Water balance in soil covered by regenerating rainforest in the Paraíba Valley region, São Paulo, Brazil

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ABSTRACT

The objective of this study was to evaluate the water balance in a Red-Yellow Latosol covered by a regenerating rainforest for 30 years in the Una River Basin between April 2016 and March 2017. Field capacity (FC) and permanent wilting-point values (PWP) used to calculate the available water capacity (AWC) in the soil were determined by the soil moisture characteristic curve obtained in pots, which made it possible to determine the soil residual water content (g / g) from the measurement of water tension in 15 Watermark (TM) sensors installed at depths of 40, 60 and 120 cm. Precipitation during the period (1962 mm) was obtained from the automatic weather station located 300 m from the experimental area. Soil surface runoff was obtained from 5 collectors distributed in the experimental area. Precipitation was characterized by a maximum of 454 mm in January 2017 and no rain in July 2016. The actual evapotranspiration was 744 mm. There were 56 runoff events (SR) totaling 60 mm. The average soil water tension remained below 37 kPa in 67% of the studied period, a condition that kept the soil moisture content high. The soil water balance of the tropical forest area, up to 120 cm deep, kept soil water content near its maximum capacity (173 mm) 49% of the time and saturated 51% of the time, so that it generated deep drainage beyond 120 cm deep and 1023 mm deep.

Keywords: environmental science, surface runoff, tensiometer, vegetation cover.

Balanço de água em solo coberto por floresta tropical em regeneração na região do Vale do Paraíba, São Paulo, Brasil

RESUMO

Objetivou-se avaliar o balanço hídrico em Latossolo Vermelho-Amarelo coberto por floresta tropical em regeneração há 30 anos, na bacia do rio Una entre abril de 2016 e março de 2017. Os valores da capacidade de campo (FC) e ponto de murcha permanente (PWP) usados para calcular a capacidade de água disponível (AWC) no solo foi determinado pela curva característica de umidade do solo obtida em vasos, a qual possibilitou determinar o teor de água residual do solo em (g / g) a partir da medição da tensão da água em 15 sensores Watermark (TM) instalados nas profundidades de 40, 60 e 120 cm. A precipitação no período (1962 mm) foi obtida na estação meteorológica automática localizada a 300 m da área experimental. O

escoamento na superfície do solo foi obtido de 5 coletores distribuídos na área experimental. A precipitação se caracterizou por atingir o máximo de 454 mm em janeiro de 2017 e ausência de chuvas em julho de 2016. A evapotranspiração real foi de 744 mm. Houve 56 eventos de escoamento superficial (ES) totalizando 60 mm. A tensão média da água no solo permaneceu abaixo de 37 kPa em 67% do período estudado, condição que manteve o solo com alto teor de umidade. O balanço hídrico no solo até 120 cm de profundidade da área de florestal tropical manteve a água armazenada no solo em 49% do tempo próximo a sua capacidade máxima (173 mm) e saturada em 51% do tempo de forma que gerou uma drenagem profunda além de 120 cm de profundidade de 1023 mm.

Palavras-chave: ciências ambientais, cobertura vegetal, escoamento superficial, tensiômetro.

1. INTRODUCTION

Water monitoring in ecosystems as a way to regulate supply can be decisive for human, industrial and irrigated-agriculture requirements, as well as for the conservation of the environment.

In the Paraiba River Valley, in the state of São Paulo, the decrease in economic activities such as cattle raising led to a change in the coverage of pasture lands to natural vegetation and then to the forest. On the other hand, there has also been an expansion of eucalyptus cultivation in large areas occupied by degraded pastures.

However, about 56% of the total area (472 Km²) of the Una River Basin is considered as "Class VIII" according to the Brazilian land-use capacity classification system, indicated for use to shelter wild flora and fauna, environmental recreation and education, or for water-storage.

The application of the CN method showed that after 17 years of natural regeneration of forest vegetation water-infiltration capacity in the pasture area increased by 31% and runoff was reduced by an average of 28% in the basin of Itaim, in Taubaté, SP (Aguiar *et al.*, 2003).

In the period from 2001 to 2007, Arguello *et al.* (2010) estimated an increase of 32.2% in the area of a eucalyptus plantation replacing pasture in the region of the Paraíba River Valley in the State of São Paulo. Anacleto and Batista (2016) mention coverage of 121,321 ha, or 8.5% of the catchment area, in 2013. However, Lima (1996) states that changes in the order of 20% of pasture for eucalyptus can have an impact on the regional economy and water dynamics in the soil-plant-atmosphere system.

The availability of total green water seems to meet the demands related to the main plant uses of the Paraíba do Sul River Basin (eucalyptus and grassland) and can still support eucalyptus growth in up to 20% of the basin area (Ferreira *et al.*, 2019).

In addition, in the Vale do Paraíba region, some studies in a basin of eucalyptus reforestation indicated soil losses below tolerance levels (0.08 mg per ha per year) in Argissolo Ranzini and Lima, 2002). When monitoring soil water -storage in the Paraiba Basin, Targa *et al.* (2017) revealed that at the end of 24 months the area with rain forest retained 88% of the maximum water storage-capacity in the soil, and that in eucalyptus only 64% of this capacity was reached.

The use of tensiometers allows the indirect determination of the moisture and water storage in the soil. Knowledge of soil water storage, precipitation, evapotranspiration and surface runoff enables the calculation of the water balance.

In the Paraíba Valley region, in a pasture-covered area (Salemi *et al.*, 2012), they observed that the potential of the soil-water matrix at depths of 15, 30, 50 and 90 cm generally does not exceed -87 kPa. In a study with tropical forests and eucalyptus in neighboring areas, Paula *et al.* (2013) found that during a 2-year monitoring period the potential of the soil matrix

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at depths of 30, 60 and 120 cm ranges between -22 and -180 kPa in the rainforest area and between -18 and -190 kPa in eucalyptus cultivation, which shows that the soil remained at a high level of humidity all the time. This study evaluated the water balance in a 30-year-old rain forest that was planted after the area was used for grazing cattle.

2. MATERIALS AND METHODS

2.1. Characterization of the study area

The study was done in an area of Atlantic forest planted 30 years ago by the Department of Agricultural Sciences of the University of Taubaté. The area is in the Una River Basin, in the municipality of Taubaté (SP), coordinates 23º01'51.13" S and 45º30'53" 04 'W, at an altitude of 594 meters (Figure 1).

The climate of the region is of the subtropical-humid type - Cwa (Köppen-Geiger), with an average annual precipitation of 1350 mm, with hot and humid summer, from November to February and cold and dry winter in the months of June to August (Fisch, 1999).
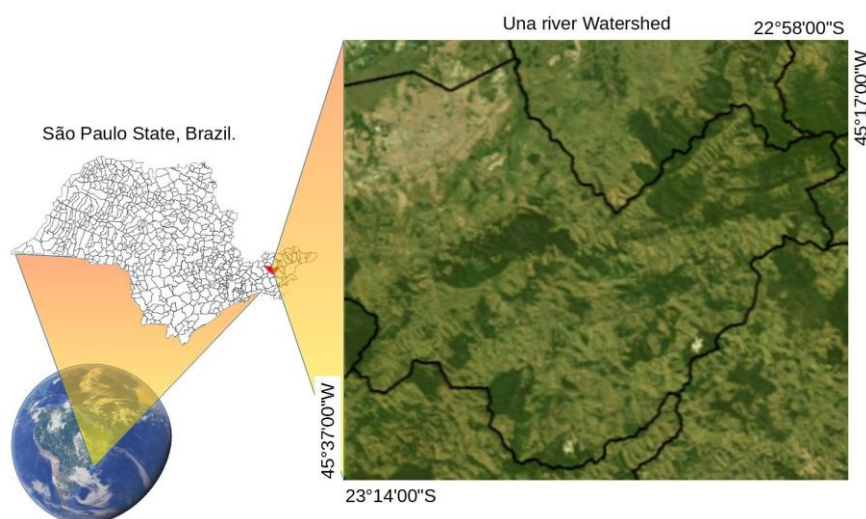

Figure 1. Location of Una River Watershed. TM/LANDSAT.
Source: Targa *et al.* (2017).

The soil sampling for textural and density analysis were done with the Ulhand-type sampler following the methodology of EMBRAPA (1997). The analyses were carried out at the Laboratory of Soils and Plants of the University of Taubaté.

2.2. Soil water retention curves

Water content in the soil was determined indirectly in the field by using WatermarkTM-type (TRACOM, 2004) sensors (Figure 2) to measure the potential of the soil water matrix in kPa, which is converted into water content (g / g) by means of the adjusted equation of the soil moisture characteristic curve.

The WatermarkTM sensor (TRACOM, 2004) consists of two concentric electrodes inserted in a granular matrix material. These electrodes are connected by wiring to a voltage meter that transforms the reading of electrical resistance into soil water potential, measuring accurately from 0 to - 200 kPa. The details of this monitoring system can be seen in Paula *et al.* (2013) and Targa *et al.* (2017).

The matrix potential of soil water (Ψm) in the rainforest areas of the Paraíba Valley generally does not exceed 200 kPa, as determined by Salemi *et al.* (2012); Paula *et al.* (2013) and Targa *et al.* (2017). Therefore, in this study, water-retention curves for each soil layer in both soil saturation and natural drought conditions was obtained inside containers based on 30-

day weighing of WatermarkTM sensor readings (Pohl, 2017). Details of the methods shown in Figures 2a and 2b.

Figure 2. (a) Procedure of installation of the Watermark TM sensor in the pots and (b) daily determination of the wet weight of the soils of the experimental area to obtain the retention curves.

The available water capacity (AWC) and current water storage (CWS) for soil layers of 0-40 cm, 40-60 cm and 60-120 cm were calculated weekly, respectively using Equations 1 and 2 from the readings of the tensiometers and transformation in humidity by means of the equations of characteristic curve of humidity in the soil (Targa *et al.*, 2017).

$$AWC = \frac{U_{FC} - U_{PWP}}{10} * ds * (z_u - z_l) \qquad (1)$$

$$CWS = \frac{U_A - U_{PWP}}{10} * ds * (z_u - z_l) \qquad (2)$$

Where:

AWC is the available soil water capacity in mm, considered as the maximum soil water-storage capacity;

CWS is the current water storage in mm;

U_{CF} is the gravimetric water content at field capacity in %;

U_{PWP} is the gravimetric water content at the withering point permanent in %;

U_A is the current gravimetric water content in %;

Z_u e Z_l are the upper (u) and lower depths (l) of the layer considered.

The residual storage in mm is calculated by the difference between the available soil water capacity (AWC) and the current water storage in mm (CWS).

2.3. Surface runoff collector

Based on the work carried out by Parchen (2007), five surface-runoff collectors were installed on the ground surface in the rain forest area, in line, with an average distance of 3.5 m between them. The collectors were made of galvanized sheets of 0.55 mm thickness, and in the front were installed two circular nozzles, where two transparent hoses of 1-inch diameter were connected to transport the collected water for two 20-liter containers (Figures 3a, b, c and d).
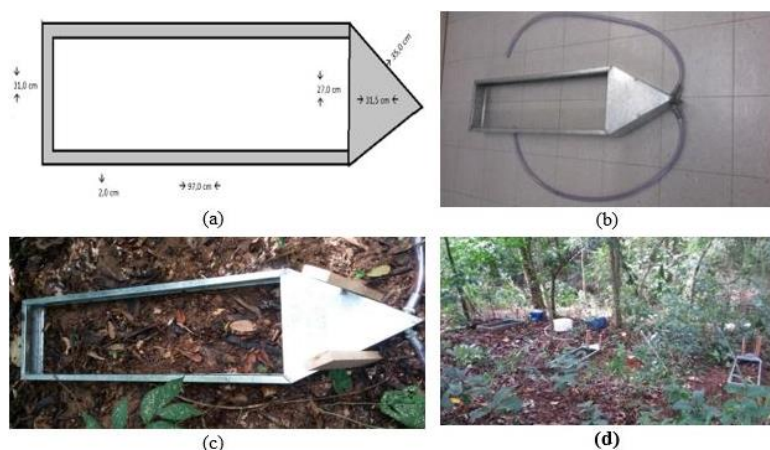
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Figure 3. Surface runoff collectors: a) dimensions, b) structure, c) installed and d) in the rain forest area.

2.4. Precipitation, Actual evapotranspiration and Temperature Data

The daily data of temperature and precipitation were obtained at the Meteorological Station of the University of Taubaté, located in the Department of Agrarian Sciences, about 300 meters from the study area. The actual evapotranspiration was calculated by the method of Camargo *et al.* (1999, adapted from Thornthwaite, 1948), by means of Equation 3 multiplied by 0.89.

$$EVT_0 = 0.01 * Q_0 * T \tag{3}$$

Where:

EVT_0 is the reference evapotranspiration in $mm.d^{-1}$

Q_0 is the extraterrestrial global solar radiation in $mm.d^{-1}$

T is the average daily temperature in ºC

2.5. Deep Drainage

"Deep drainage" was defined as the volume of water in mm that exceeds the lower limit of the control layer and was calculated by the water balance in the 0 to 120 cm profile between the various components of the hydrological cycle, using Equation 4.

$$Dp = P - ETa - SR + RWS \tag{4}$$

Where:

Dp is the Deep Drain (mm/dia);

P is the Precipitation (mm/dia);

ETa is the Actual Evapotranspiration (mm/dia);

SR is the Surface Runoff (mm/dia);

RWS is the Residual Water Storage (mm/dia).

3. RESULTS AND DISCUSSION

3.1. Rainfall in the rain forest area

The average annual rainfall in the study area is 1355 mm (Fisch, 1999). In this study, from April 2016 to March 2017, the total precipitation was 1962 mm. January 2017 had the highest rainfall, totaling 454 mm, while in July 2016 there was no rainfall (Figure 4). The greatest

precipitation occurred from November 2016 to March 2017, totaling 1512 mm, which represents 77% of the total precipitation in the period studied.
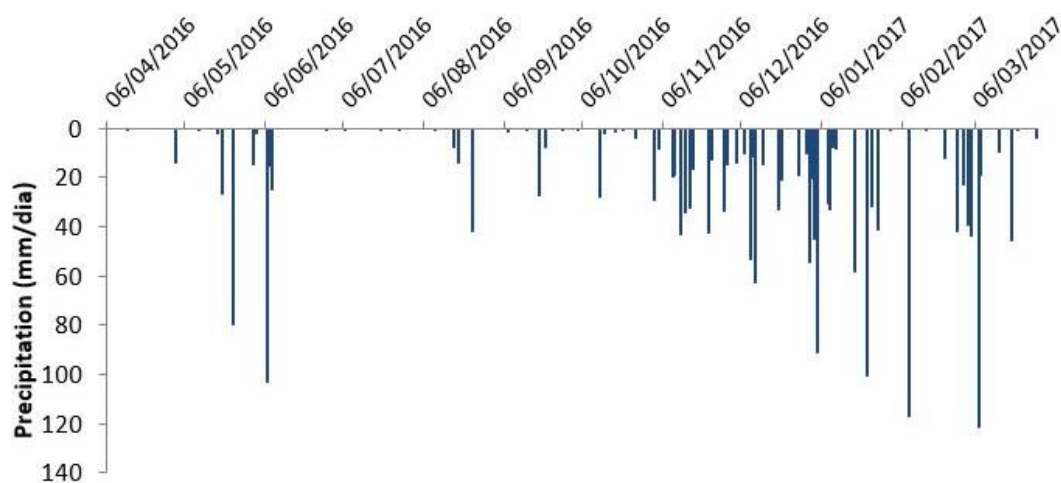

Figure 4. Precipitation (mm/dia) in the rain forest area, Taubaté, SP-Brazil, from April 2016 to March 2017.

Regarding the highest values observed (Figure 4), from November 2016 to March 2017, in November they were around 42mm (days 12 and 23), in December they were 53mm (day 9) and 62mm (day 11). In January 2017, besides some values of the order of 50 mm, the precipitation reached even higher values, with 91 mm (day 4) and 101 mm (day 23.) However, the highest values were 117 mm on February 8th and 121 mm on March 7th, 2017.

3.2. Actual Evapotranspiration in the rain forest area

For water balance, the daily values of actual evapotranspiration calculated by Equation 1 (Camargo *et al.*, 1999) were summed at each interval between precipitations. Actual evapotranspiration reached a total of 744 mm during the study period (Figure 5) which corresponds to approximately 38% of the total precipitate. The highest and lowest evapotranspiration values in the forest area were, respectively, in December (86 mm) and June (38 mm).
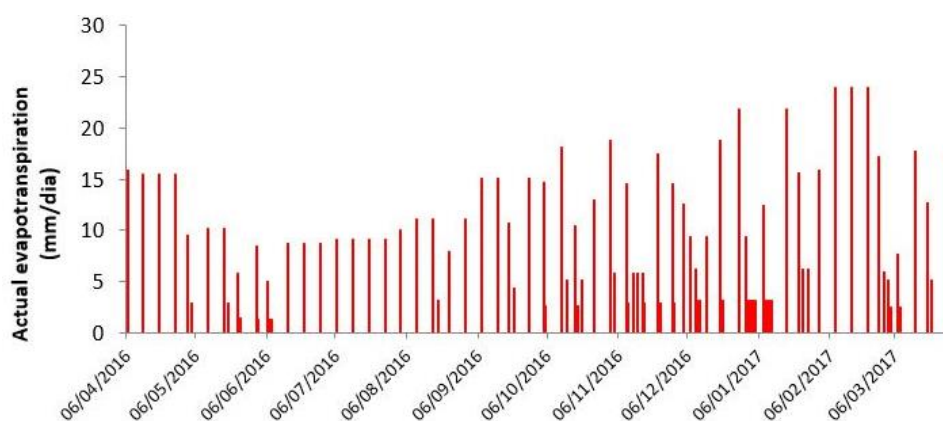

Figure 5. Actual evapotranspiration (mm/dia) in the rain forest area from, Taubaté, SP-Brazil, April 2016 to March 2017.

As shown in Figure 5, the actual evapotranspiration was more stable during the study period with an average value of 8.26 mm in the intervals between rains, denoting the availability of water in the soil. The highest values of actual evapotranspiration occurred from October 2016

to March 2017, coinciding with the days after the highest precipitation occurred. The highest values were around 16 mm (12/10), (11/11 and 11/23) and 12/20 2016. Actual evapotranspiration of the order of 19 mm occurred on 12/28 and 01/18. In February 2017, there were three moments in which the accumulated evapotranspiration in the period reached 21 mm (days 08, 17 and 22), the same occurring in March 2017 to the value of 16 mm.

3.3. Runoff in the rain forest area

Runoff in the rainforest area totaled 56 mm, which corresponds to 3% of precipitation over the entire study period. About 78% of this runoff occurred during the rainy season from October to March; the months with the highest runoff were January (47%) and March (15%). On the other hand, it is also observed that in the winter (June, July and August), which is the driest period in Taubaté, with only 7% of the annual precipitation occurring (Folhes and Fisch, 2007), surface runoff reached 18%. It should be noted that in the winter of the studied period, 11% of precipitation occurred, but in only three days in June a concentration of approximately 5% (102 mm) occurred, which justifies the large percentage of surface runoff in the dry period.

During the study period, 90 data readings were performed in the rain forest area, 50% corresponding to rainfall less than 0.7 mm, which did not generate runoff, which can be attributed to the accumulation of leaf residue on the soil surface. In addition to this, the soil of the experimental area has a higher percentage of sand in its composition, which provided greater water infiltration and decrease in runoff volumes, as shown in Figure 6.

It can be seen from Figure 5 also that only 10 events generated a flow greater than 1.0 mm. In the dry season (Figure 3), even with the occasional occurrence of high rainfall (80 mm), it was not possible to cause flow greater than 1.0 mm. However, the accumulation of 225 mm of precipitation over the previous 25 days generated a run-off of only 10 mm on June 6, 2016. The same occurred during the rainy season from October to February, when flows rarely exceeded 1 mm, and although the soil was more humid, the evapotranspiration was also higher. Flow lines generated in January 2017, with 4.7 mm (day 1), 11 mm (day 4) and 6 mm on March 4, 2017 occurred when evapotranspiration was lower, probably related to an occasional temperature drop. On days that rainfall in the order of 104 mm occurred, which in this basin corresponds to a rain of 50 years of return time (Martinez Jr. and Magni, 1999), the flow was in the order of 10 mm, denoting the positive influence of the rainforest in the infiltration of water in the soil. In pasture area in the same basin, Aguiar *et al.* (2007) found surface runoff values of 80 mm in the application of the CN method.
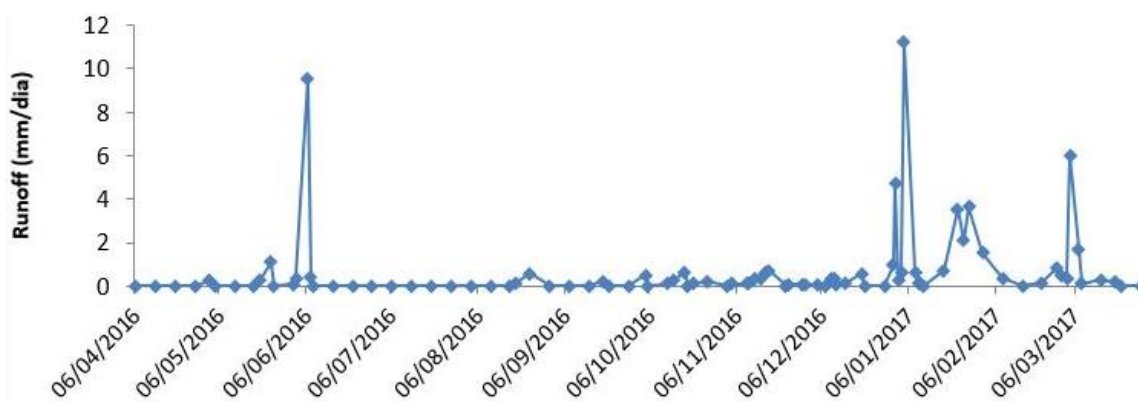

Figure 6. Runoff (mm/day) in the rainforest area in Taubaté, SP-Brazil from April 2016 to March 2017.

3.4. Physical and soil water characteristics of the rainforest area

Analysis of textural fractions and soil density (Table 1) were performed at the Soil and Plant Laboratory of the University of Taubaté. The soil of the experimental area of the rainforest

is a (Oxisol) Red-Yellow Latosol (EMBRAPA, 1997). The soil of the area presented the Franco-Argilo-Arenoso granulometric textural classification that has predominance of the sand fraction, justifying a great infiltration capacity in the rain forest area. The topography of the study area shows an average slope of 23%.

The soil moisture curves that relate the humidity and water tension in soil (kPa) for each soil layer of the forest studied are shown in Figure 7. The equations of these curves were adjusted by potential function and allowed the calculation of moisture values from soil field capacity (33 kPa) and permanent withering point (1500 kPa). The determination coefficients R^2 obtained when adjusting the soil moisture characteristic curves reached values above 0.93.
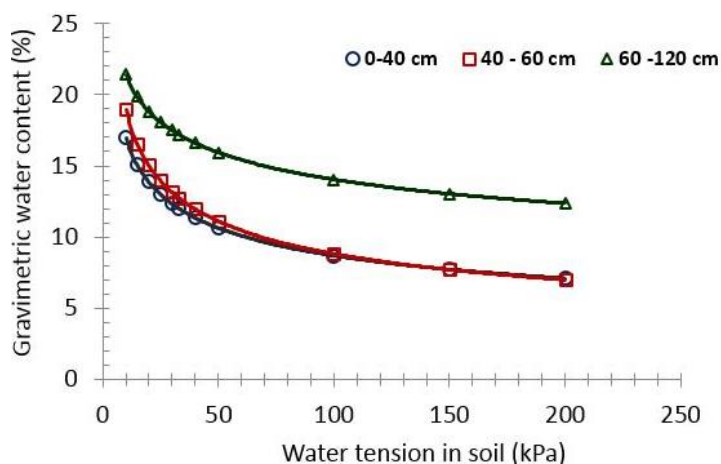

Figure 7. Characteristic soil water curves for the 0-40 cm layers; 40 - 60 cm and 60 - 120 cm in the rainforest.

With the values of gravimetric water content (%) in field capacity (U_{FC}), permanent withering point (U_{PWP}) and soil density for the layers 0 - 40 cm, 40 - 60 cm and 60 - 120 cm, it was possible to calculate from Equation 1 the Available Water Capacity (AWC) in mm for each soil layer of the rainforest area and also for the whole profile studied. These results and also the equation of the soil moisture characteristic curves of Figure 7 are found in Table 1.

Table 1. Water-retention equations and soil physical-water parameters for the layers of 0-40 cm, 40 - 60 cm, 60 - 120 cm and 0 - 120 cm in the rain forest area.

Layers (cm)	ds g.cm⁻³	Sand	Silt	Clay	(U_{FC})	(U_{PWP})	Soil Water-Retention Equations	R²	AWC
	g.cm⁻³		g.kg⁻¹		%	%			(mm)
0 - 40	1.476	619	111	270	12.0	4.0	$U = 33.187 \times T^{-0.291}$	0.93	47.50
40 - 60	1.509	567	131	302	12.8	3.6	$U = 40.885 \times T^{-0.333}$	0.98	27.69
60 - 120	1.892	560	125	315	17.2	8.6	$U = 32.615 \times T^{-0.183}$	0.98	98.14
0 – 120	1.625	582	122	296	14.0	5.4	$U = 35.552 \times T^{-0.269}$	0,96	173.34

The average soil water tension (T) measured by the tensiometers in the 12 months for the 0-40 cm, 40-60 cm and 60-120 cm layers were respectively 37.6; 38.9 and 34.3 kPa, indicate that the soil presented high moisture content during 67% of the studied period.

Considering the dry and rainy months of the region (Fisch, 1995), the average soil water tensions in the dry season (April to September) were 47.53, 38.7 and 28.1 kPa for the layers 0 to 40, 40 to 60 and 60 to 120 cm, respectively, while in the rainy season (October to March) the averages were 27.61, 39.2 and 40.5 kPa respectively for the same layers.

During monitoring with tensiometers, it was observed that the highest value found in soil tension and water was 98 kPa, slightly higher than that found by Salemi *et al.* (2012). However, the average tension between the dry and rainy periods was 37kPa, indicating that the soil was

moist most of the time as a result of water input from precipitation.

3.5. Soil water storage capacity in the rain forest area

Figure 8 shows the soil available water capacity (AWC) values as the maximum stored for the three layers, but also current water storage (CWS) in mm of this study. These data were calculated using Equations 1 and 2.

Maximum storage capacities for the 0-40 cm, 40-60 cm and 60-120 cm layers are indicated by the horizontal lines in Figure 8, and their values shown in Table 1 are 47.5 mm, 27.69 mm and 98.14 mm, respectively, for the 0 to 40 cm, 40 - 60 cm and 60-120 cm layers.

As can be observed, the soil in the three layers already presented with current storage values higher than the maximum and that came from the previous period. At various times during the study period, the maximum values of each layer were exceeded. The 0-40 cm layer presented the highest amplitudes of variation, since in approximately 62% of the period it was above the maximum storage limit of the layer, and at least five times it exceeded the maximum limit of 98.14mm of layer 60 - 120 cm, which reveals the function of the atmosphere-soil interface in the transmission of water to deeper layers. The 20-40 and 60-120 layers remained above the maximum storage limit by at least 47% of the study period.
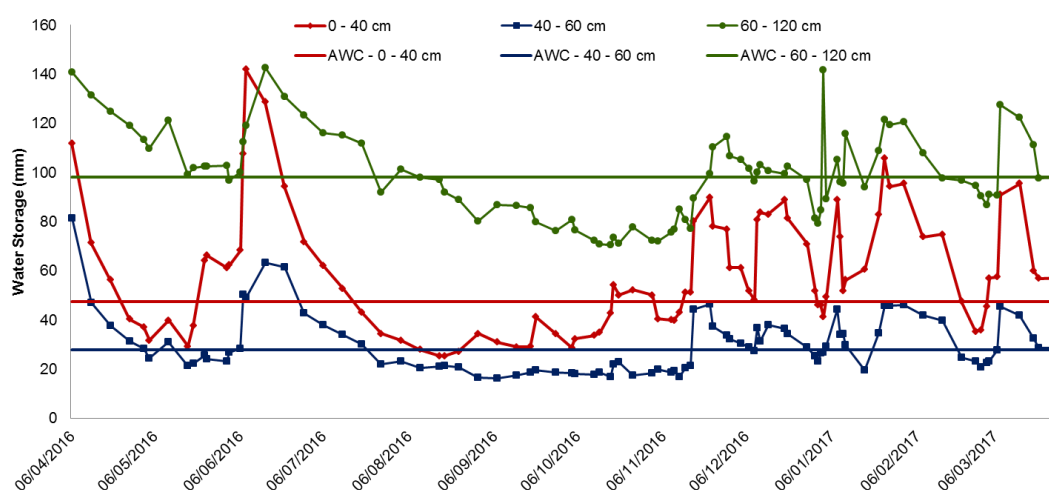

Figure 8. Soil water storage, in the layers 0 - 40, 40 - 60 and 60 - 120 cm in the rainforest area from April 2016 to March 2017.

During the driest period, between mid-July and September, as it is a period of low rainfall, soil water storage remained at an average of 28% of maximum capacity, which probably indicates that this water was supplied the deeper layer at 120 cm, slightly higher than that observed by Almeida and Soares (2003) in tropical and eucalyptus forests that found 15% of the maximum water storage capacity.

The movement of water in the soil is dynamic and in this study there were times when tensiometers indicated saturated soil, that is, values above the maximum storage capacity, such as points above horizontal lines, as shown in Figure 8. This saturation is important for rainforest river basins; due to precipitation, evapotranspiration is satisfied, runoff is low and excess water in the soil is directed to deeper layers in the form of deep drainage and can contribute to the supply of aquifers. In the present study, the soil remained saturated in all three layers for at least 51% of the period studied.

Deep drainage (Figure 9) in the rainforest area reached 1023 mm and represents the excess of water reaching depths greater than 120 cm. This deep drainage occurred whenever actual storage was greater than the maximum storage of the 0-120 cm layer, represented by the horizontal alignment in Figure 8.
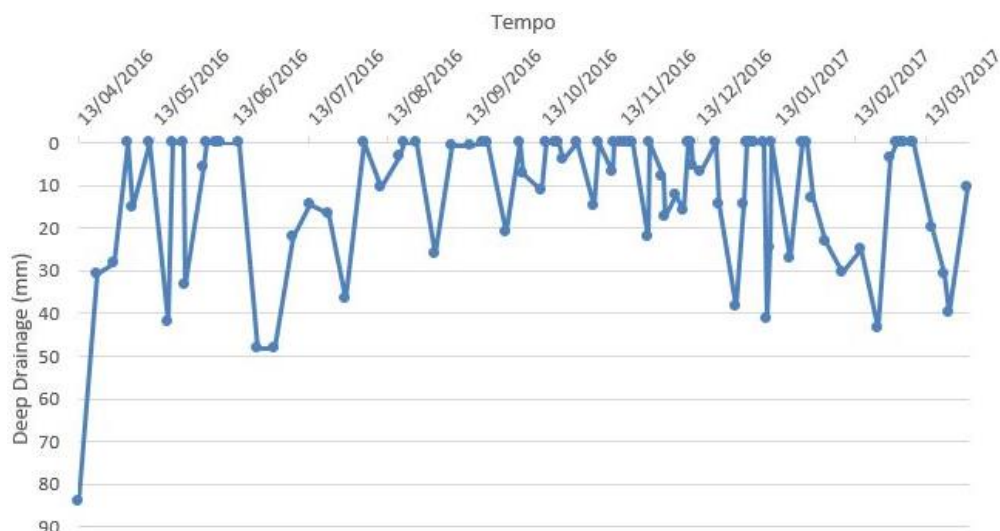
Figure 9. Deep drainage beyond 120 cm depth in soil covered with rainforest.

4. CONCLUSIONS

Based on the results obtained in the experimental area of native forest, it can be concluded that:

Soil water storage in the rainforest area throughout the study period was positive and remained close to the maximum (173 mm) during 49% of the study time and saturated during 51% of the time.

Actual evapotranspiration (744 mm) corresponded to 38% of total precipitation in the period;

The runoff was 60 mm, which represents about 3% of the total precipitation in the period.

A deep drainage beyond the 120 cm depth of the order of 1023 mm, representing 52% of the total precipitation, was generated.

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