A COMPARISON OF DRY SEASON SOIL WATER DEPLETION BENEATH CENTRAL AMAZONIAN PASTURE AND RAINFOREST

L. Pimentel da Silva[1], M.G. Hodnett[2], H.R. Rocha[3], and R. Cruz Senna[4].

1 COPPE/UFRJ - CP-68506 - 21945-970 - RIO DE JANEIRO-RJ - BRASIL

2 INSTITUTE OF HYDROLOGY - WALLINGFORD - UK - OXON - OX10 - 8BB

3 INPE - CP-515 - 12201 - SAO JOSE DOS CAMPOS - SP - BRASIL

4 INPA - CP-478 - 69011 - MANAUS - AM - BRASIL

ABSTRACT

Soil profile storage and soil water potential were measured to a depth of 2m beneath pasture and undisturbed rain forest. The maximum water storage change in the 2m profile was 154mm in the forest in both seasons studied, and 131mm and 112mm in the pasture. The behaviour of the storage in the upper metre of the profile was virtually identical but there were major differences in the second metre. Storage changes were very similar in the wet season, but in the dry season the storage under the forest decreased significantly faster, resulting in 42mm more depletion. This was equivalent to a difference in evaporation rate of 0.5mm/d.The forest was able to abstract all of theavailable water from the 2m profile studied andthere was evidence of significant abstraction from below this depth. Soil water availability is very lowand the forest requires a deep rooting strategy to avoid serious stress in dry periods.

1. Introduction

Deforestation will directly influence the hydrological response of a catchment through changes in soil hydraulic properties and through reduced evaporative losses from the replacement vegetation. Large scale deforestation in the Tropics has focussed attention on the effects of this type of land use change on climate. Changes in climate, notably rainfall, could impose significant additional effects on the hydrological behaviour of an area. General Circulation Models (GCMs) are being used to predict the effects of large scale forest clearance on climate, but their validity and accuracy is dependent on representative parameterisation of the vegetative surface before and after deforestation. Soil water storage beneath forest and adjacent pastureland was monitored between October 1990 and February 1992 to investigate differences in evaporation and infiltration. The study was a component of the Anglo-Brazilian Climate Observation Study (ABRACOS) project (Shuttleworth 1991) which is ongoing. One of the main objectives is to collect data from undisturbed rainforest and cleared (pasture) areas to provide more accurate and representative data for GCM studies.

2. Experimental Details

The pasture site is on a cattle ranch, Fazenda Dimona, surrounded by undisturbed rainforest about 100km north of Manaus. The ranch was created in 1980 by felling and burning the forest and sowing the area with hardy pasture grasses. The area was not bulldozed and many large tree trunks and stumps still remain. 11% of the area was bare soil,mainly trampled termite mounds and cattle tracks. The pasture was well managed and serious overgrazing did not occur. The forest surrounding the fazenda is of the terra firme type, which covers 60%-70% of the Central Amazon region. The climate is tropically hot and the mean annual rainfall is about 2400mm. The driest months are July-October, and the wettest months are March-May. The soils are derived from the Tertiary Barreiras sediments and range from clayey oxisols on the plateau areas through ultisols on the slopes to white sandy podzols on the valley floor. Relief variation is about 30m.

Two transects were instrumented: the pasture transect was within the fetch of the micrometeorological instrumentation which was located on the plateau. The forest transect was about 1km distant. Soil water content and potential were measured using a neutron probe and tensiometers respectively. The transects were divided into 3 "slope units" in which the processes controlling the behaviour of the soil water reservoir were expected to differ. The units were the plateau, the slope and the valley floor. In the forest, there were 5 access tubes in each unit. In the pasture there were 8 on the plateau, 5 on the slope, and 2 in the valley. All tubes were 2m deep except in the forest valley where they were 1m deep. The depth of the forest plateau tubes was increased to 3.6m in October 1991. There were tensiometer sets, one on each plateau (pasture and forest) and one in the forest valley. Observations were made weekly from mid-September 1990, and twice weekly during the dry season.

3. Results and Discussion

Fig.1 shows the mean profile storage to 2m depth for the forest and the pasture plateau from October 1990 to February 1992. The behaviour of the soil water storage was very similar in both areas, but particularly in the wet season. For the forest, the storage change from the driest (5/11/90) to wettest (20/5/91) conditions was 154 mm. The minimum storage was the same in 1991 as in 1990. Drainage will have been responsible for some of this water content change. For the clearing, the maximum change was 131 mm (between the same dates), but in 1991 the maximum storage change was 112mm. In the wet season, the storage was very high between 28/3/91 and 20/5/91, when there were rainfalls exceeding 140mm between observations. Weekly wet season forest evaporation (ie including interception) is about 25 mm(Shuttleworth, 1988). Storage increases were typically not more than 20mm, and it is clear that the excess was rapidly lost as run off on drainage. Under the forest, runoff is not observed on undisturbed soils (Nortcliff and Thornes 1981, Chauvel et al 1991) even after very heavy rain, implying that the excess water drains rapidly. In the pasture, surface redistribution of rainfall was observed, but it is not known if a significant amount runs off. The similarity of the storage curves in the wet season implies that the surface permeability in the pasture is not low enough to seriously inhibit infiltration.

Large differences in storage occurred only in the dry season. At the end of October 1990, storage was 23mm lower in the forest than in the pasture and reached the lowest value recorded in the study. Early in the 1991 dry season the storage beneath the forest began to decrease more rapidly than in the pasture and the curves continued to diverge despite rainfalls of up to 102mm between observations. By January 1992 the storage difference was 45mm and the forest storage was as low as at the end of the 1990 dry season. In January 1991 the storage under forest and pasture was within 25mm of the maximum recorded. This was because the rainfall between October 1991 and January 1992 was only 35%-63% of the long term average.

Fig.2 and 3 show the data for the study period as storage in the upper metre and second metre of the profile respectively. In the upper metre, the soil water storage was almost identical throughout the period shown; the maximum storage changes were 89.3±3.5mm and 91.6±5.4mm under forest and pasture respectively. Although the maximum storage changes were the same, the pasture took up more water from the top 0.2m of the profile . The forest took more from 0.5m and below. The water content change in the pasture was about 0.01 MVF less than in the forest at 1m and about 0.02 MVF less between 1.5 and 2m.

The second metre of the profile showed very marked differences in behaviour between forest and pasture. After wetting up in early December 1990, through to mid-July 1991, storage was almost identical after storm events, but during periods of net storage decrease (not necessarily rain-free), the forest storage consistently decreased faster. After mid-July it decreased much faster than under the pasture. The net loss of soil water from this layer between 19/7/91 and 20/9/91, was 43 mm in the forest and 13mm in the pasture, equivalent to a difference in uptake rate of 0.47 mm/d. After October, storage in the forest was almost constant until late February 1992 implying that a limit had been reached, beyond which the water was virtually unavailable. The same limit was also observed in 1990. Although there were rainfall totals of up to 102 mm in this period, they were insufficient to penetrate below 1 m. During the same 4 month period the mean storage in the lower metre in the pasture was partially replenished by rainfall on several occasions. However, the profile was wetted up to wet season levels (resulting in drainage) at some locations but not at others. This large variability in the wetting process in the pasture occurs because the permeability of the surface layers is low, leading to redistribution of water as runoff from high points into hollows, locally increasing or decreasing infiltration. Variability decreased between rainfall events because the processes of water loss from the soil act to reduce the overall variability. The large variability occurred only when the soil storage was partially filled. The low variability when the soil water reservoir was either close to saturation or wilting point indicates that the inherent variability of the soil properties is low.

Although the forest soil is 79.5% clay and might be expected to have an available water capacity of 100mm-150 mm/m depth of soil, the capacity observed below 0.3m was only about 60mm/m. This very low available water capacity is, in fact, typical of oxisols (Sanchez, 1976). Water release curves were derived from in-situ measurements. Most of the water content change (typically 0.04 MVF) occurs between -3kPa and -20 kPa, indicating that the readily available water is contained in the larger pores. Between -20kPa and -80kPa the water content change is only about 0.02 MVF. The lowest water contents recorded are only 0.01-0.015 MVF less than at -80kPa. The corresponding potential, it may be close to "wilting point" (-1500kPa) since there appears to be a marked lower limit on water abstraction.

Total forest evaporation (evapotranspiration + interception) was determined by the water balance when drainage was negligible. In October 1990 the upper metre of the profile was wetted by rainfall. Between 2/10/90 and 16/10/90 the evaporation rate was 4.33mm/d, which is close to that estimated by Shuttleworth (1988) for September and October 1984. Over the next 20 days the rate was 1.2mm/d, which is extremely low and probabily unlikely since there was no apparent increase in leaf fall, which might have indicated the build of serious stress. During this period it seems very likely that the forest was using significant amounts of water from below 2m. Nepstad et al (1991) found that forest near Paragominas, in Eastern Amazonia can tap soil water from at least 6m. In that area, the dry season is more severe (typically 5 months, with a mean interval of 37 consecutive days with < 2mm of rain. Since water availability is low in the soil studied, deep rooting may be an essential strategy. There will be less resistance to water movement through the soil-plant-atmosphere system if the trees have to raise water from a few metres deeper in the soil where matric potentials (and conductivity) are high than if they have to extract all the available water in the upper profile, against very low water potentials.

In mid-October and early December 1991, the evaporation rate from the water balance fell abruptly to below 2mm/d when the storage in the profile was close to the minimum. The forest was again probably taking up water from below 2m. The deep access tubes (3.6 m) were installed in mid-October 1991, but there was no decrease of storage below 1m from the date of installation to mid-February 1992. This could indicate that the storage had already been utilised by October 1991 and that the shortfall in water availability in October and December 1991 was made up by abstraction from below 3.6 m depth. Further data is awaited. As 2m profile storage decreased from 860mm to 810mm, the apparent forest evaporation rate decreased from 4.5mm/d to 3.5mm/d before decreasing abruptly, presumably as the limit of water availability from the top 2m of the profile was approached. The pasture evaporation data showed a steady decrease in evaporation rate from about 4.4mm/d when profile storage was above 870mm to about 2.2mm/d when it has fallen to 830mm.No sudden decrease in apparent evaporation rate was observed, probably because the limit of water availability from the top 2m of the profile was not approached.

4. Conclusions

The maximum soil water storage change recorded in the two dry seasons studied was 154mm in the forest (both seasons) and 131mm and 112mm in the pasture. There was only about 50% of average annual rainfall during the part of the 1991-2 wet season reported here. The profile beneath the forest was as dry at the end of January 1992 as at the end of the previous wet season. During the wet season, the behaviour of the soil water reservoir in the forest and clearing was identical. Major differences in soil water storage were only observed in the dry season and were only apparent in the lower metre of the profile. The forest appeared to be able to utilise all of the available water in the lower metre of the profile in both seasons studied. Evaporation rates from the top 2m of the profile remained above 3.5mm/d as profile storage decreased, but then declined abruptly as the reserve in the top 2m of the profile was exhausted. There is strong evidence that the forest was able to abstract water from depths greater than 2m and possibly from as deep as 4m. Water availability in this type of soil is low. The pasture did not utilise all of the water from the 0-2m layer, but used more water from the top 0.1m of the profile than the forest. Evaporation rates decreased more gradually as profile storage decreased. Spatial variability of soil water storage was significantly greater beneath the pasture than beneath the forest, particularly following rainfall events in the dry season. This appeared to be largely the result of redistribution of rainfall as local surface runoff. There was no evidence of redistribution or runoff in the forest.

The reduction in the permeability of the surface layers in the pasture compared to the forest is largely due to trampling by cattle. Chauvel et al (1991) indicate that the macro-structure of these soils (which is responsible for their very high permeability when undisturbed) is very vulnerable to compaction, particularly by heavy machinery.The data presented here are for a pasture which was created by felling and burning, and which is well managed. The behaviour of the soil water reservoir beneath pastures which are more heavily trampled due to poorer management, or which have been cleared by bulldozer, may differ significantly.

References

Chauvel, A., M. Grimaldi and D. Tessier, 1991. Changes in soil pore space distribution following deforestation and re-vegetation: An example from the Central Amazon Basin, Brazil. Forest Ecology and Management 38, 259 - 271.

Nepstad, D.C., C. Uhl and E.A.S. Serrao, 1991. Recuperation of a degraded Amazonian landscape: Forest recovery and agricultural restoration. Ambio 20, 248 - 255.

Nortcliff, S., and J.B. Thornes, 1981. Seasonal variations in the hydrology of a small forested catchment near Manaus, Amazonas, and its implications for management.In:Tropical Agric. Hydrology. Eds R. Lal and E.W. Russell. John Wiley, N.Y..

Sanchez, P.A., 1976. Properties and Management of soils in the Tropics. John Wiley, New York.

Shuttleworth, WJ, JHC Gash, JM Roberts, CA Nobre, LCB Molion and MNG Ribeiro, 1991. Post-deforestation Amazonian climate: Anglo-Brazilian research to improve prediction.J.Hydrol, 129, 71-86.

Shuttleworth, W.J., 1988. Evaporation from Amazonian rainforest. Proc. R. Soc. Lond. B 233, 321-346.

Wright,IR, JHC Gash, HR Rocha, WJ Shuttleworth, CA Nobre, PRA Carvalho, MVBR Leitao, CT Maitelli and CAGP Zamparoni, 1992. Dry season micrometeorology of Amazonian ranchland.submitted to Q.J.R. Meteorol. Soc.

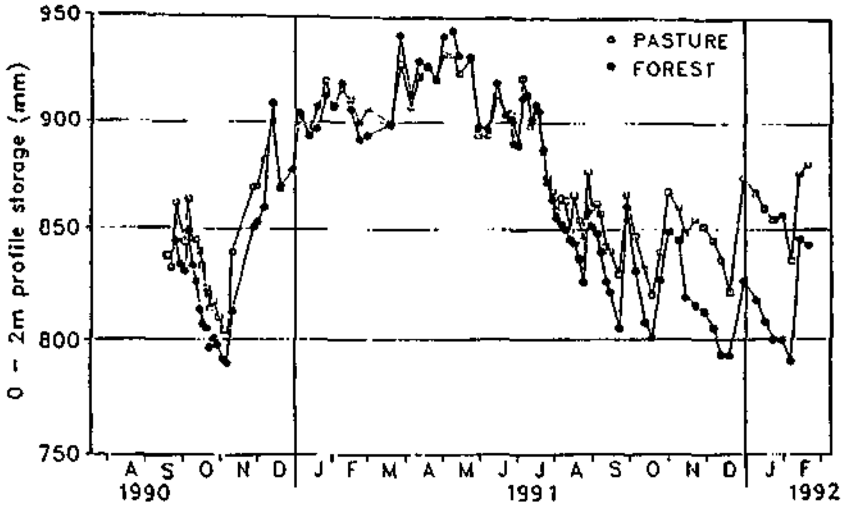

Figure 1. Mean profile storage to a depth of 2.0 m for the forest plateau (5 tubes) and the pasture plateau (8 tubes) for the period from October 1990 to February 1992.

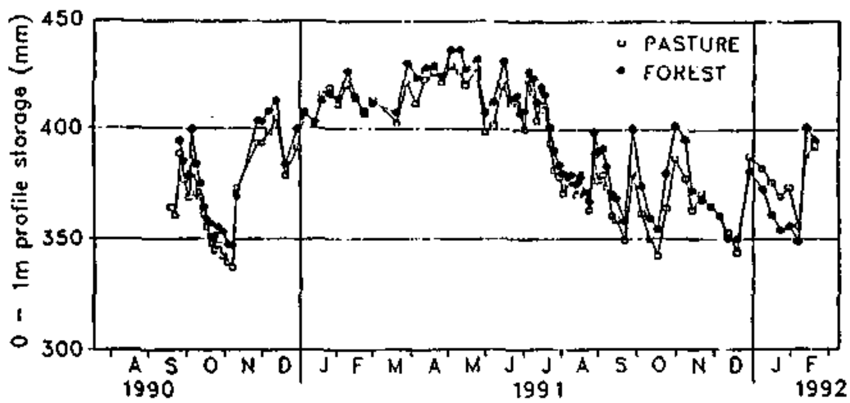

Figure 2. Mean storage between 0 and 1 m for the forest and the pasture.

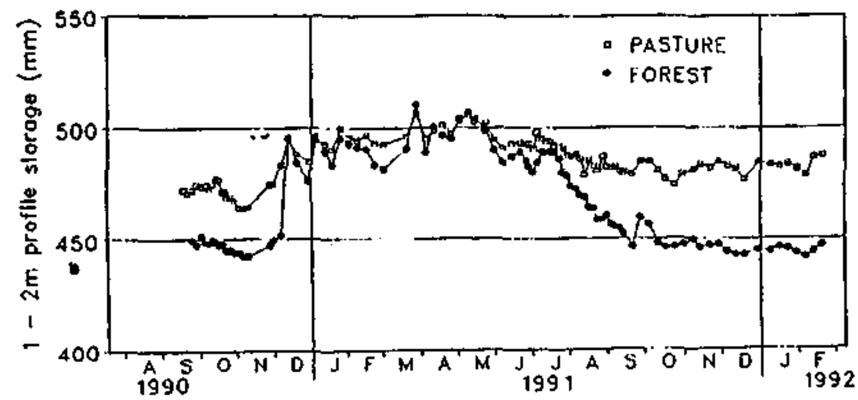

Figure 3. Mean storage between 1 and 2 m for the forest and the pasture.