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Soil Moisture Regime in Tropical Pine Plantations and in "Cerrado" Vegetation in the State of São Paulo, Brazil[1]

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ABSTRACT - Soil moisture was measured gravimetrically during a 24-month period in 12-year old plantations of *Pinus caribaea* Mor. var. *hondurensis* and *Pinus oocarpa* Schiede, as well as in an adjacent natural reserve of "cerrado" vegetation, in the state of São Paulo, and the data were used to compare the soil water regime in these different vegetations. Measurements were made monthly at the depths of 0, 50, 100, 150 and 200 centimeters, with three replications in each plot. The *P. hondurensis* and the "cerrado" plots were adjacent, whereas the *P. oocarpa* plot was about 800 meters apart. Soil in the area was typical of cerrado soils, being sandy very deep, and well drained. The results in general did not show any adverse effect to the soil water regime which could be ascribed to the reforestation of "cerrado" soils with tropical pine species. The soil under cerrado vegetation was in general more humid than the soil under the pine plantations throughout the study period. Between the pine species, the *P. oocarpa* plantation caused a smaller depletion o! the soil water, presenting an overall soil water regime which as very similar to he one observed in the "cerrado".

RESUMO - Durante um período de 24 meses consecutivos foram realizadas medições do conteúdo de umidade do solo em plantações de *Pinus caribea* Mor. var. *hondurensis* e de *Pinus oocarpa* Schiede, ambas com 12 anos de idade, bem como em uma parcela adjacente de vegetação natural de cerrado, nas florestas da CAFMA, Estado de São Paulo, As medições foram feitas por gravimetria, sendo as amostras de solo coletadas mensalmente nas profundidades de 0, 50, 100, 150 e 200 centímetros, com três repetições em cada tipo de cobertura florestal. A parcela da floresta de *P. caribaea* var. *hondurensis* era adjacente à parcela de cerrado, enquanto que a parcela de *P. oocarpa* distava cerca de 800 m. O solo predominante na área é típico do cerrado, sendo arenoso, profundo e bem drenado. Os resultados mostraram que o reflorestamento do cerrado com espécies de pinheiros tropicais não causou nenhum efeito adverso ao regime da água do solo. Comparativamente o solo sob o cerrado permaneceu mais úmido do que o solo sob as plantações de pinheiros durante o período experimental. Entre as duas espécies de *Pinus* estudadas, a floresta de *P. oocarpa* foi responsável por uma menor depleção da água do solo, apresentando, durante o experimento, um regime de água do solo similar àquele observado na vegetação natural de cerrado.

Introduction

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The study of soil water regime in forest plantations can be viewed in two important aspects: first, soil moisture is one of the most important environmental factor affecting site productivity (McCLURKIN, 1958), (ZAHNER, 1968), (ZIMMERMAN et alii, 1972), (MADER, 1978), (FRALISH et alii, 1978); secondly, it provides a means of evaluating some environmental effects of these plantations, particularly those related to any effect caused to the soil water (REYNOLD & WOOD, 1977).

This second aspect should be scrutinized in any large scale reforestation program. As PEREIRA (1973) puts it: "...it is clear that forests should neither be felled nor planted on a large scale without a study of the potential hydrological changes which may be expected... There is good sense, both practically and scientifically, in early initiation of pilot schemes to provide measurements. The reduction in guesswork can save very large sums of money.

In some parts of the country, several reforestation programs have been using various pine species for the formation of fast growing pine forests. In the region where the present study was conducted, extensive areas of "cerrado" vegetation have been replaced by tropical pine forests. In view of the need for information regarding soil moisture management in these new forests (STONE, 1978), and also considering the relevance of scientifically assessing any possible adverse hydrologic effect of such vegetation replacements, the present study was aimed at acquiring the following information:

a) the annual range of soil water under plantations of tropical pine species in comparison with that observed under "cerrado" vegetation":

b) the patterns of soil water depletion in tropical pine forests and in cerrado;

c) the total amount of water stored in the soil profile in different periods of the year in these different vegetation covers;

d) comparison of soil water utilization pattern and the growth rate of the pine species studied.

Similar studies have been conducted in various countries in the world: (COHEN et alii, 1966), (KITCHINa, 1967), (SHACHORI et alii, 1967), (ORR, 1968), (REPNEVSKAJA, 1969), (HERRING, 1970), (LAMBERT et alii, 1971), (BUBLINEC, 1972), (BREWER & LINHARTZ 1978). In Brazil, very few such studies have been carried out: (FERRI, 1961), (CERVELLINI et alii, 1972), (LIMA & REICHARDT, 1977).

Material and Methods

The Study Area

The experiment was carried out lands owned by the Companhia Agro-Florestal Monte Alegre (CAFMA), which is located in the county of Agudos, in the State of São Paulo, Brazil. Total area of the Company is about 12.000ha, almost all reforested with conifers, chiefly tropical pine species.

The plots were located in two tropical pine stands: a 28, 7 ha stand of *Pinus caribaea* Morelet var. *hondurensis* and a 53,0 ha stand of *Pinus oocarpa*, Schiede. Both were planted in 1966, on a 2,5 m x 2,0 m spacing. A third plot was also installed in a reserve of "cerrado", which represents the original vegetation cover in the area. The "cerrado" vegetation is surrounded by the stand of *P. caribaea*, whereas the stand of *P. oocarpa* is located about 800m apart.

During the study period, average d.b.h. and height were 27,0 cm and 20,1 m, for the *P. caribaea*, and 20,1 cm and 19,9 m, for the *P. oocarpa*.

TABLE 1: Thinning production and number of remaining trees (data from the file of CAFMA)

Species	Date of thinning	Number of remaining trees	Wood production (m^3/ha, debarked)
P. caribaea	1974	-	45,9
	1976	993	16,0
	1978	700	56,6
P. oocarpa	1974	-	26,2
	1976	1040	18,5
	1978	700	40,2

TABLE 2: Soil horizons, depth, mechanical analysis and bulk density of the study area

Horiz.	Depth (cm)	Mechanical analysis			Bulk density (g/cm^3)
		Sand	Silt (%)	Clay	
A_p	0-15	87,1	2,4	10,5	1,44
A_3	15-43	86,4	2,7	10,9	1,52
B_1	43-73	83,8	3,3	12,9	1,52
$B_{2.1}$	73-120	80,1	5,8	14,1	1,55
$B_{2.2}$	120-165	81,5	3,2	15,3	1,54
B_3	165-205	80,5	3,8	15,7	1,53
C	205-300	80,7	2,9	16,4	-

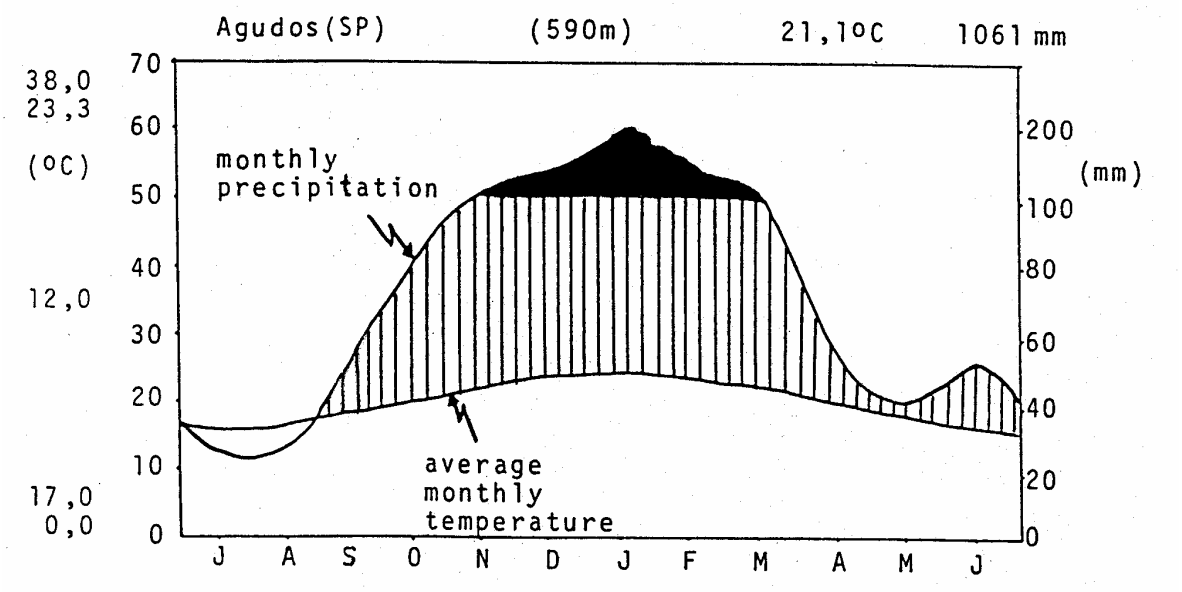

FIGURE 1: Climatic diagram of the study area

Thinning production and number of remaining trees after the three thinning performed in the study stands can be seen in Table 1.

Climatic characteristics of the study area can be observed in the climatic diagram in Figure 1.

The topography is, in general, gently sloping, but the experimental plots were located in level ground.

Soil is typical of "cerrado", being sandy, very deep, well drained, acid. and of low fertility. Table 2 shows some profile characteristics of the soil in the study area.

Methods

Precipitation was measured weekly in nearby open with three, non-recording, rain gages.

Soil moisture was monitored monthly by the gravimetric method. In each stand, samples were taken in three different points, at the depths of 0, 50, lOO, 150 and 200 centimeters, using a core-type soil auger.

Data collection prolonged from June 1977 through may 1979.

Soil pits were excavated in each plot for the purpose of collecting appropriate samples in each depth for the laboratory determination of soil bulk density, and soil water retention at the - 1/3 and - 15 atm pressure.

Results and Discussion

The analysis of the soil water data showed large variations in total soil water in the two-meter soil profile along the months for all vegetations.

These fluctuations in soil moisture were not similar in all the soil depths studied. Much of the monthly variation in soil water content occurred only at the surface (0 cm depth) and down in the 50-cm depth. At the depth of 100-cm and below, the water content in the soil was more uniform throughout the period of study in the three different vegetations.

The differences in soil water content among the species studied were greatest in the surface layer of soil. Considering the 24 months of the study period, and taking the average monthly values of soil moisture content for the total profile, and rainfall data, these average values were used to construct Figure 2, which shows the mean annual fluctuation of total soil water, in mm, for the tropical pine forests in comparison with that of the "cerrado" vegetation, together with the mean monthly precipitation, and with the average values of moisture retention in the soil at 1/3 - and 15 atm of negative pressure.

The figure shows that the soil under "cerrado" vegetation was, in general, always more humid than the soils under the tropical pine forests. Between the pine species, the soil was always more humid under the *Pinus oocarpa* forest. The *Pinus caribaea* var. *hondurensis* forest, therefore, was responsible for the highest depletion of soil water throughout the study period. The differences in soil water utilization among the covers tended to be higher during dry months of the year .As shown in the average pattern of soil moisture utilization of Figure 2, only in the case of *P. caribaea* plot did the soil water content fall below the 15 atm tension during the driest period of the year (August-September).

The differences in soil water regime thus discussed are, therefore, in terms of monthly values of soil moisture, species studied, and different depths of the soil profile. To test the significance and the extent of these differences, the data was submitted to analysis of variance, which showed that the difference in monthly soil water content among the covers during the study period was significant at the 5% level. Results of the Tukey's test showed, however, that the difference was significant only between *Pinus caribaea* and "cerrado". In another words, there was no difference, from the statistical viewpoint, between the tropical pine species, or between the *Pinus oocarpa* forest and the cerrado vegetation, in regards to soil moisture utilization.

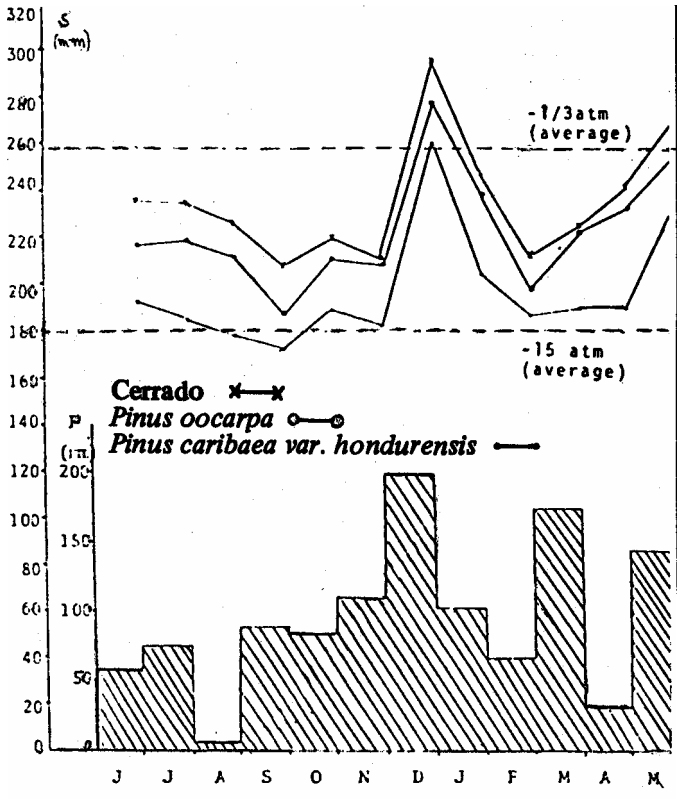

FIGURE 2: Average monthly fluctuation of total son water in the 200 cm soil profile (S) in millimeters and average monthly precipitation for the study period (average of two-year measurements)

Partitioning of the degrees of freedom and further comparison through Tukey's test showed that the difference between *P. caribaea* and cerrado was significant only at the surface layer of the soil. In another words, only the surface layer of the soil (0 cm depth) of the"cerrado" vegetation was significantly more humid than the corresponding layers in the pine forests. In all other studied depths, monthly soil water contents were not significantly different among the covers, as well as there were no differences between the pine species in any individual soil depth.

Another way of viewing the differences in the pattern of soil moisture utilization by the study vegetation during the experimental period is through the curves of Figures 3 and 4. Figure 3 shows the distribution of soil water in the entire profile in two occasions: part A of the figure depicts the lowest reading of soil moisture contents, which were determined in august 31st, 1977; part B shows the highest values determined in January 2nd, 1979. The values of the 1/3 -and 15 atm tensions are averages for individual determination in each depth in the three plots. In Figure 4, part A is the mean moisture content in the soil for the dry season (April September), and part B is the mean moisture content for the rainy season (October-March). Again the values of 1/3 -and 15 atm tensions are averages for each depth. The differences in the pattern of soil moisture utilization by the three covers along the 200 cm of soil profile are again shown in these figures, noticing the glaring tendency of the soil

under *Pinus caribaea* var. *hondurensis* forest of being always drier in comparison with the other pine forest and with the cerrado vegetation

FIGURE 3: Volumetric moisture profile in the 200 cm depth of soil : (A) smallest values of moisture content observed during the study period, as determined in august 31, 1977; (B) highest reading observed in January 02, 1979

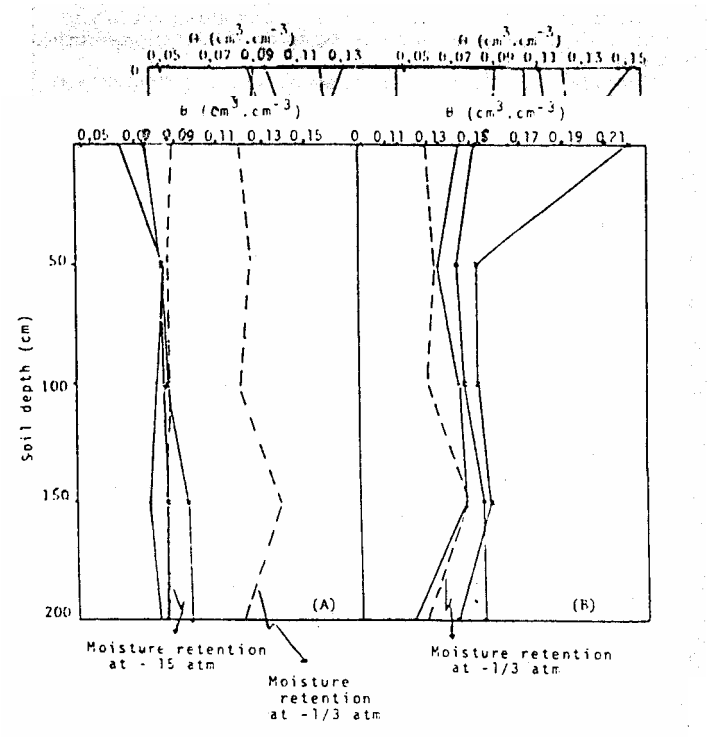

FIGURE 4: Average volumetric moisture content in the 200 cm soil profile. (A) dry period (April September) average; (B) rainy season (October-March) average: 1977 through 1979

It is interesting to make additional comments on the difference in soil water utilization between the two tropical pine species. Although the quantitative differences in soil water depletion between them were not statistically significant, they can however, be compared with differences in silvicultural characteristics of each species, as already given in Table 1. On the other hand, BERTOLANI & NICOLIELO (1977) state that *Pinus caribaea* var. *hondurensis* forests in Agudos are presenting excellent volumetric growth, with mean annual increment around 28 m3/ha.year of debarked wood at the age of 15 years. For this species, however, the authors cite that the percentage of defective trees is high. As for the *Pinus oocarpa* forests, mean annual increment in Agudos is around 20 to 25 m3/ha.year, at the same age, but presenting less defective trees. In terms of wood specific gravity for populations of the two pine species in Agudos, Table 4 is according to data given in FERREIRA et alii (1978), and shows values of specific gravity -according to the age of the plantations.

It can thus be seen that the *P. oocarpa* species presents a smaller rate of development in comparison with *P. caribaea* var. *hondurensis* in the study area. This difference should, however, be viewed in terms of the better form of the trees in the case of P. *oocarpa*, of the higher value of the wood specific gravity, as well as from the hydrological standpoint, according to the results of the soil water regime obtained in the presenty study, Le., of the tendency of the *P. oocarpa* forest to use less water in comparison with *P.caribaea* var. *hondurensis*.

Rainfall interception was also measured in the study plots, and the results (LIMA NICOLIELO, 1981) can also be used to give additional explanation of the differences in soil water utilization patterns. Average values of rainfall interception are as follows: "cerrado", 27,3%; *P. oocarpa*, 12,0%; *P. caribaea* var. *hondurensis*, 11,7%. RUTTER (1968), SINGH & SZEICZ (1979), and BORMAN & LIKENS (1979), for instance, determined that the evaporation of intercepted water occurs at a rate 2 to 3 times greater than the transpiration that would have occurred if it had not rained and that about 1/3 to 1/20 of the intercepted water corresponds to the economy of soil water use as a consequence of the reduction in transpiration.

TABLE 4: Wood specific gravity of population in g/cm^3 (after FERREIRA *et alii*, 1978)

Species	Age (years)	Specific gravity (g/cm^3)
Pinus caribaea var. hondurensis	6	0,351
	12	0,408
	14	0,417
Pinus oocarpa	6	0,390
	12	0,413
	13	0,443

Conclusions

From the viewpoint of soil water utilization, the results of the present study did not show any adverse effect which could be ascribed to the replacement of "cerrado" vegetation by fast growing forest of tropical pine species. The soil under "cerrado;' vegetation was always more humid than the soil under pine, throughout the study period, but the difference was statistically significant only in relation to the surface layer of soil, and only in relation to one of the pine species studied. Comparing *Pinus oocarpa* with *Pinus caribaea* var. *hondurensis*, the first species would be recommended for reforestation in areas of "cerrado" similar to the study area. Besides presenting a relatively good development, this species presented an overall soil water utilization pattern which was very similar to that observed under the original "cerrado" vegetation.

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