSION

Figure 4 is a representation of the monthly variation of the soil water storage, or the soil water regime, for the three different studied soil water regime, for the three different studied vegetation, during the period July 1981 through July 1983.

A field equipment failure occurred during the first summer of the experimental period precluded the measurement of the soil moisture for the months of December 1981 and January and February 1982.

The parallel lines in Figure 4 are relative to the values of water depth retained in the soil at -0.03 MPa and -1.5 MPa of pressure, as an average for the whole 180-cm profile. They are intended to give an idea of the pattern of the monthly variation in the soil water stored under the forest plantations and the natural savanna in relation to an approximate size of the soil reservoir of available water. As already stated, the pattern of precipitation distribution in the region is responsible for a seasonal period of critical soil water availability in the soil, which can extend from July up to November.

Interesting in this figure is the visual comparison of soil water regime under Eucalyptus, pine and the natural savanna vegetation. During the critical months, for instance, soil water storage under eucalypt remained higher than both pine and savanna. This pattern of comparative soil moisture regime has already been observed in previous, similar studies with eucalypt (SMITH et alii, 1974), (LIMA & REICHARDT, 1977).

With the daily values of precipitation, daily tensiometric readings, and also with the daily values of the soil hydraulic conductivity, determined as a function of the actual soil moisture content, a daily water balance was run aiming at the calculation of the value of soil drainage (deep percolation) and capillary rise for the 180-cm soil profile. These values, coupled with the fortnightly determinations of soil water storage, allowed the estimation of evapotranspiration for the three plots.

A summary of these results, as average monthly values for the entire period of study, is presented in Table 1.

The measured values of precipitation conform to the already discussed regional pattern of precipitation distribution, with practically all of the annual total occurring during the summer period of October through March.
The evapotranspiration results will be discussed more thoroughly based on the comparative presentation of the waterbalance in the three plots shown in Figures 5 and 6. The seasonal distribution of the monthly values shows higher values of evapotranspiration in eucalypt, followed by pine, and savanna being the least, during most of the period November to April. For the dry months of June, July, August, and September, however, eucalypt monthly evapotranspiration values fell below those measured in both pine and savanna plots. The year total, as average for the two-year study period, is higher for eucalypt, followed by pine and then by savanna, which was also expected and in accordance with results of recent experimental watershed studies with eucalypt species (VAN LILL et alii, 1980), (CALDER, 1986), (SAMRAJ et alii, 1988). Thus, if we consider the limitations of the plot results, in terms of the adopted soil depth and also of the assumptions of the soil water balance methods, one can observed in Table 1 that the difference in annual evapotranspiration between the eucalypt and the savanna is around 345 mm. In a study carried out in three small catchments in South Africa, VAN LILL et alii (1980) found that, in comparison with the natural savanna, the reforestation of the catchment with *Eucalyptus grandis*, the same species of this study, was responsible for a reduction in streamflow of approximately 340 mm/year, when the eucalypt trees were about the same age as in the present study. In the Nilgiris experimental watersheds in India, SAMRAJ et alii (1988) also determined that converting natural grasslands to *Eucalyptus globules* plantation caused a reduction of about 87 mm/year during the first rotation of ten years.

![Graph of monthly soil water storage](image)

**FIGURE 4** – Pattern of monthly soil water storage under *Eucalyptus* and pine plantations, and under natural savanna vegetation, for the 180 cm soil profile. Break during December 1981 to February 1982 was due to field equipment failure.
Table 1 – Average monthly values of precipitation (P), evapotranspiration (ET), and drainage (-) / capillary rise (+) for the entire period of study and for the three types of cover.

<table>
<thead>
<tr>
<th>Mo.</th>
<th>P (mm)</th>
<th>E. grandis</th>
<th>P. caribaea</th>
<th>“Cerrado”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ET (mm)</td>
<td>Drain/rise (mm)</td>
<td>ET (mm)</td>
<td>Drain/rise (mm)</td>
</tr>
<tr>
<td>Jul</td>
<td>0.0</td>
<td>9.2</td>
<td>0.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Aug</td>
<td>16.0</td>
<td>21.1</td>
<td>0.9</td>
<td>15.1</td>
</tr>
<tr>
<td>Sep</td>
<td>4.0</td>
<td>7.8</td>
<td>2.8</td>
<td>22.7</td>
</tr>
<tr>
<td>Oct</td>
<td>11.3</td>
<td>49.6</td>
<td>-7.1</td>
<td>38.0</td>
</tr>
<tr>
<td>Nov</td>
<td>167</td>
<td>88.4</td>
<td>-35.6</td>
<td>53.5</td>
</tr>
<tr>
<td>Dec</td>
<td>174</td>
<td>73.4</td>
<td>-64.0</td>
<td>54.5</td>
</tr>
<tr>
<td>Jan</td>
<td>232</td>
<td>151.4</td>
<td>-108.9</td>
<td>106.5</td>
</tr>
<tr>
<td>Fev</td>
<td>138</td>
<td>77.7</td>
<td>-110.4</td>
<td>78.7</td>
</tr>
<tr>
<td>Mar</td>
<td>198</td>
<td>178.9</td>
<td>+31.3</td>
<td>141.6</td>
</tr>
<tr>
<td>Apr</td>
<td>56</td>
<td>159.3</td>
<td>80.3</td>
<td>86.6</td>
</tr>
<tr>
<td>Mai</td>
<td>23</td>
<td>81.0</td>
<td>8.6</td>
<td>65.5</td>
</tr>
<tr>
<td>Jun</td>
<td>0.0</td>
<td>24.0</td>
<td>0.2</td>
<td>38.2</td>
</tr>
<tr>
<td>annual total</td>
<td>1121.0</td>
<td>921.8</td>
<td>-201.6</td>
<td>716.6</td>
</tr>
<tr>
<td>capillary rise total</td>
<td>124.4</td>
<td>19.6</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Dariange total</td>
<td>-326.0</td>
<td>-449.9</td>
<td>-556.0</td>
<td></td>
</tr>
</tbody>
</table>

Thus, the observed difference in evapotranspiration between the natural savanna vegetation and eucalypt is about the expected increase in water consumption as a result of the higher growth and biomass production of the plantation forest (JARVIS & STEWART, 1978). This can be better observed in Figure 5, which shows a schematic representation of the three, 180-cm soil plots with the figures representing the terms of the soil water balance method as average annual values for the two-year study period.

In order to have a better appreciation of the water balance comparison among the covers, the interception loss values in Figure 5 were estimated based on results of interception study in plantations of eucalypt and pine similar to the ones used in the present study (LIMA, 1976). In this way, the interception component of the total evaporation from the plantations was separated, which permitted the recalculation of the soil water balance components based on the net values of precipitation. The production figures of the eucalypt and pine plantations were measured in the experimental plots, while the savanna value was estimated by ALBERT (1973). Thus, for a 10-fold increase in wood production, the eucalypt plantation used around 215 mm more soil water than the savanna vegetation. Ignoring some small interception loss from the savanna, this difference is about the same decrease observed in the drainage component. What is important to emphasize, though, is the fact that this higher soil water deficit under the plantation only diminished, but did not stop, ground water recharge.

*       *       *
Another interesting aspect of these results can be observed in Figure 6, which represents the seasonal separation of the soil water balance results of the three covers. The figures, now, show a surprising similarity of the eucalypt, pine and savanna transpiration for the summer, wet period. During the dry season, all covers developed a soil water withdrawal, which was about 150 mm higher in eucalypt as compared with the savanna. This difference is very close to other results of soil water deficits developed by eucalypt obtained elsewhere (LIMA & REICHARDT, 1977), (HOLMES & WRONSKI, 1979), (WILLIAMS & COVENTRY, 1979), (NICOLLS et alii, 1982), (LANGFORD et alii, 1982).

FIGURE 5 – Schematic representation of the components of the soil water balance for the three studied covers (see text for the inclusion of the interception loss values).
FIGURE 6 – Schematic representation of the seasonal components of soil water balance for the three studied covers.

CONCLUSIONS

Overall results are positive in both aspects raised in the introduction of this paper. The growth of the plantations (both eucalypt and pine), as revealed by the results of volume production in Figure 5, can be considered very good. The 366 m$^3$/ha for the eucalypt, for instance, are for the age of 8 years (measurements of May 1985), which gives an annual mean increment of approximately 45 m$^3$/ha.

Soil water regime in the natural savanna plot and in the plantation plots followed a similar pattern of variation for the 180-cm measured profile. During the dry season, soil water content in the savanna plot was slightly drier than both plantation plots.

Evapotranspiration was higher for the eucalypt, followed by pine, and leastly the savanna. The measured difference in evapotranspiration between eucalypt and savanna was quite similar to recent results of watershed experiments with eucalypt plantations.
Considering interception loss apart, the eucalypt plantation used approximately 215 mm more water per year than the natural savanna vegetation, a result which was normally expected and within the range of differences encountered in other similar studies.

Wood production, soil water regime and average annual evapotranspiration of the pine plantation remained intermediate between eucalypt and savanna.

* * *

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