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Spatial-temporal soil-water content dynamics in toposequences with different plant cover in a tropical semi-arid region[1]

Dinâmica espaço-temporal da água no solo em toposequencias com cobertura vegetal distinta no semiárido tropical

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ABSTRACT - Anthropogenic effects on the natural environment and on soil moisture in the tropical semi-arid region have not yet been determined. As such, the temporal variability of soil moisture was investigated in two toposquences under different types of plant cover: i) Caatinga under regeneration since 1978 (CReg); ii) Caatinga thinned by 40% (CThn). The research was carried out in two catchment located in the northeast of Brazil, with an area of 2.06 and 1.15 ha for CReg and CThn respectively. Soil moisture was determined using the gravimetric method. Three random soil samples were collected daily from the upper, middle and lower section of each catchment, giving a total of nine daily collections and 1620 collection in the period. CThn displayed higher values and a longer period for soil moisture. The lower section of the catchment showed values for soil moisture that were higher and statistically different ($p < 0.05$) from the other sections. The increasing value for the correlation between moisture and the seven days of antecedent rainfall indicates a low rate of decrease for soil moisture.

Key words: Plant cover. Spatial distribution. Water dynamics.

RESUMO - Os efeitos antrópicos sobre o ambiente natural e umidade do solo no semiárido tropical ainda não foram estabelecidos. Portanto investigou-se a variabilidade temporal da umidade do solo em duas toposequências com coberturas vegetais distintas: i) Caatinga em regeneração (CReg) desde o ano 1978; ii) Caatinga raleada (CRal) em 40%. A pesquisa ocorreu em duas microbacias localizadas no nordeste brasileiro, com áreas de 2,06 e 1,15 ha para CReg e CRal, respectivamente. A umidade do solo foi determinada pelo método gravimétrico. Foram coletadas, diariamente, três amostras aleatórias de solo na parte alta, média e baixa, totalizando nove coletas diárias e 1620 amostras por microbacia durante todo o período. A CRal apresentou maiores valores e maior tempo úmidade do solo. O trecho baixo apresentou umidades do solo estatisticamente distinta ($p < 0,05$) dos outros trechos. O valor crescente de correlação entre a umidade e a precipitação antecedente nos últimos 7 dias indica uma baixa taxa de decaimento de umidade do solo.

Palavras-chave: Cobertura vegetal. Distribuição espacial. Dinâmica da água.

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INTRODUCTION

Regions of semi-arid climate are characterised by an irregular rainfall regime, where rainfall is poorly distributed in space and time (MARENGO; TORRES; ALVES, 2017). These regions correspond to one third (22.6 x 10^6 km^2) of the total dry area - hyper-arid, arid, semi-arid and sub-humid, equal to around 41.3% of the surface of the continents (UNITED NATIONS, 2019). Semi-arid regions are inhabited by 14.4% of the global population, and, especially in these regions, their survival economic, social and environmental depends, among other factors, on the availability of water, a scarce resource. The constant demand for water by the population results in competition for the minimum amount required to maintain the ecosystems.

Other characteristics of the semi-arid region, especially the tropical semi-arid, such as the northeast of Brazil, are the water courses (rivers or streams), the majority of which are intermittent or ephemeral, reducing water availability for a very long period each year (8 to 10 months). In addition to the intrinsic particularities of the semi-arid region, the intensified anthropogenic exploitation of natural resources is another factor that has accelerated degradation of the soil, vegetation and water resources (SANTOS *et al*., 2016). For society to coexist with the semi-arid environment, necessarily requires a greater knowledge its hydrological processes and natural resources potential.

Recent research in the semi-arid region has demonstrated the relationship between vegetation management and its effects on the other processes of the hydrological cycle (FRY; GUBER, 2020; SANTOS *et al*., 2016) and ecosystem services (ANDRADE *et al*., 2019). Among the variables affected by vegetation management, soil moisture, which is all-important, should be highlighted, as it is decisive in the sustainability of the environment (PALÁCIO *et al*., 2013), the generation of runoff, infiltration and biomass production (AQUINO *et al*., 2017; RODRIGUES *et al*., 2013). Vegetation management that result in the increase and maintenance of higher soil moisture values are ways of mitigating the effects of climate change (LAL, 2018), as it results in greater production of above- and belowground biomass, with a consequent increase in the carbon stock of the environment.

It is known that soil moisture occupies a critical position in relation to hydrology, agroecology and ecology, as it regulates various natural processes (PINHEIRO; COSTA; ARAÚJO, 2013).Soil moisture in both time and space is controlled by different factors, such as: the arrangement of the soil attributes (physical, chemical and biological) (POLTORADNEV; INGWERSEN; STRECK, 2016); the characteristics of the rainfall events (WENKUI BAI *et al*., 2019) and the characteristics of the topography (HONGCHANG HU *et al*., 2019; WEI *et al*., 2019;), in addition to land use (HUANG *et al*., 2016; PINGPING ZHANG; MING'AN SHAO, 2015). However, identifying the relative significance of each of these factors is a challenge since they have a mutual influence on soil moisture. This challenge is even greater in dry regions, where soil moisture remains low for a period of 8 to 10 months of the year, and the only water input to the system is via rainfall.

There is therefore a clear need to investigate the complex spatio-temporal distribution of soil moisture in tropical dry regions, as is the case in the northeast of Brazil. To address this question, the aim of the present study was to investigate the temporal variability of soil moisture in a toposequence of two catchments inserted in the Caatinga phytogeographical domain, under different plant cover: i) tropical forest under regeneration since 1978; ii) 40% thinning of the native vegetation.

MATERIAL AND METHODS

Study area

The two toposequences under study are inserted in the Caatinga phytogeographical domain - CPD, in the district of Iguatu, in south-central Ceará, between 6°23'42'' to 6°23'47'' S and 39°15'24" to 39°15'29" W (Figure 1). The climate in the region is classified as type BS, hot semi-arid, by both the Köppen climate classification and the Thornthwaite Aridity Index (1948) of 0.44. The mean rainfall in the estadied area for the historical series from 1912 to 2017 was 880 mm. The rainfall events show a unimodal distribution, with 84% concentrated from January to May, and 30% in a single month, March. The mean potential evaporation is approximately 1988 mm yr^{-1} (FUNDAÇÃO CEARENCE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2019). The soil was classified as a VERTISSOLO EBÂNICO Carbonático típico according to the Brazilian System of Soil Classification (SANTOS *et al*., 2018). Table 1 presents some soil characteristics of the study area.

The catchment is formed from first and second order watercourses, and are therefore an area of springs. They display ephemeral runoff, with water flowing in the main channel during the rainfall event and for an average period of not more than 24 hours after the end of the rainfall. The two catchments have the following vegetation cover: i) CReg - Caatinga under regeneration since 1978 (Figure 2) and ii) CThn - thinned native vegetation (Figure 3).

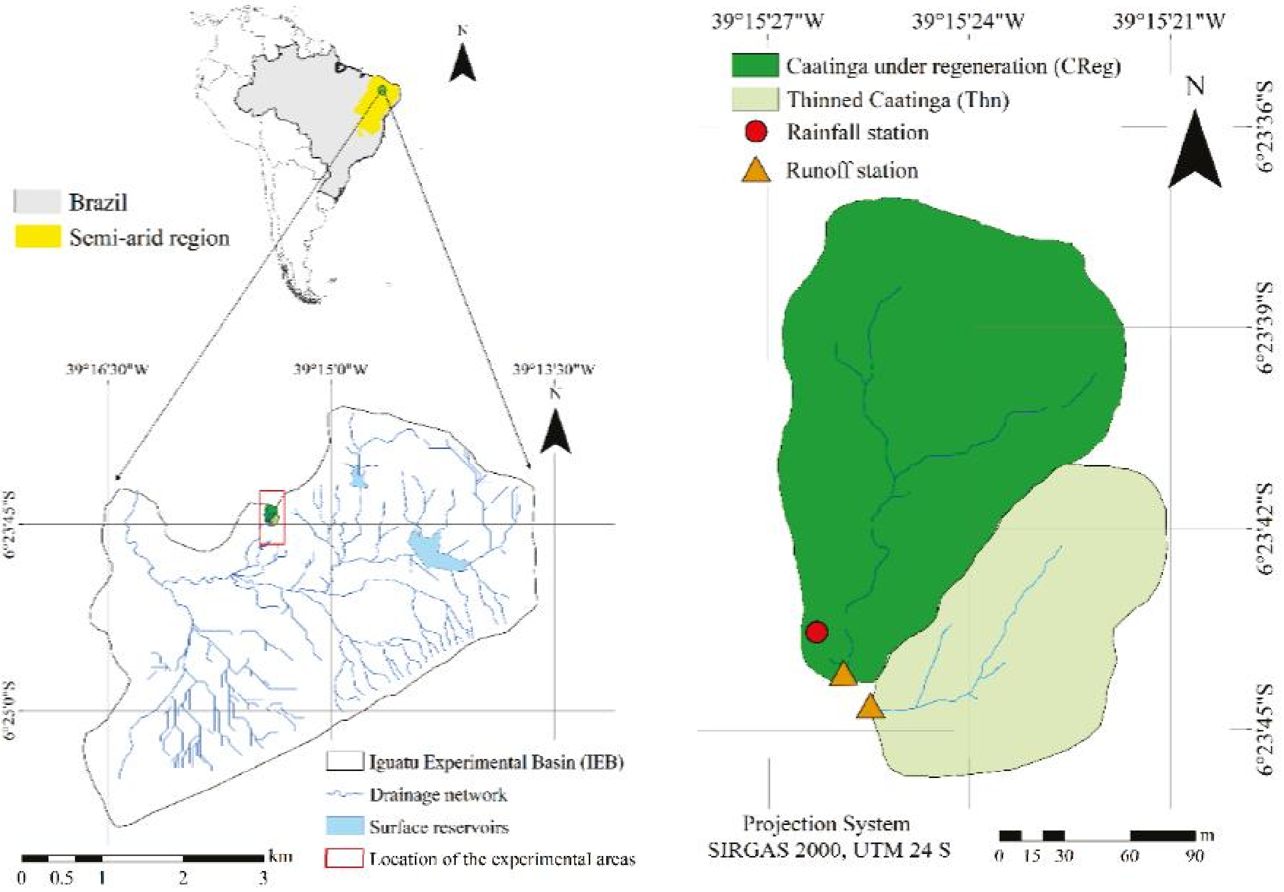
The caatinga vegetation of the CReg area displays denser tree stand and shrublike deciduous plants, with the species *Croton sonderianus, Mimosa caesalpiniifolia*

Table 1 - Soil characteristics of the study watershed

Physical and chemical soil attributes			
Horizons	A	B	BCv
Layer (cm)	0 to 5	5 to 21	21 to 31
Sand (g kg^{-1})	137	205	182
Silt (g kg^{-1})	447	405	470
Clay (g kg^{-1})	416	390	348
Silt / Clay	1	1	1
C (g kg^{-1})	24.1	13.3	10.2
pH	7.6	8.2	8.2
Ca (cmol$_c$ kg^{-1})	35	43	39
Mg (cmol$_c$ kg^{-1})	12	10	8.6
K (cmol$_c$ kg^{-1})	1.04	0.37	0.29
Na (cmol$_c$ kg^{-1})	0.13	0.13	0.15
H + Al (cmol$_c$ kg^{-1})	1.7	1.2	1.2
$CaCO_3$ (cmol$_c$ kg^{-1})	145	144	151
P (mg kg^{-1})	42	62	59
Electrical conductivity (dS m^{-1})	0.48	0.3	0.29

C - Carbon; pH - Hydrogenpotential; Ca - Calcium; Mg - Magnesium; K - Potassium; Na - Sodium; H + Al - Hydrogen + aluminum; CaCO3 - Calcium carbonate; P - Phosphorus; EC - Electrical conductivity

Figure 1 - Location of the study area in the experimental catchmentss in the district of Iguatu, Ceará



and *Aspidosperma pyrifolium* predominating (Figure 2) (PEREIRA JÚNIOR *et al*., 2016). Whereas CThn represents a suitable management practice by small farmers in the Brazilian semi-arid region for promoting an increase in ruminant feed (ARAÚJO FILHO, 2013). Thinning was applied in order to check the influence of this practice on runoff generation, water erosion and sediment production (Figure 3).

Thinning consisted of eliminating individuals with a diameter of less than 10 cm. The removal of these individuals resulted in a 40% reduction in canopy cover. Branches and twigs with a diameter of less than two 2 cm were chopped up and spread over the soil as mulch (Figure 3A), serving as an additional source of organic matter and reducing the impact of raindrops on the soil. The treatment was applied at the beginning of November 2008, with maintenance carried out in December 2010 and December 2012. Opening the tree layer by thinning, allowed more sunlight to enter, with greater development of the herbaceous layer (Figure 3B). Regarding the history of land use, before 1980, the area of the two catchments was used for cultivating subsistence crops, specifically maize (*Zea mays* L.) (AQUINO, 2015).

Since the catchments are adjacent and part of the same drainage network, the rainfall data were obtained from a automatically rainfall station installed at the confluence of the watercourses with 5-minute reading interval.

Figure 2 - Caatinga under regeneration since 1978 (CReg). (A) aspect of the plant cover during the dry season, when the plants completely lose their leaves. (B) aspect of the plant cover during the rainy season, with regrowth of the leaves

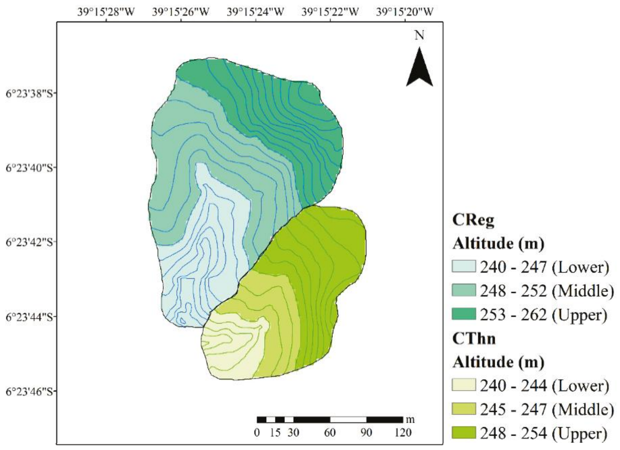
Figure 3 - Caatinga subjected to thinning (CThn). (A) aspect of the plant cover immediately after application of the thinning technique. (B) aspect of the plant cover after the start of the rainy season and the appearance of the herbaceous layer

Soil moisture

To determine the collection points for soil moisture representative of the toposequence in each area based on the topographic map, areas corresponding to the upper, middle and lower third of each of the catchment were chosen. With the aid of the ArcGis software, the hypsometric curve for each catchment was obtained, thereby defining the sections for each area (Figure 4), which varied between 240-247, 248-252 and 253-262 m respectively for the lower, middle and upper sections of CReg; and 240-244, 245-247 and 247-254 m for the lower, middle and upper sections in CThn. The division between each section also made it possible to define zones of different slopes, an important factor in controlling runoff.

The standard or gravimetric method was used to determine the soil moisture, with samples taken from the 0-10 cm layer. Adoption of the surface layer only is based on the following considerations: 1) the greatest spatio-temporal dynamics for soil moisture occurs in the first layer of soil, which sees the greatest interaction between the atmosphere and the lithosphere; 2) the study area is located in a dry region with a depth from the profile to the impermeable layer between 2 to 3 m. Three random samples were taken every 24 hours in each section, giving a total of nine daily samples per toposequence. The mean value of the three samples per section represented the average level of soil moisture for the respective section. The mean daily value for soil moisture in each basin is represented by the average of the nine collection points. The study period was from 23 January 2019 to 17 July 2019, resulting in 1620 samples per toposequence (180 days of collection x 9 samples). The wet period, and the transition period between the wet and dry periods were defined from the following dates: from 23 January to 17 May (wet period), when the soil moisture persisted due to the rainy season; and from 20 May to 18 July (wet/dry transition), when the soil water loss was intensified.

Figure 4 - Division of the sections, lower, middle and upper in the CReg (A) and CThn (B) catchment



The soil samples were packed in properly sealed aluminium cans to prevent moisture loss. Each sampled volume corresponded to the volume of the can. The samples were sent to the Water, Soil and Plant Tissue Laboratory of IFCE - Iguatu Campus, where they were dried in an oven at 105 ºC for 24 hours. After drying, the moisture was obtained using the method described in the Handbook of Soil Analysis (PANSU; GAUTHEYROU, 2007), where the gravimetric soil moisture is determined as per equation 1.

$$U = \frac{M1 - M2}{M2 - M3} * 100 \qquad (1)$$

where: h - soil moisture, expressed as a percentage (%);

M1 - wet soil weight plus the weight of the container, expressed in grams (g)ç

M2 - dry soil weight plus the weight of the container, expressed in grams (g);

M3 - weight of the container, expressed in grams (g).

Statistical Analysis

The first step was to verify whether the data showed a normal distribution or not, using the Anderson-Darling test ($p \leq 0.05$). When the data distribution was not normal, the Kruskal-Wallis test was used to verify the differences between the mean values for moisture between the sections and between the catchment, in addition to identifying the effect of the antecedent rainfall on soil moisture, Pearson’s Correlation (r), soil moisture, daily rainfall and 1 to 5 days antecedent rainfall (ANTR1 to ANTR5) were performed. The data were processed using the MINITAB v18 software, where the statistical analysis was carried out.

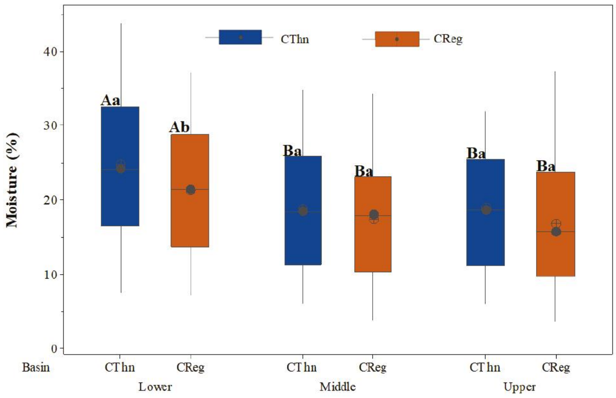
RESULTS AND DISCUSSION

The lower section registered the highest values for soil moisture in both basins, followed by the middle and upper sections (Figure 5), however only the lower section differed statistically in each basin. Although soil moisture in the CThn catchment was higher throughout the entire toposequence (Figure 5), only the lower section of this catchment showed any significant difference ($p < 0.05$), both in relation to the other sections and between the catchment. Since the characteristics of soil texture were similar in both areas (ANDRADE *et al*., 2019), the greater values for soil moisture quantified in CThn may be due to:

The dense herbaceous layer that imposes greater roughness on the soil surface, reducing the speed of the water flow and increasing the opportunity time for the water to infiltrate the soil. This increase in soil moisture by the undergrowth was also seen by other authors (ANDRADE *et al*., 2019; WANG *et al*., 2018). Another way for the herbaceous layer to contribute to the increase in soil moisture is via the fine roots of the root system, which act as microchannels that favour infiltration (AQUINO *et al*., 2017; PINHEIRO; COSTA; ARAÚJO, 2013).

The slope of the toposequence, which has a direct influence on rainfall distribution in catchment. The interference of topography in soil moisture and biomass production was seen by Wei *et al*. (2019) in studies developed on dryland grassland ecosystems in Inner Mongolia, China. The authors also identified a significant difference in the lower section of the area under study only. The effect of topography was also found by Fry and Guber (2020), studying the temporal stability of field-scale spatial patterns for soil water content in topographically diverse agricultural landscapes. The authors point out that the topography can influence rainfall redistribution, affecting the variability of the soil moisture.

Figure 5 - Average soil moisture by toposequence section and plant cover. Identical uppercase letters between the sections of the same catchment do not show any statistical difference for $p < 0.05$. Identical lowercase letters between catchment in the same section do not show any statistical difference for $p < 0.05$



Since the data presented similar median and mean values (Figure 5) without the occurrence of outliers, an analysis was carried out per period, between the wet period (23 January to 17 May, 2019) and the transition period between the wet and dry periods (20 May to 18 July) (Table 2). The mean values for both the wet period and the transition period showed the same trend as did the overall values, i.e. the lower section presents the highest values, and in the middle and upper sections, the soil moisture is similar. For both periods, CThn contains the greatest soil moisture. During the transition period, the soil moisture in both areas presented greater spatio-temporal variability, expressed by the high values for the Coefficient of Variation (CV > 39%), with the highest CV values recorded in CReg. The lower values for soil moisture express most effectively the variability of the soil, contributing to higher CV values during the transition period (DARI *et al*., 2019). The lower CV values for the rainy period express the effectiveness of the rainfall with a smaller variability in soil moisture, as discussed by Wenkui Bai *et al*. (2019).

The influence of topography on soil moisture can be seen in both catchment, since the moisture gradient in each runs from the high to the low sections. This soil moisture gradient is due to a larger slope in the upper section and a smaller gradient in the lower section, i.e. to the topographic aspect of the longitudinal profile of the hydrographic basin (WEI *et al*., 2019) and to the difference in level expressed by gravitational energy (ZHAO *et al*., 2014). It is known that in the upper section of a catchment, the

Table 2 - Mean, coefficient of variation and standard deviation of soil moisture by toposequence section in the two catchmentss

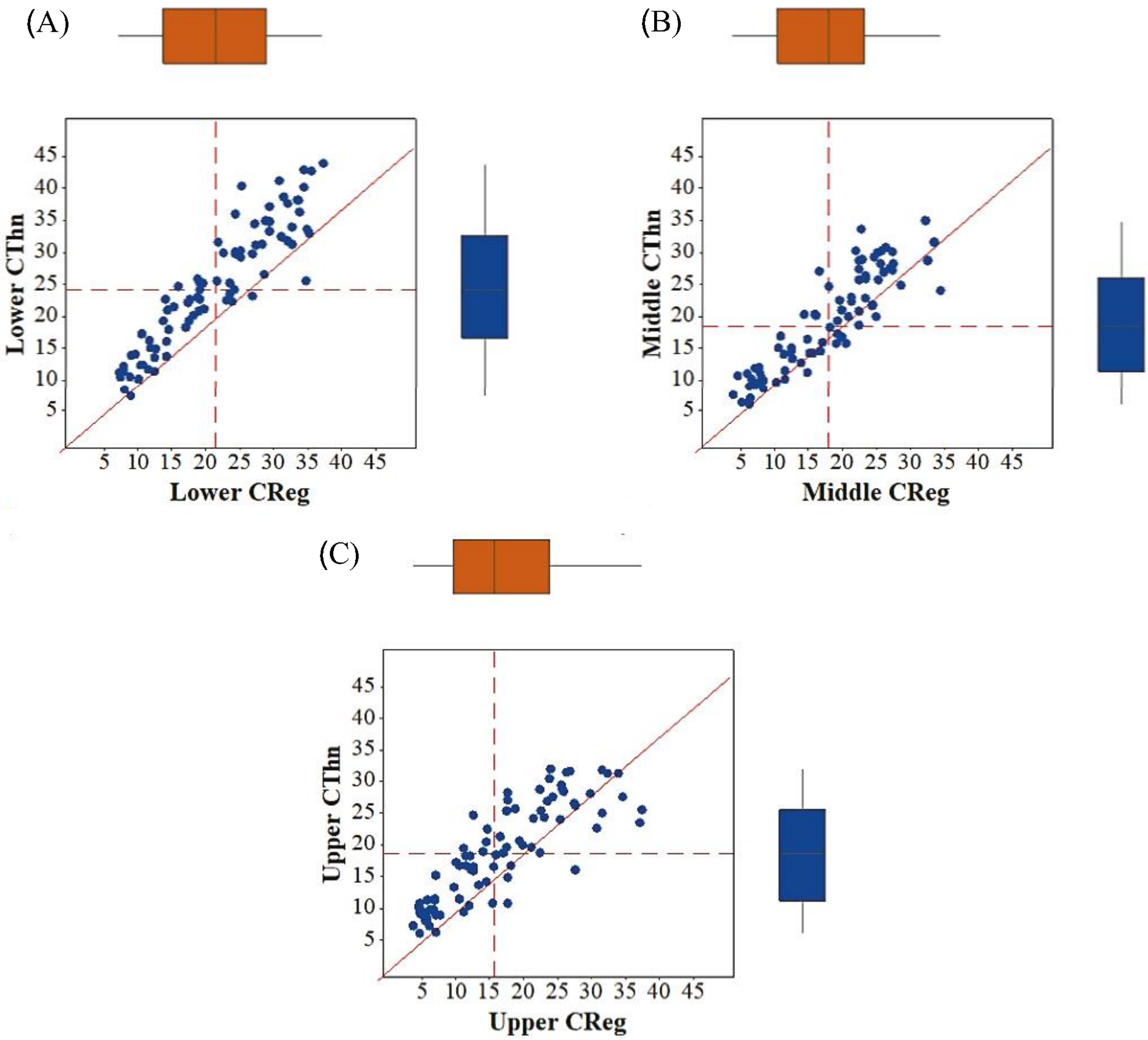
Section	Wet period			Transition period wet/dry		
	Mean (%)	SD (%)	CV (%)	Mean (%)	SD (%)	CV (%)
Lower CReg	26.11	6.62	25	13.84	6.15	44
Middle CReg	21.45	6.17	29	10.98	6.12	56
Upper CReg	21.87	7.44	34	8.79	4.79	55
Lower CRal	30.39	7.05	23	16.34	6.41	39
Middle CRal	22.73	6.44	28	12.79	5.70	45
Upper CRal	22.53	6.20	27	13.22	6.24	47
Basin	Mean (%)	SD (%)	CV (%)	Mean(%)	SD (%)	CV (%)
CReg	23.25	6.22	27	11.31	5.51	49
CRal	25.22	5.91	23	14.12	5.81	41

runoff speed is greater due to the greater topographic gradient; whereas the lower section of a basin is a deposition zone, with a reduced topographic gradient (HONGCHANG HU *et al*., 2019) and a lower runoff speed, which can favour greater soil moisture.

It is believed that the greater soil moisture recorded in the CThn catchment, both in the overall mean value for the catchment, and in the mean value per section throughout the toposequence, is the result of the greater density of herbaceous vegetation, as discussed by Andrade *et al*. (2019). It is known that herbaceous vegetation contributes to a reduction in runoff (RODRIGUES *et al*., 2013), with a consequent increase in water infiltration in the soil, and a reduction in its temperature (PINGPING ZHANG; MING'AN SHAO, 2015).

Comparing soil moisture between the two types of plant cover throughout each section of the toposequence, the points can be seen to be distributed along the 1:1 curve (Figure 6). This distribution pattern shows that both areas respond in a similar way to rainfall pulses that promote an increase in soil moisture. For the lower section (Figure 6A), the area of CThn plant cover presented values for soil moisture higher than those recorded for CReg in 86% of the samples. This percentage decreases towards the upper sections of the catchment, becoming 68 and 72% in the middle and upper sections respectively. The greater dispersion of the point cloud in the upper section (Figure 6B) shows that the mitigating effect of the plant cover is less in the upper sections and becomes more obvious in the lower section.

Figure 6 - Moisture dispersion in the toposequence sections



The increasing difference in soil moisture with slope between the two catchments can be explained by the effect of the herbaceous cover on the runoff process along the ramp. One explanation is that the occurrence of denser herbaceous plant cover after thinning (Figure 3B) promotes an increase in the roughness of the surface over which the water flows. This results in a reduction in runoff speed, increasing the initial abstraction and the infiltration capacity of the soil (ANDRADE *et al*., 2019), which results in greater soil moisture. Increases in the herbaceous layer result in better soil structure due to the root system, favouring the formation of preferential paths for water to infiltrate the soil (PINHEIRO; COSTA; ARAÚJO, 2013; WILCOX *et al*., 2017).

Since the water courses are ephemeral with no base runoff, the temporal variability of the soil moisture under both types of plant cover responded directly to the variations in rainfall (Figure 7), the only source for water entering the system. Over the 180 days of monitoring soil moisture, CThn showed greater moisture than did CReg, except in 14% of the determinations made. The average moisture varied from 4.8 to 35.4% and from 7.9 to 36, 8% for CReg and CThn respectively. The highest value for moisture occurred on 3 April in CThn (36.75%), however, it did not coincide with the largest rainfall event (71.25 mm). In CReg, the highest value for moisture (35.4%) on April 12, occurred one day after the largest rainfall event (71.3 mm). As the process is multivariate, the high spatial-temporal variability in daily hydrological events makes it difficult to establish a direct relationship between soil moisture and any one isolated variable (POLTORADNEV; INGWERSEN; STRECK, 2016).

The rainy season lasted until 20 May (Figure 7), when a sharp decrease in moisture values begins. This behaviour is expected, since rainfall is the main determining factor of soil moisture in dry regions (KE ZHANG *et al*., 2019; WENKUI BAI *et al*., 2019). From 10 June, the soil moisture began to show a constant value of around 8%, with the exception of 18 June, when there was 8.5 mm of rainfall, which raised the soil moisture from 8.5 and 6.9% to 23.0 and 20.7% in CThn and CReg respectively. This proves that soil moisture responds to rainfall pulses of less than 10 mm. In the surface layers of the soil, the moisture is generally quite variable and dependent on the recharge from rainfall (LEI YANG *et al*., 2014). However, small rainfall events only affect storage in the surface layer, since the wet front of the infiltration process that originates in small rainfall events does not reach to great depths (HE *et al*., 2012).

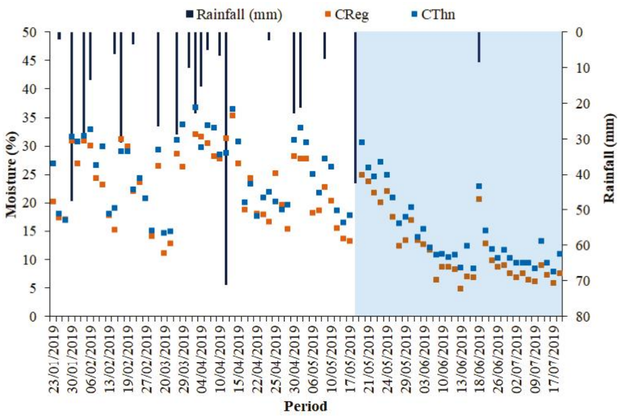
The dependence of moisture on rainfall was also seen in each section of the catchment, with its most striking effect in the lower section of CThn (Figure 8). On the other hand, in CReg, the difference in absolute moisture values between one section and another was relatively less, proving that rainfall distribution is affected both by management of the plant cover and by the topography (WEI *et al*., 2019). As such, there can be significant differences in soil moisture due to the influence of the topography on rainfall redistribution, even in relatively small areas with similar soil and geomorphological characteristics. Another process that determines the variability of soil moisture even in catchment is the spatio-temporal variability of the rainfall (WEI *et al*., 2019). This highlights the importance of obtaining information on the spatial variability of rainfall, even on a small scale.

There is also a difference in moisture between the extreme values (maximum and minimum) in the sections of each catchment. In CThn the highest value for moisture was registered in the lower section (43.8%), while the highest value in CReg for the same section was 37.1%, a difference of 6.7%. The minimum value for each catchment was recorded in the upper section, with values of 3.6 and 6.0% for CReg and CThn respectively.

Despite the variation in soil moisture throughout the toposequence having shown greater dependence on the larger rainfall events (Figure 8), the soil moisture showed a greater correlation ($p < 0.001$) with the accumulated rainfall (Figure 9). For example, it should be noted that on 8 April a rainfall of 5 mm and soil moisture of 43% were recorded in the lower section of CThn. The occurrence of daily rainfall with a total of 62 mm was identified in the five days preceding 8 April (Figure 8).

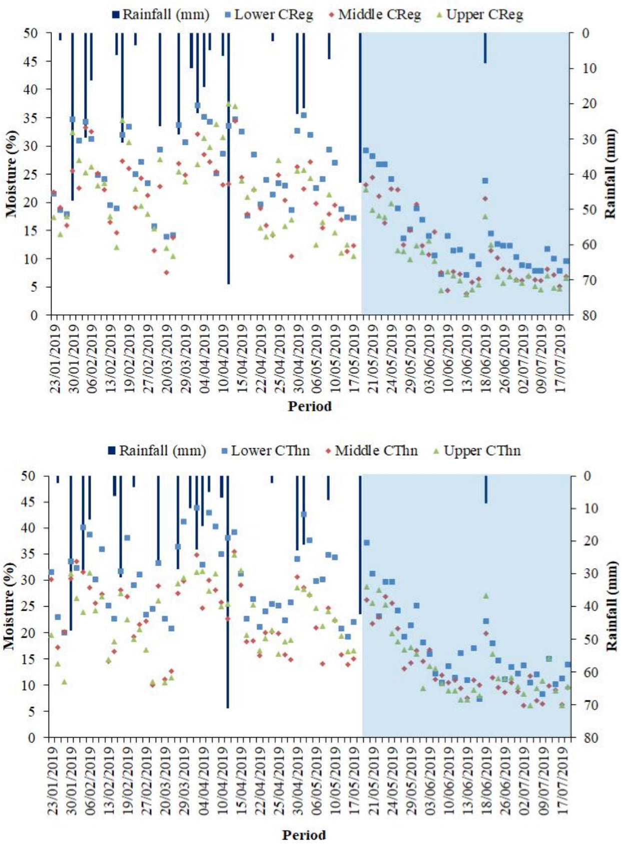
The degree of influence of accumulated rainfall on soil moisture, regardless of the position in the toposequence, is shown in Figure 9. Both the average soil moisture of the catchment under each type of plant cover and the soil moisture per section showed a significant

Figure 7 - Rainfall and daily mean values for soil moisture in CReg and CThn



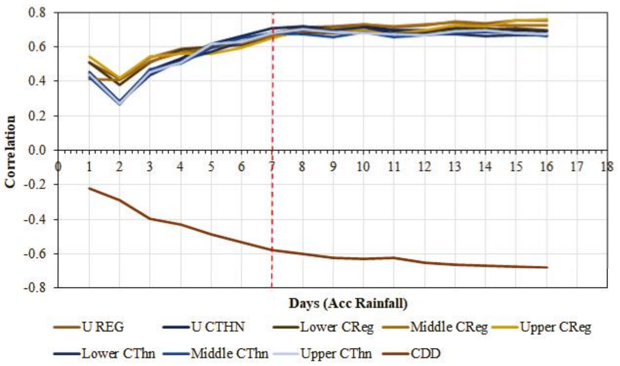
The areas highlighted on the graph (light blue) represent the start of the transition period, when the soil began the process of moisture loss and increasing correlation ($p < 0.001$) with the number of days of antecedent rainfall, until stabilising at seven days. Compared to CThn, soil moisture in CReg showed a greater correlation with accumulated antecedent rainfall

Figure 8 - Rainfall and moisture variability in the toposequence sections



The areas highlighted on the graph (light blue) represent the start of the transition period, when the soil began the process of moisture loss

Figure 9 - Pearson's correlation coefficient between the moisture in the 0-20 cm layer of the catchment and in the sections with rainfall, accumulated antecedent rainfall and consecutive dry days



up to five days (Figure 9), when both catchment began to show the same correlation.

The lower correlation of the soil moisture in CThn for the first five days of accumulated rainfall demonstrates that during the initial phase, soil moisture can be explained by other factors, such as the herbaceous layer present in CThn. The undergrowth favours greater soil moisture, whether by an increase in the roughness of the soil surface (ANDRADE *et al*., 2019), or by the formation of root channels (PINHEIRO; COSTA; ARAÚJO, 2013; WILCOX *et al*., 2017), or even by a reduction in runoff and an increase in infiltration (RODRIGUES *et al*., 2013).

There was a negative correlation between soil moisture and consecutive dry days (CDD), since there is a reduction in soil moisture as the amount of dry days increases. With few CDD (<4), soil moisture showed little dependence on the number of CDD; after seven CDD, the correlation is equal to or greater than -0.6, with a tendency to become established. This behaviour demonstrates that soil moisture is better explained by CDD from seven onward.

The increase in the degree of correlation between soil moisture and antecedent rainfall shows that the rate of decrease of the moisture is low, since, even after a period of five days, the moisture content still presents a moderate increasing correlation. This low rate of decrease for soil moisture is explained by the characteristics of the soil in the area, which, being a Vertisol, has a high clay content, affording good conditions for water retention (SANTOS *et al*., 2018).

CONCLUSIONS

1. The difference in soil moisture was clearly affected by the plant cover, in the thinned caatinga, affording higher values and a longer period of moisture (higher percentage of herbaceous cover) compared to the caatinga under regeneration;
2. The lower section of the catchment under study, i.e. the section nearest the outlet, had the greatest moisture and differed statistically from the other two sections in both catchmentss. This behaviour shows that the slope was fundamental to the difference in moisture between the sections, where the greatest moisture was recorded in the more level areas;
3. The correlation between moisture and antecedent rainfall was higher than the correlation with same-day rainfall in both catchment. This correlation gradually increases until reaching that of the accumulated antecedent rainfall at seven days, when it stabilises. This shows that up to seven days antecedent rainfall is a parameter that should be considered in studies of soil moisture.

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