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Monitoring of soil moisture in Long-Term Ecological Research (LTER) sites of Romanian Carpathians

Lucian Dincă[1§], Ovidiu Badea[2], Gheorghe Guiman[3], Cosmin Bragă[3], Vlad Crișan[1], Victor Greavu[4], Gabriel Murariu[5], Lucian Georgescu[5]

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Abstract. Understanding soil moisture and its relationship with different climatic and soil characteristics is essential for better analysing the interactions between forest and soil water dynamics, allowing us to more precisely predict climatic changes. The present paper investigates the temporal variability of soil moisture in three different forest ecosystems (LTER – long term ecological research site) with the same soil type (Eutric Cambisol). Soil moisture was measured daily from 2011 to 2016 by using three sensors at three different depths (20, 40, 70 cm). We identified the interactions between soil properties, vegetation type, local climatic conditions and soil moisture. In order to establish the temporal variability of the soil moisture content, we have applied two procedures, namely the Fourier series and the neural network fitting. A high variability in time and depth for soil volumetric water content was identified. The highest soil moisture levels were recorded at higher depths (70 cm) for almost all surfaces, with the exception of the Fundata surface because of the occurrence of limestone. In the mountainous areas, with higher precipitation (Fundata and Predeal sites), volumetric soil water content was mainly influenced by soil physical characteristics. Soil moisture levels below the drought level were only recorded for the Stalpeni site from September to October 2012. There was a delay between the precipitation event and soil humidification of 0.4-0.8 time units (days). We also found a significant correlation between soil moisture and soil texture and a weak correlation with vegetation type. Temperature influenced soil moisture levels at almost all depths, while precipitation only had an impact when there was a delay of 1 or 2 days. Our results can serve as a scientific base in the monitoring and analysing of soil moisture against the background of a changing climate.

Keywords: soil moisture, sensor, forest, precipitation, temperature

Authors. [1]"Marin Drăcea" National Research and Development Institute in Forestry, 13 Closca Street, 500040 Brașov, Romania | [2]"Marin Drăcea" National Research and Development Institute in Forestry, 128 Eroilor Av., 077190 Voluntari, Ilfov, Romania | [3]"Marin Drăcea" National Research and Development Institute in Forestry, 10 Principală Street, 117470 Mihăești, Romania | [4]Faculty of Silviculture and Forest Engineering, Transilvania University of Brașov, 1 Șirul Beethoven, 500123 Brașov, Romania | [5]Chemistry, Physics and Envi-

ronment Department, “Dunărea de Jos” University of Galați, 47 Domnească, 800008 Galați, Romania.
§ Corresponding author: Lucian Dincă (dinka.lucian@gmail.com)

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Introduction

Soil moisture is a suitable and promising variable to explain vegetation growth in dry conditions and is useful for guiding adaptation plans that respond proactively to water related global challenges (Manrigue Alba et al. 2017). Knowledge of soil moisture is essential to broaden our understanding of different hydrological processes in soil ecology (Broca et al. 2010, Sun et al. 2015). Soil moisture only accounts for a small part of terrestrial water and it’s defined as the water contained in the unsaturated soil area, even if only a fraction of soil moisture is measurable (Seneviratne et al. 2010), and can be calculated as the ratio between the water volume and the sol volume.

Soil moisture directly or indirectly controls runoff generation, groundwater recharge, evapotranspiration and even soil respiration (Garcia-Estringana et al. 2013). It is an important parameter of ecosystem processes and influences nitrogen and carbon cycles and well as nutrient exchange with soil (Daly and Porporato 2005, Legates et al. 2011). Generally, the level of water from soil can affect vegetation productivity (forest), microbial community dynamics and soil biodiversity. The stress caused by limited soil water content can select the main drivers of biotic interactions in soils (Liancourt et al. 2012). The water balance ecosystem is established by inputs represented by precipitation and by outputs such as evapotranspiration, transpiration, percolation or surface drainage. Locally, these elements differ based on their spatial and temporal location, the speed of the wind or the type of vegetation and slope. However, the interaction between these factors was not studied in more depth and in the context of climate change (Legates et al. 2011). The effects of vegetation on soil water content and vice versa are complex and not entirely understood. Vegetation variation can influence soil moisture patterns by intercepting rainfall or shading the soil surface (Garcia-Estringana et al. 2013, Zheng et al. 2015), with the capacity to boost soil drying by transpiration. However, the opposed effect of raising water up from deeper soil layers can also happen, together with reducing soil evaporation by changing the soil hydraulic properties (Legates et al. 2011, Garcia-Estringana et al. 2013).

The feedbacks between soil moisture patterns and vegetation cover are insufficiently understood, emphasizing the need for more research in order to clarify any interactions. Plant transpiration processes depend on the species and region, showing seasonal climatic variability (Vivoni et al. 2008). Vegetation type is generally identified with certain soil properties, structures and communities. As such, the variation of vegetation can have a significant impact on soil moisture patterns (Lull et al. 1955).

Soil water content and precipitation are important topics in climate research and monitoring as they can improve the predictability of climate change (May et al. 2015). In this sense, soil moisture is a suitable parameter in evaluating water stress and flood control. Seneviratne et al. (2010) have provided an overview of the linking between soil water content and climate, introducing new concepts for soil moisture-temperature and soil moisture-precipitation interactions.

The tree species European beech (*Fagus sylsvatica L.*), silver fir (*Abies alba Mill.*) and sessile oak (*Quercus petraea Matt.*) are the main species that grow individually or together (mixt) in many places in Romania under natural conditions. In the domain of forest ecosystems, the Long-Term Ecological Research (LTER) program which intends to explain the function and structure of forest ecosystems through long-term monitoring, and discerning soil moisture is one of the most important parameters of the LTER program. In this paper, we analyze the multiannual variability of soil moisture at different soil layer depths in three LTER sites and the interaction between soil water content (SWC) and the effects of vegetation type and soil properties.

Materials and methods

Location and description of sampling sites

The experimental sites were situated in three Long-Term Ecological Research forests (LTER sites) managed by "Marin Drăcea", National Research and Development Institute (Fig. 1). All stands are located in the southern and central part of Romania (Badea et al. 2012), in locations with different characteristics (Table 1). Predeal site is a mixed Norway spruce-Silver fir stand. It is located an elevation of 1,054 m, with an average slope of 20 degrees, facing east. The average annual rainfall recorded is 866 mm and the average annual temperature is 5.3˚C. Soil type was Eutric Cambisol, (SRTS 2003, Romanian nomenclature adopted from FAO- WRB, Dincă et al 2015) rich in clay and sand, characterised by a high depth, providing optimal conditions for spruce and fir. The stand is regenerated natural from seeds, and a canopy cover of 0.7, N = 224 (tree density), DBH = 47.3 cm (diameter at breast height). Fundata site is a pure beech stand, situated at an elevation of 1,461 m, with an average slope of 20˚, facing west, north-west. Average annual rainfall was 847 mm, with an average annual temperature of 5.1˚C. The soil was Eutric Cambisol , rich in clay and sand, with a medium depth. The stand has an average age of 50 years, is regenerated naturally and has a canopy cover of 0.9, with N = 1146 and the mean DBH = 18.2 cm. Stalpeni site is a mixed beech -sessile oak site, located at an elevation of 573 m and with an average slope of 10˚, facing west, south-west. Average annual rainfall was 760 mm, with an average annual temperature of 9.1˚C. Soil type is Eutric Cambisol, characterised by a medium, lush and moderately compact depth. The trees were naturally

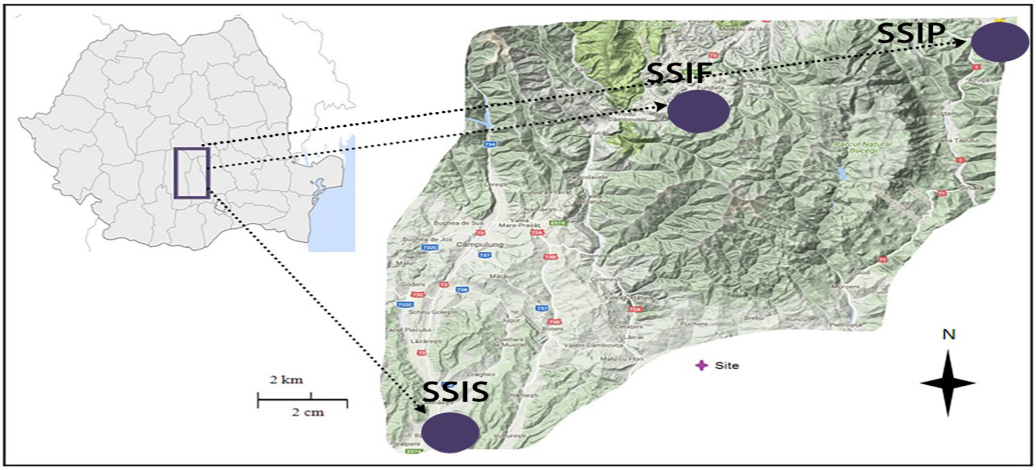


Figure 1 Study area (SS1S – Stalpeni, SSIF – Fundata, SSIP – Predeal)

Table 1 Main characteristics of the study sites

Plot	Coordinates		Altitude (m)	Aspect	Annual precipitation sum (mm)	Average annual temperature (°C)	Geology	Soil type	Main species
	Latitude	Longitude							
Stalpeni	45°01'44”	24°59'50”	573	south-west	760	9.1	grevel, sands	eutric cambisol	sessile oak, beech
Fundata	45°29'45”	25°11'16”	1461	north-west	847	5.1	lime stone	eutric cambisol	beech
Predeal	45°30'16”	25°34'28”	1054	east	866	5.3	conglomerates	eutric cambisol	spruce

regenerated from seeds and sprouts, have an average age of 70 years, and a canopy cover of 0.8, with N = 324 and mean DBH = 28.8 cm.

Measurement of soil moisture and climate

Soil moisture variation was analysed both for all three depths and for the same depth within all sites. To measure soil moisture, we used Trime-Pico sensors (IMKO GmBh, Germany) which use the TDR technique (time domain reflectometry), placed at three depths (0-20, 20-40, 40-70 cm).

To measure soil moisture, we used Trime-Pico sensors (IMKO GmBh, Germany) which use the TDR technique (time domain reflectometry), placed at three depths (0-20, 20-40, 40-70 cm). The soil moisture is measured at intervals of 1 min, 10 min, 3 h, 6 h, 12 h and 24 h. The data are then transmitted through a GSM signal. Soil moisture values were recorded as dielectric values at the station once per day (in a 24-h interval) and then transmitted to a server. After data storage on the server, the controlled dielectric value was converted to VWC (water partition by volume m^3 m^{-3}). At Stalpeni site, the meteorological station is situated at approximately 2 km from the forest stand, while other two stations are located at a maximum of 500 meters from their respective sites. To record the climatic data for plots, the Vaisala Automatic Weather Station AW310 was used. This station is configured to measure wind direction and speed, as well as air temperature, relative air moisture, precipitation quantity, global solar radiation and snow depth. Data was recorded periodically at intervals of 1 min, 10 min, 3 h, 6 h, 12 h and 24 h. Energetic independence was ensured with an internal 52 Ah/12 V battery, which was constantly charged via a photovoltaic panel. The obtained data were transmitted through a wireless device (GSM, GPRS) by using the MCC 301 data collection software. The meteorological data used for this study were air temperature and precipitation quantity, using the average values recorded within 24 hours.

Soil sampling

Soil sampling was performed in accordance with the UNECE 2007 Manual. The organic layer from the soil surface is composed of organic horizons, namely litter (OL), fermentation horizon (OF) and/or humus (OH). As such, this layer was examined independently from the underlying mineral soil. A frame of 25 x 25 cm was used for sample collection; the mineral layer was sampled at a fixed depth (0-10 cm, 10-20 cm, 20-40 cm and 40-80 cm). For every layer, 24 subsamples were taken and combined to obtain three composite samples (i.e. three composites for each of the eight subsamples). To avoid autocorrelation, a distance of at least 5 m was established between two sampling points.

For the determination of bulk density, we collected five samples with a minimal volume of 100 cm^3 per site from the mineral topsoil (0-10 cm) of non-stony soils, by using an Eijkelkamp sample ring kit with an open ring holder. The moisture content was established by measuring fresh and dried soil; soil texture was established by using a Kubiena dropper and separating the mineral fractions (<2 μm, 2-63 μm, 63-2,000 μm) based on the dimension and expressed in percent. Mean bulk density was determined as the ratio between the dry mass and soil volume. Soil pH was determined by potentiometrically measuring the concentration of hydrogen ions in the soil/water suspension. Organic carbon was determined by oxidising the soil carbon at CO_2, followed by analysis via a CNS (Leco) analyser. Total nitrogen was determined through the Dumas method, using a CNS analyser (Dinca et al. 2012).

Soil water content (SWC)

Soil water retention is the physical property of soils influenced by the soil's texture, bulk density and organic material. As such, its variability appears in each site both vertically (horizons/layers in the profile) as well as horizontally. In order to determine the general hydrological performance of soil profiles, this layered sampling method based on horizons or specific layers becomes a prerequisite (UNEP. 2010). The ISO 11274 protocol was used for determining soil water retention, by taking into account the drying or desorption curve.

In each site, at least three separate soil profiles were taken. The locations of these profiles within the site were select randomly, but by taking into account a number of requirements such as: the individual profiles need to be representative for the soil condition within the site; they should be located in more than one single profile pit (i.e. profiles should be situated at a distance of meters between them); they should be located very closely to the location where the soil moisture measurement sensor is.

Within the established depth intervals (0-20, 20-40 and 40-80 cm), minimum one undistributed soil core was taken from the same depth of the soil moisture measurements (TDR sensors depth). Metal cylinders (sleeves) were used for gathering soil cores, their volume ranging between 100 and 400 cm^3. The cores were taken directly from a soil profile pit using the sample ring, without extra material such as an open or closed ring holder. The undisturbed cores were collected during a wet period, when the soil matric pressure was equal with or near 5 kPa.

Soil-water retention characteristic (SWRC) is the relationship between the content of volumetric soil water and matric pressure. As such, it relies on soil texture, organic matter content and bulk density. Furthermore, it varies in the soil profile both vertically and horizontally (Cools and De Vos 2010). The volumetric water content (θ in volume fraction, m^3 m^{-3}) was established at predefined matric potentials (ψ, in kPa) **i**n order to establish the SWRC. As indicated in Table 3, six of these matric heads were determined. Determination of the SWRC was achieved by using sand, kaolin and ceramic suction tables (Eijkelkamp soil & water, The Netherlands, 2010).

Data analysis

The continuous temperature and precipitations recordings from the Stalpeni, Fundata and Predeal meteorological stations were used to determine the correlations between soil moisture and meteorological data. Only the days in which values were recorded for both soil moisture and meteorological data were taken into consideration (sometimes, due to technical reasons, the sensors did not present recordings). Data normality was tested with the "Shapiro Wilk's W" test (Shapiro et al. 1965). Data were analysed based on principal components analysis method PCA. The p threshold level was considered at p = 0.05. The two approaches are frequently used (Timofti et al. 2016), mainly because they are complementary; the first is used for data analysis, while the second is used for the analysis of the correlation coefficient matrix (Iticesu et al. 2016, Burada et al. 2017).

We used non-parametric statistical tests, namely Spearman´s correlation and Pearson´s correlation. Because our data set was consistent and dense, the trust level was calculated for each Pearson´s correlation coefficient, with the p coefficient's limit considered as 0.05.

We have collected a high number of soil moisture records in order to establish the temporal variability in volumetric soil moisture content among vegetation types and soil layers. All values recorded within 24 h were averaged. Principal components analysis (PCA) was applied to investigate the importance of different variables in explaining the soil volumetric water content.

The temporal variability of soil moisture was also investigated. For this, we applied the Fourier series (Haidu 1997, Murariu et al. 2015) and neural network fitting procedures (Puscasu et al. 2009) to emphasise regularities and synchronisation between the measurement sets. This approach enabled us to evaluate the time delay between the moisture level time series for different depths (Sarah et al. 2003).

In the last stage, the neural network method was used by employing nonlinear sorting procedures regarding the soil moisture values at different depths. In this context, a set of 20 network models with different structures and activation functions was constructed for each area. The first five most performing models were kept for each area studied. Temperature and precipitation recorded on the surface of the studied area were used as entrance parameters, while the soil moisture levels recorded at three distinct depths were considered as target parameters. The data set was divided as follows: 70% for training models, 20% for testing and 10% for validation. A series of Multilayer Perceptron (MPL) models was also constructed. The top five models with the best performances were retained. The statistical analysis consisted of the Statistica 8.0 software packages and Microsoft Excel. The literature contains a series of numerical approaches that describe the soil's humidity values by using Penman models (Shang et al., 2007), different statistical analyses (Reichle et al. 2002, Zhang et al. 2004, 2006) or by using hydrodynamic equilibrium equations (Shuwen et al. 2005). All these approaches use as a main entrance factors the level of precipitations and temperatures from the soil surface and the soil's humidity values recorded at a certain reference depth. Based on these entrance parameters, and by using mathematical approaches, the humidity values at the level of other depths can be evaluated. In the present case, such a non-linear mathematical model was developed.

Results

Soil moisture

Variability of soil moisture with soil depth

Table 2 shows the maximum, minimum and mean soil moisture contents as well as the standard deviation (SD) values at each soil depth for all sites. At a depth of 70 cm, soil moisture was generally higher in the Predeal site compared to the two other sites. Maximum soil moisture was higher in Predeal (34.51%) and in Stalpeni (30.65%) than in Fundata (26.73%). Amongst the three locations, Stalpeni had the lowest Mmin (4.72%) and Mi (20.32%) values and the largest difference between Mmax and Mmin. The variation coefficient (CV) of soil moisture content was higher for Fundata and Predeal in the surface layer (first layer: 12.49 and 16.89%, respectively) than in the deeper layers (7.80 and 5.18%; 9,78 and 7.59%, respectively), while in the Stalpeni site, the value was almost the same for all layers, i.e. 31.22, 32,16 and 32.02%, respectively. The Stalpeni site had the largest amplitude

Table 2 Characteristics of soil moisture by site and soil depth

Site and soil depth (cm)	Average (± standard deviation)	Minimum	Maximum
Fundata (20)	24.982 ± 3.123	11.600	31.600
Predeal (20)	20.597 ± 3.481	10.600	31.566
Stalpeni (20)	19.423 ± 6.062	8.866	32.033
Fundata (40)	18.793 ± 1.466	12.366	21.800
Predeal (40)	24.946 ± 2.441	14.100	33.366
Stalpeni (40)	18.539 ± 5.956	1.800	28.366
Fundata (70)	23.684 ± 1.228	18.300	26.800
Predeal (70)	27.931 ± 2.121	20.500	38.600
Stalpeni (70)	23.012 ± 7.365	3.500	33.700

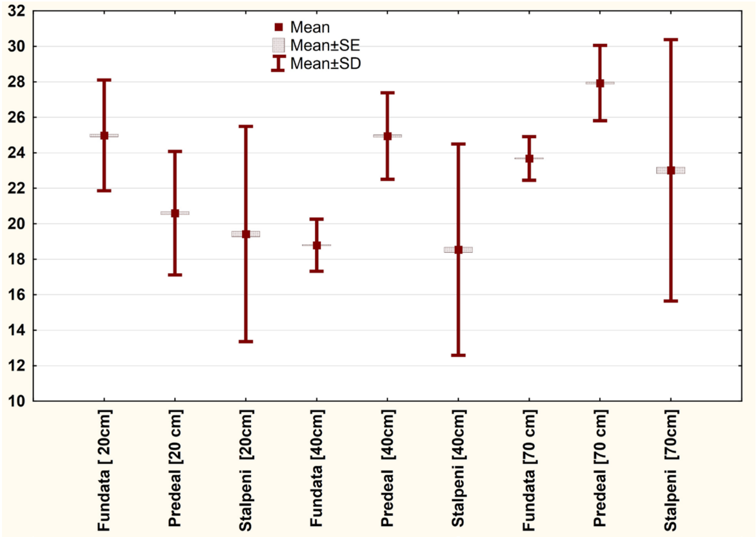


Figure 2 Average soil moisture on different soil depths

(Table 2). The values of Mmin for Fundata and Predeal increased with depth, while in Stalpeni, it decreased from the first layer (8.87%) to the second one (1.8%) and subsequently increased (3.5%). The values of Mmax for Fundata and Stalpeni decreased from the 20-cm layer (31.6 and 32.03%) to the 40-cm layer (21.8 and 28.37%), with a subsequent increase (26.8 and 31.57%), while in the Predeal site, Mmax values increased with depth from 31.57% in the first layer to 33.37% in the second layer and 38.6% in the third layer (Fig. 2).

The highest soil moisture level was recorded at a depth of 70 cm in the Stalpeni and Predeal sites and at 20 cm depth in the Fundata site, where the calcareous rock situated at low elevation influences soil moisture at a depth of 70 cm. The Predeal site showed the highest soil moisture at 40 and 70 cm, with levels lower than in the Fundata site only at a depth of 20 cm. This could be explained by the silt-loam texture of this site, with a lower sand content and, subsequently, a higher soil moisture level.

Temporal variability of soil moisture

Regarding the monthly soil moisture variation, similar patterns were observed for the multiannual variation curves for all three sites. As it was expected, the highest soil volumetric content throughout the year was recorded by the sensor situated at a depth of 70 cm, with the exception of the Fundata site, where the highest values were recorded from July to October, while the remaining year periods having the highest soil moisture values for the sensor located in the first 20 cm of the soil (Fig. 3).

The maximum monthly values (February) as well as the minimum values (September) were

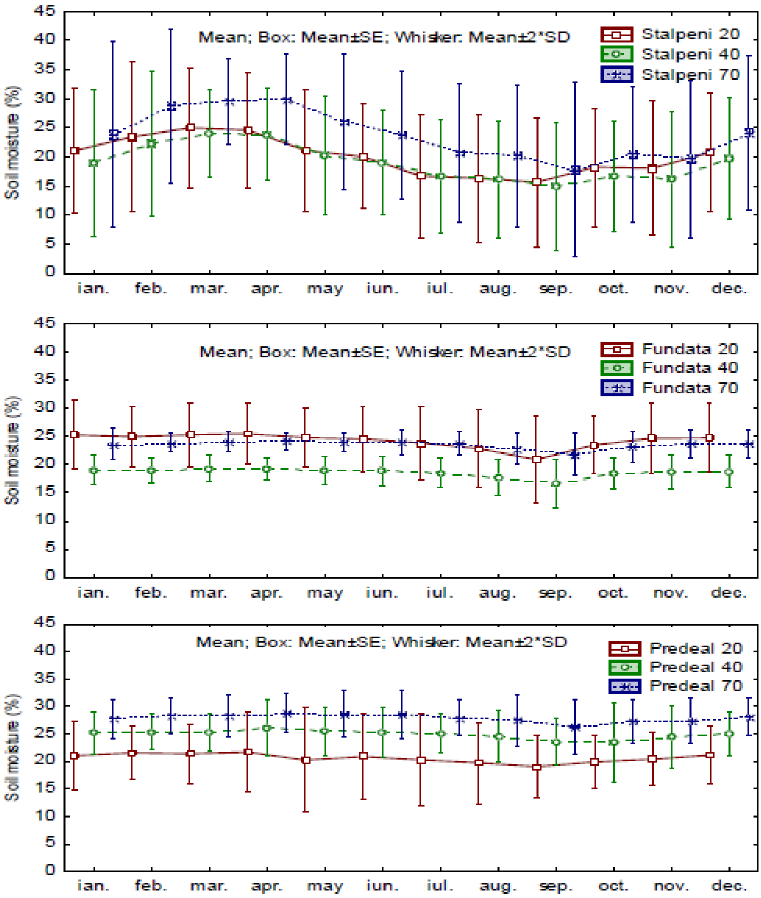


Figure 3 Average monthly soil moisture at each soil depth by sites

recorded in Stalpeni, with intermediary values during the remaining multiannual period for the other two sites, Fundata and Predeal (Fig. 3). As such, it can be asserted that under the conditions of higher precipitation in the mountainous areas, namely Fundata and Predeal, the level of the water volumetric content from the soil is mostly influenced by soil physical characteristics such as clay content, soil structure and bulk density. Furthermore, from August to September, based on a higher evapotranspiration from the Stalpeni forest site, soil moisture levels were significantly lower than in the two other sites.

Soil water content

The soil water volumetric content values were rendered for each location by the sensor's number and soil depth as well as for each threshold established by the suction forces (pF)

Soil moisture presented similar trends in terms of the established suction thresholds. When analyzing the data for the entire measurement period, periods with soil water scarcity were not recorded because the soil water values were below the drought threshold at Fundata and Predeal sites. At Stalpeni site, however, soil moisture was 7.5% below the drought level during September-October 2012. The period with low soil moisture was a result of the lower elevation, consolidated by lower precipitation caused by higher soil temperatures and an increased evapotranspiration.

Relationships between soil moisture and other soil, climatic and forest structural characteristics

Pearson's analysis was used to investigate correlations between soil moisture and the main soil properties. The maximum SWC value was positively correlated with soil texture (silt content), while the minimum SWC value was correlated with total soil nitrogen and the average SWC value with soil pH.

Precipitations are influencing soil moisture values at a depth of 40 cm, while temperature had an impact on soil moisture at a depth of 20 cm onwards. When the external factors (temperature and precipitation) were delayed for 1 day, the correlation model between the data was changed. In this case, temperature influenced soil moisture at all three depths (20, 40 and 70 cm), while precipitation had no impact. At a delay of 2 days, temperature influenced soil moisture at all three depths, while precipitations influenced soil moisture only at a depth of 20 cm.

In the Fundata site, the external factors have a different influence than in the Predeal site. As such, temperature influenced soil moisture values at all three depths, while precipitation had no impact. With a delay of 1 day, the situation changed dramatically: both temperature and precipitation influenced soil moisture at all three depths; this was also the case with a delay of 2 days.

In the Stalpeni site, temperature only had an impact on soil moisture in the upper soil layer (20 cm), while precipitation influenced soil moisture levels from a depth of 40 cm onwards. When we introduced a delay of 1 day for external factors, the same situation as observed in the Fundata site occurred, namely that temperature and precipitation influenced soil moisture at all three depths; the same situation was observed with a delay of 2 days. As such, temperature influenced soil moisture values at all depths, while precipitation only had an impact at 20 and 40 cm. The monthly variation in precipitation was similar to that in soil moisture (regardless of the soil depth). The discontinuous sections of the precipitation curve do not have to be considered for this correlation as they represent winter periods when precipitation is generally in the form of snow and does not significantly influence soil moisture.

The soil moisture value at P/ETP excess was smaller than that at P/ETP equilibrium, mainly because during the winter, precipitation does not enter the soil. The snowmelt in March and April results in higher soil moisture values.

The correlation analyses were tested and concluded with a positive correlation (r = 0.26) between forest canopy and soil moisture at 20 cm soil depth and a negative correlation between forest canopy and soil moisture at 40 cm (r = -0.51) and 70 cm (r = -0.35). The pattern of correlation between soil moisture and the number of trees per hectare was following the statistical significant between soil moisture and forest canopy index. In comparison with them, the correlation between soil moisture and diameter at the breast high was significantly negative (r = 0.22) for soil moisture at 20 cm and significant positive at the soil depths of 40 cm and 70 cm (r = 0.55; r = 0.37). Furthermore, the correlation was lower (Table 3) for all cases and statistically significant ($p < 0.05$).

Temporal influence of precipitation on soil moisture

A breakdown in the main factors was obtained for each area, based on the data sets obtained with sensors and by taking into consideration the delay established through the previous

Table 3 Correlation analysis between soil moisture and structural characteristics of vegetation

Structural characteristics	Soil depth (cm)	r	p	r^2
K	20.00	0.26	0.00	0.07
	40.00	-0.51	0.00	0.27
	70.00	-0.35	0.00	0.12
N	20.00	0.33	0.00	0.11
	40.00	-0.33	0.00	0.11
	70.00	-0.22	0.00	0.05
DBH	20.00	-0.22	0.00	0.05
	40.00	0.55	0.00	0.31
	70.00	0.37	0.00	0.14

Note. Abbreviations: K – canopy cover, N - number of trees, DBH – diameter at breast high method. Figure 4 presents the diagrams obtained for the first three main factors identified. Only the first three main groups were considered, as they explained over 94% of the entire variance (Fig. 4). By using the database with the previously mentioned delay, an identical structure could be obtained. The structure and percentage of dispersion in the space of the main groups represent an important argument in explaining the dynamics of measured data sets through the same mechanism that implies physical transport phenomena through diffusion and capillarisation as well as phenomena related to water absorption by vegetation. We therefore conclude that the entrance parameter set (precipitation level and temperature values) as well as certain values in regarding soil and vegetation characteristics can fully explain the soil moisture mechanism and dynamics in the different soil layers.

An unstable dynamic equilibrium surface was obtained, with a maximum area and a concentration of main points in the areas with relatively reduced precipitation, but with a high frequency (Fig. 5).

The dynamic equilibrium was obtained through the action of two opposed processes: increasing the soil moisture value (more accentuated at reduced temperatures) and a decrease mechanism accentuated by high temperatures (mainly based on capillarisation and water absorption by vegetation). The evaluation using the Fourier series emphasises the presence of a delay for the most important frequencies, namely of approximately 0.4-0.8 time units.

Based on the evaluations on the first and second ordinal derivates, there was a delay between the variations in soil moisture at a depth of 20 cm (first time series) and the soil moisture measured at a depth of 70 cm (second time series). The values obtained on samples of 40 consecutive daily soil moisture data have emphasized the presence of an average delay of 0.6-0.8 time units (Fig. 6).

Discussion

Soil moisture has a spatio-temporal variability, determined by soil heterogeneity, local climatic conditions, vegetation and topography (Vereecken et al. 2007, Baroni et al. 2013). Similar to soil temperature, soil moisture is an important variable that influences vegetation productivity in natural ecosystems (Bell et al. 2013). According to the latter authors, triplicate-sensor installation at individual soil depths provides numerous possibilities for studying the variability and uncertainty of soil measurements.

Each location can provide an opportunity to better investigate the soil heterogeneity and to assess any measurement uncertainties in analyzing soil moisture. The present study used soil moisture and its inter- and intra-annual variability as a preliminary investigation, followed by the soil-climate interactions and by the exploration of the influence posed by vegetation type on soil moisture. Furthermore, soil property analysis offered some valuable answers in relation to soil moisture. The three analyzed surfaces were situated at the average elevation specific to eutric cambisols in Romania. This soil type is the third most common soil type of Romanian forests, covering a total area of 869.909 ha (Dincă et al. 2014). The characteristics of these soils vary with elevation (Spârchez et al. 2017), and average organic carbon levels resulted in average organic carbon stock values (186 t/ha) in Romania (Dincă et al. 2015). For each sensor that measures soil moisture, an investigation of seasonal patterns was performed to analyze any temporal changes between them.

Variation of soil moisture by soil depth

Soil moisture in different soil layers is highly important for assessing the hydrological response of the catchment (Broca et al. 2007). However, only a number of studies have considered soil moisture variability in the context of different soil depths. As such, the depiction

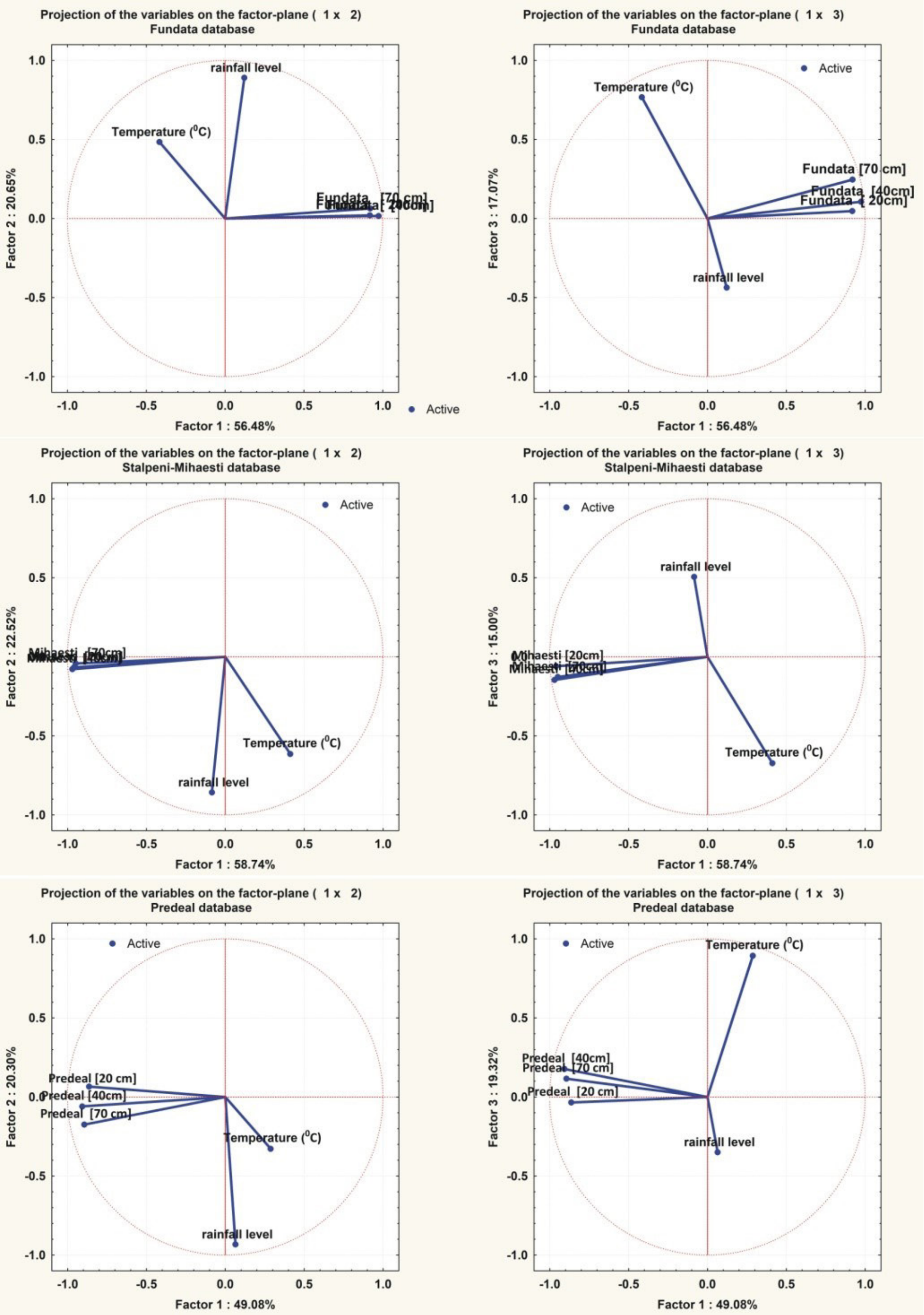
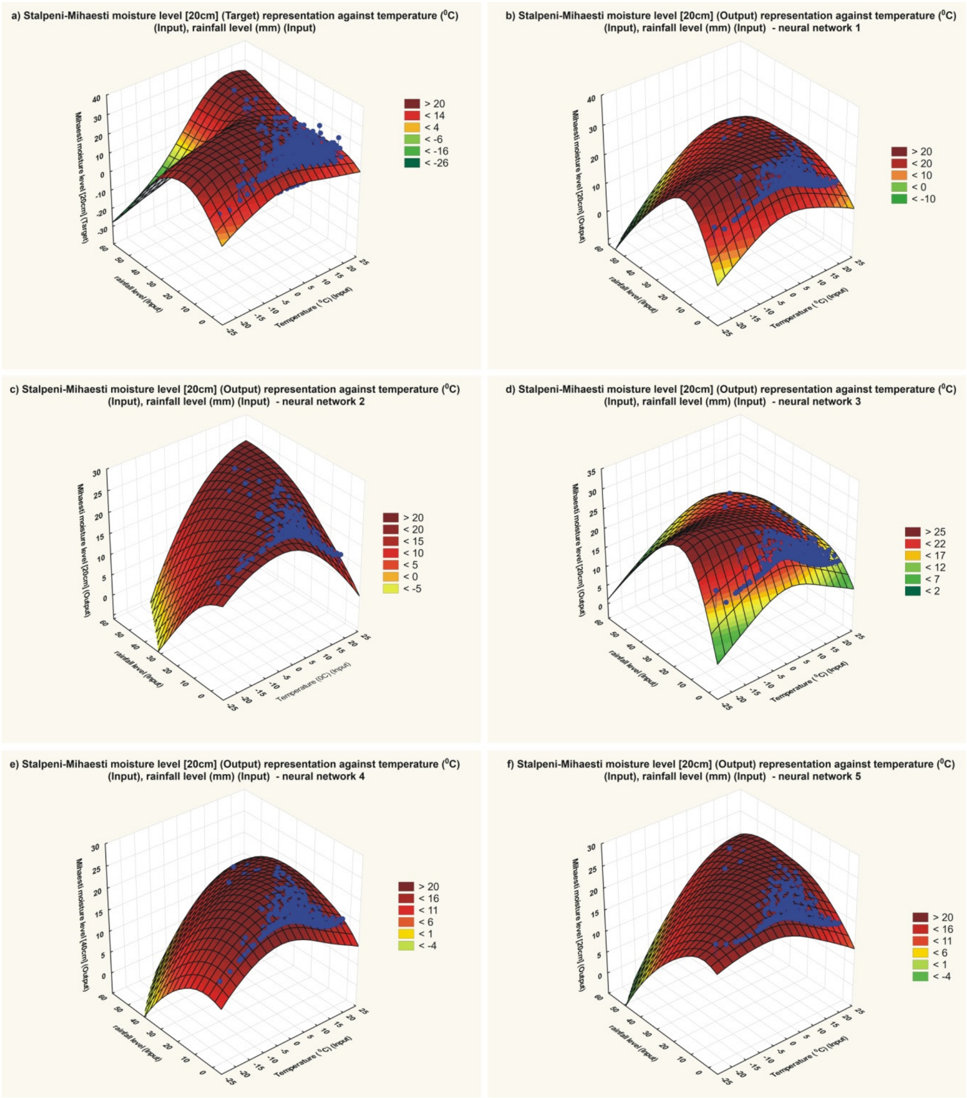


Figure 4 Relationship of soil moisture at different depths with the temperature and rainfall



a) Stalpeni-Mihaesti moisture level [20cm] (Target) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input)

b) Stalpeni-Mihaesti moisture level [20cm] (Output) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input) - neural network 1

c) Stalpeni-Mihaesti moisture level [20cm] (Output) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input) - neural network 2

d) Stalpeni-Mihaesti moisture level [20cm] (Output) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input) - neural network 3

e) Stalpeni-Mihaesti moisture level [20cm] (Output) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input) - neural network 4

f) Stalpeni-Mihaesti moisture level [20cm] (Output) representation against temperature (^{0}C) (Input), rainfall level (mm) (Input) - neural network 5

Figure 5 Multidimensional plot of neural networks results applies to soil moisture at Stalpeni site (20 cm soil depth), based on the entrance modelling parameters (precipitation and temperature)

of temporal variability from soil moisture persists as a challenge for the domain of hydrological sciences (Baroni et al. 2013, Vereecken et al. 2007). Random measurement errors generally decrease with sensor depth (Dirmeyer et al. 2016). The pattern for most depths is a decrease in the average soil moisture during summer and an increase during autumn. This was observed during the beginning of summer (Bell et al. 2013), when mean soil moisture increased with depth. In our study, the standard deviation of soil moisture measurements among sensor levels showed a modest decreasing trend with depth soil for Fundata and Predeal, but a rather unconvincing trend for the Stalpeni site. James et al. (2003) have

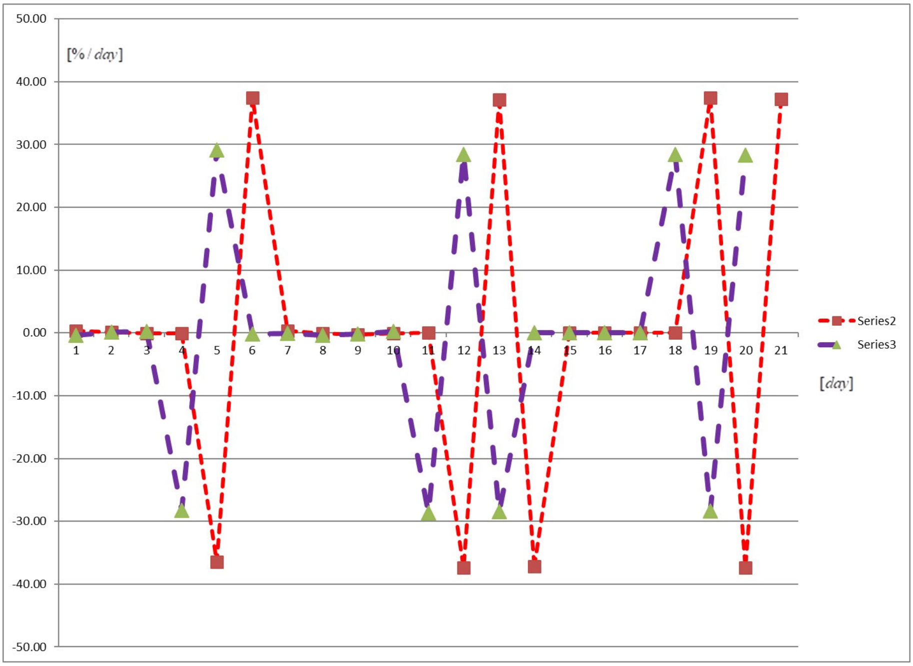


Figure 6 Difference in soil moisture monthly time series for soil depths of 20 cm (series 3) and 70 cm (series 2)

encountered a similar variation: soil moisture was always greater at 30 cm than at 10 cm, suggesting that the soil's sandy texture could be one of the causes. Interestingly, the standard deviations of soil moisture measurements among the three probes at each level showed a modest increasing trend with greater depth from the soil surface. As noted earlier, some of the probe sets showed strong variations in soil moisture at 100 cm because of the effects of clay cations and saturation, most likely resulting in the increasing trend in standard deviation for soil moisture. The pattern for most depths is a decrease in the average soil moisture during summer, followed by an increase during autumn, except for a depth of 100 cm, where soil moisture continues to diminish during autumn. Soil water recharge starts in the upper layers following plant senescence, but the downward percolating water does not reach the 100-cm layer in many places until the end of autumn, which is likely the cause of the decreasing trend across sensors situated at this depth.

Temporal variability in soil moisture

During the entire study period, soil moisture showed different variability patterns with depth. This has also been reported by Garcia-Estringana et al. (2013). The highest soil moisture value was recorded in Stalpeni at 70 cm, while the smallest value was found at 40 cm. As an exception, in Fundata, the pattern of soil moisture variability was unclear at the interaction between the 20- and 70-cm soil depth curve. The relocation of rainwater towards deeper soil layers can be relatively slow (1-2 days) and is dependent on the amount and intensity of rain as well as on vegetation structure and soil properties. Normally, soil water infiltration varies with rain characteristics and with the interval of consecutive rains. In addition, rainwater is seized by canopies, can knock down tree trunks, and is kept in the litter layer for some time and subsequently reaches the mineral soil profile (Zheng et al. 2015). Our results can therefore be explained by the variability in soil texture, although different water soil infiltration errors of the data log sensors cannot be excluded. In contrast, Zheng et al. (2015) have reported a soil moisture decrease with soil depth profile, as more water was consumed from the deeper soil layers by tree roots. In comparison to e.g. grasses, deep-rooted trees basically transpire more water and can extract water from deeper soil layers (Wang et al. 2014).

The correlation between soil moisture and soil characteristics was weak. In contrast, Zheng et al. (2015) have applied the same statistical methodologies and found a better correlation between soil properties and soil moisture. The maximum SWC was positively associated with soil porosity, soil organic matter and total nitrogen content while negatively correlated with soil acidities and soil bulk density. Furthermore, the same study did not identify a significant relationship between SWC and soil texture. Baroni et al. (2013) could show a positive correlation of soil moisture with clay and silt and a negative relationship with sand content, further suggesting a correlation between soil moisture and texture in wet conditions (percolation) and between soil moisture and vegetation variables in dry conditions. The significant interactions between habitat and climatic factors and time reflect differences between habitats and climatic factors in temporal soil moisture patterns.

Understanding the spatiotemporal dynamics of soil moisture can improve climatic and hydrological modelling and prediction (Broca et al. 2012, Western et al. 2002). Bell et al. (2013) have concluded that soil moisture levels gradually decline during the growing season, from March to September, with a downward trend broken only by precipitation. The response of soil moisture to precipitation is rapid in the 5-, 10- and 20-cm layers, but changes are considerably slower at the 50- and 100-cm layers. Mean annual precipitation is a good predictor of soil water content. In our study, soil moisture showed a good correlation with this climatic parameter ($R^2 = 0.89$).

Temporal influence of precipitation on soil moisture

The existence of a temporal lag between data sets regarding precipitation and soil moisture values at different depths has previously been studied, mainly with the use of Fourier series (Murariu et al. 2015) or non-linear methods based on neural networks (Puscaus et al. 2009). The lag between data sets is not the only aspect worth mentioning. Changes in amplitude and time variation intervals at different depths also exist between the measured volumes. As noted, a slight alteration was found for Pearson´s correlation coefficients when the lag between the recorded temporal data series was taken into account.

Another interesting aspect is that the periodograms generated for the data set regarding precipitation registered at the surface as well as for the data set regarding soil moisture levels at different depths showed that the value sequences were not perfectly correlated in time and did not follow the same pattern. As the amplitude of components with higher frequencies was diminished, a “filter goes down” effect was emphasised for the link between precipitation levels and soil moisture values for the 20-cm layer. As such, the important daily variations in precipitation recorded at the soil surface were quite “flattened” in time, causing the soil moisture levels at 20 cm to follow only “signals” with low frequencies, i.e. with low variations in time. This way, rapid fluctuations in surface precipitation levels do not determine percental increases in soil moisture levels for the reference depth. Because of this, the obtained PCA diagrams for the recorded measurement vectors showed a weak link between surface precipitation and soil moisture in different layers.

Influence of vegetation on soil moisture

Generally, vegetation affects the soil water regime, with soil moisture being higher in forests than in grassland areas. Furthermore, soil moisture can be influenced by tree density, when we had more tree, the soil water content at higher levels (40 and 70 cm) was more higher compare with 20 cm soil depth. Zheng et al. (2015) have investigated the variability in soil moisture in three different sites and inferred that SWC is largely dependent on the tree species, with the highest values in the stand with the tallest trees. In our study, the highest average annual value of soil moisture was recorded in the Predeal plot, which had the highest DBH and total height values per hectare and the smallest densities. However, the cover vegetation did not significantly vary among stands. Differences in rooting depth can also explain variations in soil water uptake efficiency (Breda et al. 1995), leading to a different competitive achievement among stands. The available soil water content may be influenced by tree density and cover vegetation. We found weak correlation between soil moisture and canopy cover, although tree density or DBH are important factors influencing soil moisture. A previous study (Zheng et al. 2015) has shown an increase in soil moisture when tree density was higher or a decrease in the content of soil volumetric water when the vegetation cover was denser. Because structural characteristics of stand were statistical significant but weak, we have concluded that soil moisture can’t be influence statistically by vegetation type in time, only during the short periods of the year when the recorded evapotranspiration (transpiration) and are different.

Liu et al. (2008) argue that different land cover types can result in different dynamic responses of soil volumetric water content. Liancourt et al. (2012) state that vegetation has no effect on volumetric soil water content, most likely because of soil moisture loss through foliage transpiration or evaporation. The relationship between vegetation patterns and temporal soil moisture variability can be used to assess the afforestation argument, especially in dry lands (Sun et al. 2015). Similar to our study, Schwinning et al. (2002) failed to observe depth partitioning for water uptake between tree species.

Conclusions

The study of seasonal soil moisture variability under different climatic and vegetation type conditions has revealed a link between this important hydrological process by soil depth and site, even though the control and analysis of the influencing factors was difficult to quantify. First of all, the different climatic conditions between sites (air temperature and rainfall) were the main drivers influencing the patterns of soil moisture over time. Secondly, the local topography, including elevation or shape, may have also played an important role. As such, soil moisture values at different depths can be sufficiently explained based on four important elements: precipitation, temperature, soil type and vegetation type. However, a temporal lag between data sets regarding precipitation and soil moisture levels at different depths was encountered. A change in amplitude and time variation intervals was also found between the measured values for different depths. As such, rapid fluctuations for the level of precipitation at soil level are not necessary determining the increase percentage of soil moisture levels at the reference depth.

The evaluation based on the Fourier series emphasized the existence of a delay for the most important frequencies. The characteristics of soil are an essential element for explaining soil moisture variations at different depths in comparison with the effect produced by the vegetation type. The long-term monitoring of soil moisture will emphasize the existence of different ecological processes, thereby broadening our knowledge of interactions between vegetation and climate, especially as soil moisture soil directly and indirectly represents a water source for both plants and the atmosphere. Based on our results, the biotic and abiotic factors which interact with soil moisture can provide a scientific database for eco-hydrological modelling.

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