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EVOLUTION OF THERMAL AND HYDRIC REGIME OF SOILS FROM THE TRANSILVANIAN PLAIN DURING 2008-2014

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Abstract

Tranyilvanian Plain is considered as an area with a low capacity to adapt to climate changes, monitoring the climate and implementing the adaption measures being essential for the development of certain durable agricultural technologies. The monitoring and variability of climate elements were achieved during 2008 (March) - 2014, through a network of 10 HOBO stations which store soil temperature data electronically (at 10, 30, 50 cm deep) and air (at 1 m hight), soil moisture (at 10 cm depth) and are equipped with rain gauges. The purpose of the paper is to establish the tendency in the evolution of the soil thermal and hydric regime, to predict and identify the climate tendencies from the Transylvanian Plain. The thermal regime of soils in this area is mesic, the differences between the annual averages of summer temperatures and the average of winter temperatures 50 cm deep in the soil are ranging between 12.81-20.01°C. The evolution of temperatures at the soil level during 2008-2014 indicate the clear tendencies of rising temperatures at the soil surface (0 cm). The coefficients of linear correlation among the data lines analyzed indicate a rising synchronous evolution of the annual average temperature, with values of the correlation indices of 0.52-0.81. The same linear tendency in evolution of rising of the annual average temperature is recorded also in the case of temperatures from 10 cm and 30 cm deep in the soil. The evolution of temperatures in the air during 2008-2014 shows slightly rising evolutionary tendencies. The evolution of rainfall during 2008-2014 shows a falling linear tendency of them, the highest values of the annual average is recorded in 2010 (631 mm), and the lowest quantities of rainfall were recorded in 2012 (263.9 mm). The value of the correlation coefficient associated to the falling evolution tendency of rainfall is r = -0.51. The multiannual average of rainfall from the Transylvanian Plain is 466.52 mm. From the analysis of the statistical relation between rainfall and soil moisture, the calculated correlation coefficient has a value of r = 0.92 which indicates a direct and positive causal relation between the two parameters.

***Key words**: thermal regime, hydric regime, climate changes, Transylvanian Plain.*

INTRODUCTION

Climate is the dynamics of all meteorological phenomena from the atmosphere, including the soil thermal and hydric regime, from a certain place or region in the world, during a very long period of time (Dumitrescu et al., 2015). The climate change supposes the systematic deviation from the average state which defines a climate, which lasts for a longer period of time, usually tens of years or even more, to a new average state, a new climate (Coste, 2015; Purton et al., 2015). Climate changes can be caused by the simultaneous action of certain internal as well as external natural factors and/or certain external anthropogenic factors which result in the change of the atmosphere composition by the increase of concentration of greenhouse gases (Perry, 2015; Marin et al., 2016).

In the fourth evaluation report, AR4 (IPCC, 2007) of *Intergovernmental Panel on Climate Change* it is mentioned that during 1956-2005 a rise of temperature by 0.13°C/decade took place, a value approximately double compared to the value of 0.74°C from the last 100 years (during 1906-2005). This rise of temperature during the last 50 years is much and with a high probability caused by greenhouse emissions coming from human activities (Heinrich and

Gobiet, 2012; Lereboullet et al., 2013; Niacsu et al., 2015; Luo et al., 2016).

According to the fifth evaluation report, AR5 of IPCC (IPCC, 2014) the climate projections during 2016-2035 compared to 1985-2005 show a rise of the air temperature worldwide by 0.3ºC up to 0.7ºC, this warming being caused by the emissions resulted from the anthropogenic activity, but also by the natural climate variabilitaty. The global temperature average, calculated during 1880-2012 shows a rising tendency by 0.85ºC (0.65ºC-1.6ºC) for several series of independent data, with a varied interannual and decade variability; during 1998-2012, the warming rate was 0.05°C per decade, with variations up to 0.15ºC per decade (AR5, IPCC, 2014).

Changes in the rainfall regime, at a European level, show a higher time and space variability compared to temperatures, these rising in the north and north-west of Europe, but falling in the south of Europe. Most of the projections of the climate models show a continuity of rising rainfall in the north of Europe and their decrease in the south of Europe (EEA, 2012).

For Romania, in "*The Guidance on adaptation to climate change*" prepared by the Ministry of Environment and Forests in 2008, approved by the Order of Ministry no. 1170/2008 are mentioned rising of extreme temperatures during 2070-2099 compared to 1961-1990 by 4.0°C-6.0°C inside the Carpathian region and lower in the rest of the country in the case of minimum winter temperatures and 0.8°C-0.9°C in the north-west and north-east of the country. As for the average of the summer maximum value, there is a rising recorded of 4.0°C-5.0°C in the north of the country, a higher rising is recorded in the south of the country. These temperature changes were obtained by projecting the simulations made with HadAM3H global climate model under the conditions of A2 IPCC scenario (Coste, 2015).

When it comes to the soil moisture there aren't any clear clues in the tendencies to retain water in the soil due to the lack of systhematic and harmonized data. Projections suggest a reduction of the soil moisture in the greatest part of Europe, significant reductions in the mediterranean region and its rising in north-eastern Europe (EEA, 2012). At a European level, from the point of view of the need of water for irrigations during 1975-2010, in Italy and in the Iberian Peninsula we have noticed an increase of the water volume needed for irrigations while in other parts of south-eastern Europe it decreased. According to the EEA report (2012) under the influence of future climate changes in the south of Europe, an increase of the need for irrigations in agriculture is forecast (Trif and Oprea, 2015).

The Transylvanian Plain (TP) which has a surface of approximately 395,616 ha is favoured for cereal crops on relatively large surfaces (wheat and maize), but also for soy, sunflower and sugar beet, these are the main agricultural crops present in this geographical unit, which covers surfaces from Cluj, Bistrita-Năsăud and Mures counties. The surface of arable lands, which occupies approximately 60% of the territory of the Transylvanian Plain tends to reduce due to the transformation of certain large surfaces of productive lands into degraded lands, and even unproductive, process resulting from: applying certain irrational agricultural technologies, deforestation, setting up communal pasturs on fast slopes, pseudogleization, alkalinization and salinization of soils (Sopterean, 2012; Haggard, 2012).

The Transylvanian Plain is considered as an area with a low capacity to adapt to climate changes thus, under these conditions, monitoring the climate and implementing measures to adapt to these conditions are essential for the development of certain durable agricultural technologies. The climate changes from the last years modified significantly the climate indicators of the Transylvanian Plain, as our previous research shows (Rusu et al., 2017).

Monitoring the soil thermal and hydric regime, the air temperature and the rainfall from the Transylvanian Plain aims to set up the tendency in the evolution of these parameters. The paper responds to the need of making a long term monitoring of climate variability, a forecast and an identification of climate tendencies which had a negative impact on agriculture in order to evaluate the risk of agricultural surfaces and of the species cultivated as well as to take the best measures to adapt to the effects of climate changes.

MATERIALS AND METHODS

Monitoring and variability of climatic elements was achieved during 2008 (March) - 2014, through a network of 10 HOBO-MAN-H21-002 (On-set Computer Corp., Bourne, MA, USA) stations which store soil temperature data electronically (at 10, 30, 50 cm deep) and air (at 1 m hight), soil moisture (at 10 cm depth) and rain gauges. HOBO Smart Temp (S-TMB-M002) temperature sensors and Decagon EC-5 (S-SMC-M005) moisture sensors were connected to HOBO Micro Stations. Additionally, tipping bucket rain gauges (RG3-M) were deployed to measure rainfall. Data was downloaded from the Micro Stations every four months via laptop computer using HOBOware Pro Software Version 3.7.2. Soil types, land slope and exposition, altitude and geographic coordinates of the locations in which stations were set are shown in Table 1 (Haggard et al., 2010). The majority of soils have a loam-clay texture, pH between 6 to 8.69 and humus content of 2.5 and 4.15 in the first 20 cm (Rusu et al., 2014).

The determination of modifiations of the soil thermal and hydric regime from the Transylvanian Plain is based on the calculation of primary data recorded by HOBO stations, during the research years 2008-2014. Upon the opening of the electronically stored data files, a diagram is generated with the series of data recorded by each sensor for the period starting with launching the program and up to the download of data.

After the data was visualized, its export was made into Excel calculation sheets ordering the data series into a continuous form for each year according to the station and to the climate parameter analyzed.

The analysis instruments of the program allow the customization of graphs and the differentiated analysis of data series (calculation of monthly, annual and multiannual averages of soil, air temperatures and soil moisture for each station).

For the calculation of rainfall, HOBOware program allowed to record events (daily monitoring of the number of dumpcart of the arm to collect rainfall) which in their turn have been exported into Excel calculation sheets where the monthly and annual quantity of rainfall was calculated by multiplying the number of events by 0.2 (mm), value which corresponds to each swing of the dumpcart mechanism the rain gauge is equipped with.

Table 1. Analytical data on location of measuring stations

No	*Station (County)*	*Soil Type and Subtype**	*Latitude*	*Longitude*	*Elevation, m*	*Slope, %*	*Exposition*
1	Caianu (CJ)	Chernozem calcaro-calcic	46º79’	23º52’	469	17	SE
2	Mociu (CJ)	Chernozem luvic	46º47’	24º04’	435	5	V
3	Taga (CJ)	Preluvosol typic	46º97’	24º01’	469	17	N
4	Branistea (BN)	Eutricambosoil typic	47º17’	23º47’	266	1	V
5	Dipsa (BN)	Phaeozem typic	46º96’	24º26’	356	3	E
6	Zoreni (BN)	Preluvosol typic	46º89’	24º16’	445	17	NV
7	Silivasu de Campie (BN)	Eutricambosoil mollic	46º78’	24º18’	463	7	NV
8	Filpisu Mare (MS)	Districambosoil typic	46º74’	24º35’	375	19	S
9	Band (MS)	Phaeozem luvic	46º58’	24º22’	318	1	SE
10	Triteni (CJ)	Phaeozem vertic	46º59’	24º00’	342	10	N

SE =southeast; V = west; N = north; E = east; NV = northwest; S = south; *RSST, 2012

CJ = Cluj county; BN = Bistrita-Nasaud county; MS = Mures county

RESULTS AND DISCUSSIONS

Soil thermic regime from the Transylvanian Plain. The soil thermal regime depends on a complex of factors, first on the intensity of solar radiation and its periodic variations in time, to which we add the soil physical properties, composition, structure, texture, the soil moisture or dryness degree, the specific heat and thermal conductivity, the orientation and tilt slopes, as well as the nature and degree of covering the soil surface with vegetation. The soil surface receives a certain quantity of energy which is converted into thermal energy which subsequently is propagated and/or taken over, then, by the soil layers by conduction.

The soil thermal regime influences in its turn the plant growth, the biological activity and water movement inside the soil. In the evaluation of the soil thermal regime, the multiannual average of temperature represents the value mostly used.

The analysis of the soil thermal regime from the Transylvanian Plain during 2008-2014 by indirect determination according to RSST, 2012 (adding 2°C to the annual average temperature of the soil 50 cm deep from the surface) is not confirmed as, in the case of the majority of stations from the Transylvanian Plain, the values of the annual average temperature, 50 cm deep in the soil are higher than the air ones. Figure 1 presents the multiannual averages of soil temperatures during 2009-2014 in the Transylvanian Plain, where one can notice that the highest values are registered at Filpisu Mare, and the lowest at Triteni, Caianu and Silivasu de Campie stations.

The resulted values of the thermal regime of the soils, directly, by calculating the difference between the average of summer temperatures and the average of winter temperatures of soils, 50 cm deep, were used to establish the thermal regime of the soils from the Transylvanian Plain. It results that the thermal regime of the soils from the Transylvanian Plain is ***mesic***, with values of the annual average temperature of the soil 50 cm deep ranging from 8°C to - 15°C, and the differences between the averages of summer temperatures and the averages of winter temperatures are higher than 6°C at 50 cm deep in the soil.

The annual averages of the soil temperature have values ranging between 10.58°C and 13.72°C and one can notice, during 2012-2014, increases of values of the annual averages by 0.55°C up to 0.86°C compared to the previous period 2008-2011. Even if the value limits of the annual average temperatures grew during 2012-2014, the soil set up in the *mesic type* thermal regime established previously (Rusu et al., 2014) hasn't changed.

Evolution of soil temperatures during 2008-2014. The temperature from ***the soil surface (0 cm)*** was recorded at Taga, Filpisu Mare, Band, Triteni and Zoreni stations, the annual averages ranging between 10.12°C (Triteni, 2013) and 13.00°C (Filpisu Mare, 2014). The annual average temperatures of the soil recorded ***10 cm*** deep ranged between 10.32°C, in 2013, at Triteni and 13.89°C, in 2014, at Filpisu Mare station. At ***30 cm*** deep in the soil, the annual average temperatures ranged between 10.91°C at Caianu station in 2012 and 12.22°C at Dipsa and Branistea stations in 2014. At ***50 cm*** deep in the soil, a percentage of 53.33%, is represented by the annual average temperatures ranging between 11.01°C and 12.00°C, recorded at the majority of stations from the Transylvanian Plain. In a percentage of 26.66% are found the annual average temperatures ranging between 10.01°C and 11°C at Band, Triteni, Zoreni and Silivasu de Campie stations.

In order to analyze, statistically, the general direction in time of the soil temperature, the *linear tendency* of the annual average temperatures at the soil surface was used, 10 cm, 30 cm and 50 cm deep during 2008-2014, achieved based on the size of the determination index R^2 and of the correlation coefficients. Temperature data indicate clear growing tendencies of temperature at the ***soil surface (0 cm)*** for Band, Taga (Figure 2), Triteni, Filpisu Mare and Zoreni stations. The linear correlation coefficients of the data lines analyzed indicate a growing synchronous evolution of the annual average temperature, with more clear tendencies at Zoreni, Filpisu Mare and Band stations, where the value of the correlation indices is 0.81 at Zoreni station, 0.61 at Filpisu Mare station and respectively 0.52 at Band station (Figure 3).

At ***10 cm*** deep in the soil the linear tendencies of evolution of the annual average temperature are rising at the majority of stations except for Triteni station, where the linear tendency shows a slight evolution down of the annual average temperature. The same linear tendency in growing evolution of the annual average temperature is recorded also in the case of temperatures ***30 cm*** deep in the soil, except for Silivasu de Campie station where the tendency indicates a clear decrease of the annual average temperatures (Figure 4).

The linear correlation coefficients indicate a rising evolution of the annual average temperature, with clear tendencies for Branistea, Dipsa and Zoreni stations, followed by Filpisu Mare, the value of correlation coefficients of which is 0.82, 0.73 and 0.72, respectively 0.63 for Filpisu Mare station. In the case of Triteni station, the value of correlation coefficient associated to linear tendency (-0.04) indicates a drop of the anual average temperature insignificant almost inexisting, and for Silivasu de Campie station is -0.46, indicating a higher decrease of the annual average temperature 30 cm deep (Figure 5).

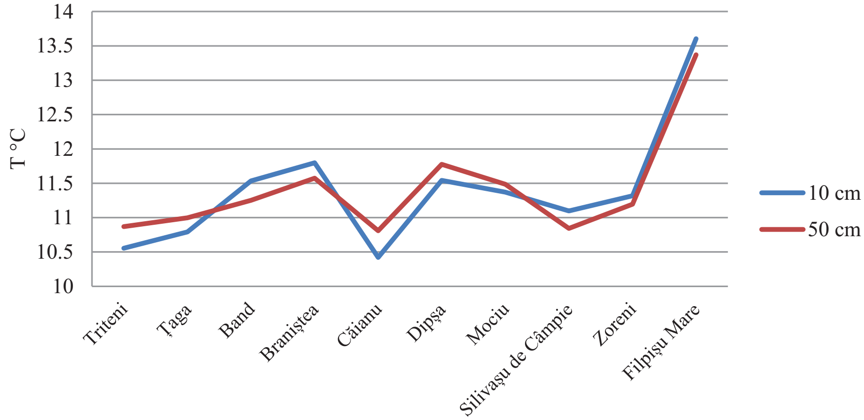

Figure 1. Multiannual average of soil temperature in Transylvanian Plain (2009-2014)

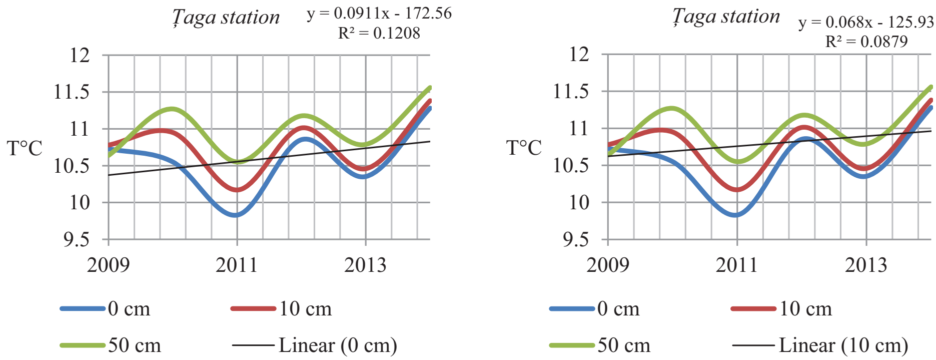

Figure 2. Linear trend of annual averages temperature evolution (0 cm, 10 cm) at Taga Station

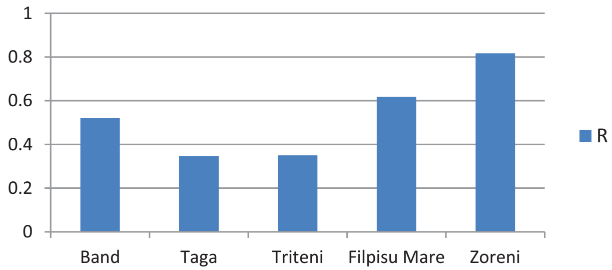

Figure 3. Values of correlation coefficient associated with trend evolution of annual average temperature at soil surface (0 cm)

The tendencies of temperature evolution 30 cm deep in the soil indicate growing, moderate to significant tendencies, for Dipsa (r = 0.57) and Branistea (r = 0.8) stations compared to Silivasu de Campie (r = -0.4) station where there is a moderate falling tendency.

Evolution of soil moisture during 2008-2014. The soil moisture is one of the meteorological elements derived from atmosphere with a determining role, next to other factors, for the ongoing under optimal conditions of the plant vegetation cycle.

The evolution analysis of the annual average values of soil moisture, recorded 10 cm deep, during 2008-2014 the Transylvanian Plain indicates a general falling tendency at the majority of stations except for Dipsa station where the linear tendency indicated a rising evolution of soil moisture.

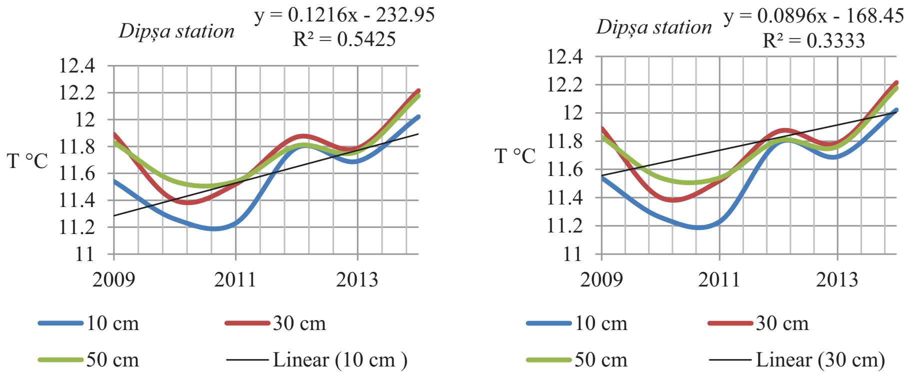

Figure 4. Linear trend of annual averages temperature evolution (10 cm, 30 cm) at Dipsa station

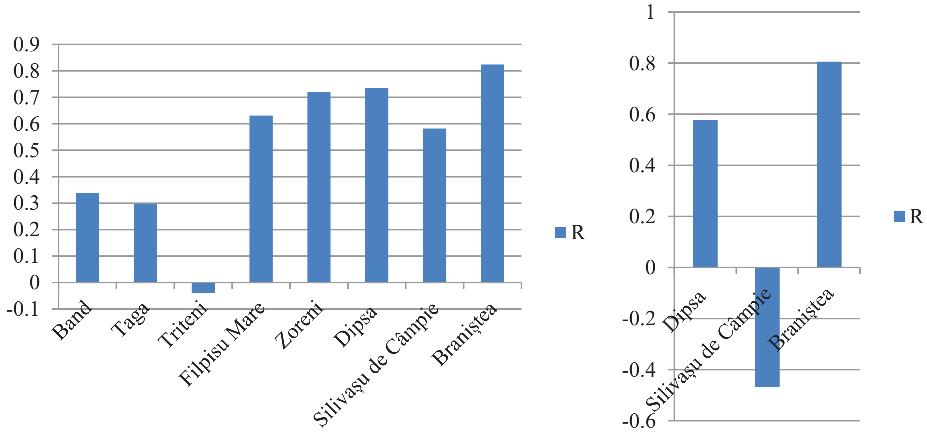

Figure 5. Values of correlation coefficient associated with trend evolution of annual average temperature at 10 cm (left) and 30 cm (right)

The correlation coefficients associated to the falling linear tendencies of soil moisture, presented in Figure 6 have values ranging between - 0.95 at Branistea and -0.04 at Caianu station.

The negative values and the values close to zero of the correlation coefficients from Caianu and Taga stations (-0.13) indicate us slightly falling tendencies, almost insignificant to nul of the soil moisture.

The positive value, close to zero, of the correlation coefficient in the case of Dipsa station (0.13) indicates a growth almost insignificant of the soil moisture.

The most clear tendencies of falling evolution of soil moisture were recorded at Branistea, Silivasu de Campie and Filpisu Mare stations, followed by Zoreni and Triteni stations.

For a synthetic image of the space and time variability of the soil moisture variation we used the *standard deviation*, frequently used in climatology, index which has the same measuring unit like the one of the values from the data lines used. From the analysis of the values of the standard deviation calculated for each station, it results that the soil moisture varies by 0.021 m^3/m^3 up to 0.027 m^3/m^3 compared to the multiannual average of each station analyzed (Figure 7).

Evolution of air temperature during 2008-2014. Air temperature was recorded at the station equipped with rain gauge, 1 m high from the soil surface. The annual averages of air temperature are ranging from 10.53°C at Band (2012) to 12.18°C at Mociu (2014).

The variation of air temperatures (daily, monthly and annual) is determined by a complex of factors which comprises aspects related to orientation and tilt slope, altitude variation, circulation of air masses, content of water vapors or powders in suspension, vegetal cover etc.
After the analysis of evolution tendencies of the annual average temperatures, based on the data recorded during 2008-2014 one can notice that at Dipsa, Silivasu de Campie (Figure 8) and Branistea stations they are rising, and at Caianu station the evolution tendency of the annual average temperature is falling. The values of the correlation coefficients (Figure 9) associated to the evolution tendencies of the air annual average temperature at Branistea and Dipsa stations indicate insignificant growths of air temperature, and at Caianu station the value of the correlation coefficient of -0.55 indicates a moderate tendency of falling evolution of the air annual average temperature. At Silivasu de Campie station, the value of the correlation coefficient associated to the evolution tendency of the air annual average temperature indicates a very slight rising tendency.

Evolution of rainfall during 2008-2014. From the data recorde at the stations equipped with rain gauges, the highest quantities of rainfall from the Transylvanian Plain were recorded at Branistea station in 2014 (580.65 mm/year), and the lowest at Mociu station (267.06 mm/year).
From the analysis of data regarding the quantity of rainfall recorded in the Transylvanian Plain during 2008-2014 one can notice its falling linear tendency, the highest values of the annual average are recorded in 2010, with an average value of 631 mm, it is considered a year with rainfall close to the normal in the area. The lowest quantities of rainfall were recorded in 2012 (358.62 mm), a drought year from the point of view of the quantities of rainfall (Figure 10). The multiannual average (2009-2014) of rainfall in the Transylvanian Plain is 466.52 mm, under the inferior limit of the area (500-700 mm/year).
The value of the correlation coefficient associated to the falling evolution tendency of rainfall is -0.51 which indicates a reverse, moderate to good index of the relation between the two variables analyzed.
In 2009, the average of rainfall recorded at the stations from the Transylvanian Plain was 533.1 mm, value close to the inferior limit in the area, and in 2011 rainfall was recorded in average value of 372.75 mm, 2011 being considered a year with deficit in rainfall. In 2012 the rainfall deficit emphasized, a drop of their average by 14.13 mm compared to the previous year was recorded. In 2013 and 2014 the annual average values of rainfall were under the inferior limit of the normal value in the area, they were 466.72 mm, respectively 436.93 mm.
In order to visualize the statistical relation between rainfall and soil moisture we used the correlation graph betwen the two variables. The correlation coefficient calculated for the analysis of the relation between rainfall and soil moisture 10 cm deep has a value of r = 0.92 which indicates a very close, direct, positive and significant relation between the two parameters (Figure 11). The value of the relation coefficient indicates a very good association between the two parameters, and the value of the determination coefficient R^2 indicates the fact that 84% of moisture variation can be explained by the linear relation with rainfall.

CONCLUSIONS

The Transylvanian Plain is the unit with the highest water deficit from the Transylvanian Depression. The soil thermal regime in this area shows a *mesic type* regime, the differences between the annual averages of summer temperatures and the averages of winter temperatures 50 cm deep in the soil are ranging between 12.81-20.01°C. The multiannual averages of the differences between the averages of the summer months and the averages of the winter months are ranging between 13.77-15.89°C.
The evolution of temperatures at soil level during 2009-2014, indicate the clear growing tendencies of temperature at the *soil surface (0 cm)*.
The coefficients of linear correlation among the data lines analyzed indicate a rising synchronous evolution of the annual average temperature, with values of the correlation indices of 0.81 at Zoreni station, 0.61 at Filpisu

Mare and respectively 0.52 at Band station. The same linear tendency with a rising evolution of the annual average temperature is recorded also in the case of temperatures *10 and 30 cm deep* in the soil.

The evolution of air temperatures during 2008-2014 shows slightly rising evolution tendencies, except for Căianu station where the evolution tendency of the annual average temperature is slightly falling.

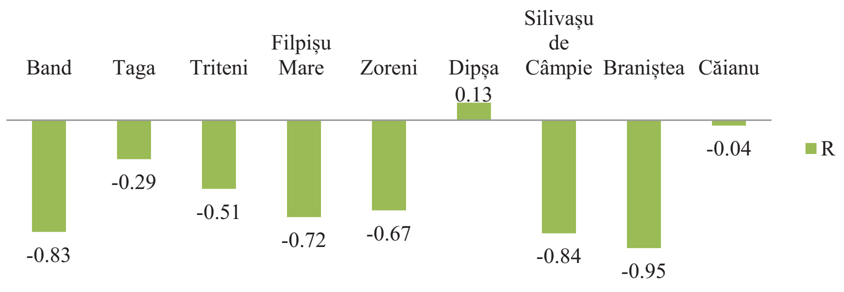

Figure 6. Values of correlation coefficient associated with trend evolution of annual average soil moisture in Transylvanian Plain

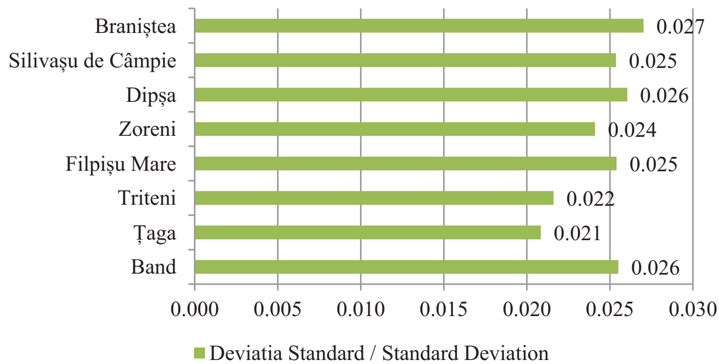

Figure 7. Standard deviation of annual value of soil moisture (m^3/m^3)

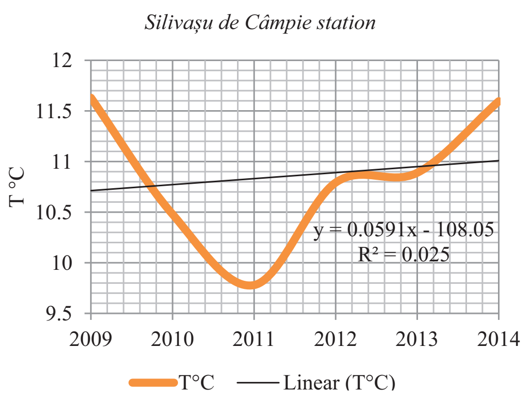

Figure 8. Linear trend of annual averages air temperature evolution at Silivasu de Campie station

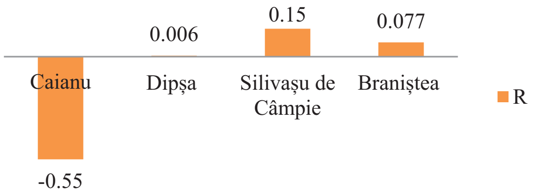

Figure 9. Values of correlation coefficient associated with trend evolution of annual average air temperature

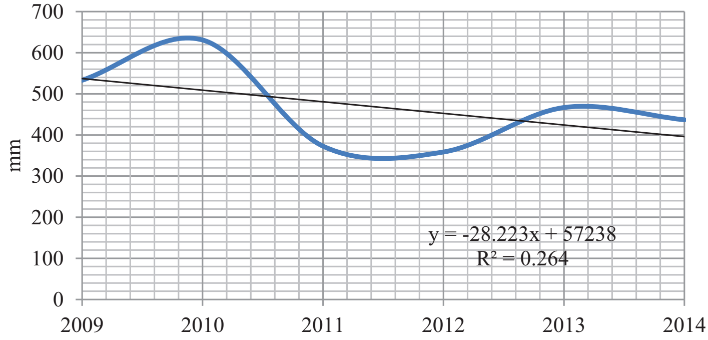

Figure 10. Linear trend of rainfall evolution in Transylvanian Plain during 2009-2014

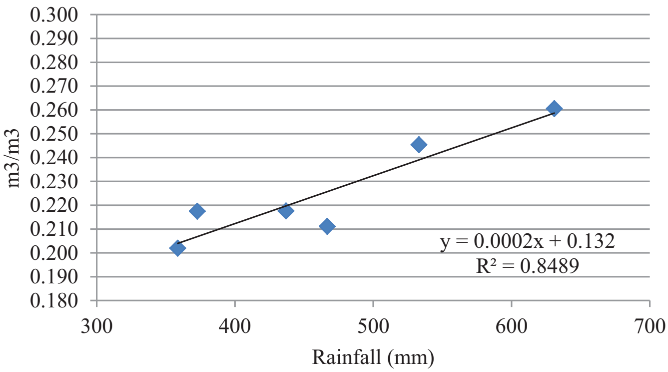

Figure 11. Correlation between annual value of soil moisture and rainfall during 2009-2014

The evolution of rainfall during 2008-2014 shows its falling linear tendency, the highest values of the annual average is recorded in 2010, with an average value of 631 mm, 2010 is considered a year with rainfall close to the normal of the area, and the lowest quantities of rainfall were recorded in 2012 (263.9 mm) a drought year from the point of view of rainfall quantities. The value of the correlation coefficient associated to the falling evolution tendency of rainfall is r = -0.51 which indicates a negative, moderate to good correlation of the relation between the two variables analyzed.

The multiannual average (2008-2014) of rainfall from the Transylvanian Plain is 466.52 mm, under the inferior limit of the area (500-700 mm/year). At the level of the Transylvanian Plain, the standard deviation of the annual values compared to the multiannual average of the area is 93.8 from which it results that, on an average, the annual values deviate by ±93.8 mm compared to the multiannual value of the area.

The evolution of soil moisture during 2008-2014 recorded 10 cm deep indicates its general falling tendency at the majority of stations except for Dipsa station where the linear tendency indicated a slightly rising evolution, almost negligeable of soil moisture. The values of the correlation coefficients associated to linear tendencies of soil moisture are ranging between -0.95 at Branistea and -0.04 at Caianu station. The most clear falling evolution tendencies of soil moisture were recorded at Branistea, Silivasu de Campie and Filpisu Mare stations, followed by Zoreni and Triteni stations.

From the analysis of values of the standard deviation calculated for each station it results that soil moisture varies by 0.021 m^3/m^3 up to 0.027 m^3/m^3 compared to the multiannual average of each station analyzed. From the analysis of the statistical relation between rainfall and soil moisture, the calculated correlation coefficient has a value of $r = 0.92$ which indicates a direct and positive causal relation between the two parameters, a very good association between them, and the moisture variation can be explained by the linear relation with rainfall (84%).

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