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SEASONAL HETEROGENEITY OF SOIL MICROCLIMATE IN *FAGUS SYLVATICA* FOREST IN RELATION WITH STAND AGE

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Abstract

The heterogeneity of soil temperature (Tsoil) and soil moisture (Usoil) is recognized as bearing an influence on plant communities, due to the variability of vegetation-specific resource requirements. We tested the temporal differences of heterogeneity of the soil microclimate in an even aged beech forest with four different stand age (10, 30, 80, 120 years) located in the southern part of Romania. The bimonthly measurements of Tsoil and Usoil, made over almost a year (April-December) aimed to investigate the interaction between the age of the trees and these climatic variables in the soil. Both climatic parameters were calculated for each experimental plot for each season and for the entire measurement period. The one-way analysis of variance (ANOVA) was used to test the differences between the plots with trees of different ages for the temporal variability of the soil microclimate. The temporal patterns of soil microclimate differ significantly between tree ages, being more sensitive to Usoil compared to Tsoil. The analysis of our data showed a decrease in Tsoil with the age of the tree in the spring and similar trends in the rest of the measurement periods. On the other hand, the Usoil model showed less seasonality compared to the Tsoil, probably being more receptive to the characteristics of local conditions, such as the slope of the land, the thickness of the litter layer, the porosity of the soil or the degree of closure of the forest canopy. These results can conclude that, the ability of forest at small stand ages will increase seasonal the soil microclimatic parameters (Tsoil and Usoil) at highest levels.

Key words: *forest, heterogeneity, soil temperature, soil moisture, stand age.*

INTRODUCTION

The climate is one of the most crucial environmental factors affecting the forest ecosystem architecture and function (Zheng et al., 2000; Vlad et al., 2019; Ducci et al., 2021; Kutnar et al., 2021). While the effects of macroclimate influence at large scales, the microclimate directly dominates the ecological and biogeochemical processes of ecosystem at local scale (i.e., forest stand, tree species). Likewise, the microclimate is highly interactive with other ecosystem components (i.e., vegetation cover, soils features or topography of terrain) and demand an assessment of the ecosystem behavior (Zheng et al., 2000; Nurudin and Tokiman, 2005).
The dynamic behavior of the forest is being changed by interactions between cover, biotic and abiotic characteristics and especially climatic and microclimatic conditions (Kovacs et al., 2016).
It is well known that, in general, the vegetation cover and in particular, the forest canopy can regulate the climatic conditions and achieve a specific microclimate, by influencing soil temperature regime and the hydrological process (Latif & Blackburn, 2010; Lozano-Parra et al., 2018; Ni et al., 2019; Dinca et al., 2020; Ilek et al., 2021). This local microclimate depends on the climate itself and the physical attributes, with implications in the design (structure and nature) of vegetation cover (Figure 1). In addition, microclimatic variables (i.e., soil temperature and soil moisture) can act as drivers for simulating the plant water status and photosynthesis (Zheng et al., 2000; Ozcelik and Sengonul, 2021).

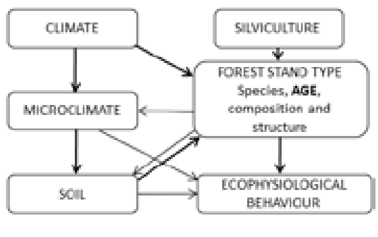

Figure 1. Interactions between climate and forest stand (Adapted by Gilbert Aussenac, 1999)

Other factors such as elevation and exposition can alter soil microclimate fundamentally (especially soil moisture) with potential impact in development of forest (Pichler et al., 2009; Dinca et al., 2020). One the other hand, lower levels effects on soil microclimate (i.e., temperature and moisture) can be influenced by soil features and stand characteristics, such as humus content, the amount of litter layer, species composition, age and vertical structure of stand, cover and distribution of vascular plants, etc. (Kovacs et al 2016, Fekete et al., 2019). Both tree age and heterogeneity together with silvicultural interventions are the variables that explain the most variability of species composition from the local to regional scale (Aude & Lawesson, 1998; Dinca and Achim, 2019). Therefore, solar radiation modulated by phenology is a considerable environmental parameter for competition, restraining vegetation survival and plant growth (De Frenne et al., 2013). Indeed, phenological behaviour can differ greatly when taking in consideration trees of different development stages, specific each of forest age stand (Gressler et al., 2015).
Forest structure (e.g., vertical complexity) can directly control the amount and variability of light (De Frenne et al., 2013), while the amount of litter can alter bellow-canopy microclimate culminating in reduced soil water evaporation or change albedo (Fekete et al., 2019). In addition, it has been shown that the forest canopy is an important driver in controlling stand climate. Besides, age stand can influence thermodynamic efficiency, absorb and dissipates incoming solar energy more efficiently (Kovacs et al., 2016; Dinca et al., 2019).

However, while many studies have focused on the relationship between age stand, forest structure and vegetation dynamics (Murariu et al., 2021), relatively little attention has been given to understanding the link between age forest and soil microclimatic conditions throughout all seasons. The aim of this study is to explore the dynamics of soil microclimate in even age deciduous forest, in particular the effect that stand age poses on soil temperature and soil moisture.
The specific objectives of our study were as follows:
(1) to determine soil microclimate variability per each season (Spring, Summer, Fall and Winter);
(2) to highlight the link between soil microclimate components (temperature and moisture) and gradient of stand age.
In order to achieve the objectives, we conducted a study on even age beech forest, in four age classes (10 years-old, 30-years-old, 80-years-old, 120-years old). The analysis of influence of stand age on seasonal soil microclimate was carried out over unreplicated age classes.

MATERIALS AND METHODS

Study area, experimental design and soil microclimate measurements

Field investigations were conducted in the Experimental Forest District Mihaești (Argeș county) managed by the National Institute for Research and Development in Forestry "Marin Drăcea", throughout the southern part of Romania (Figure 2).

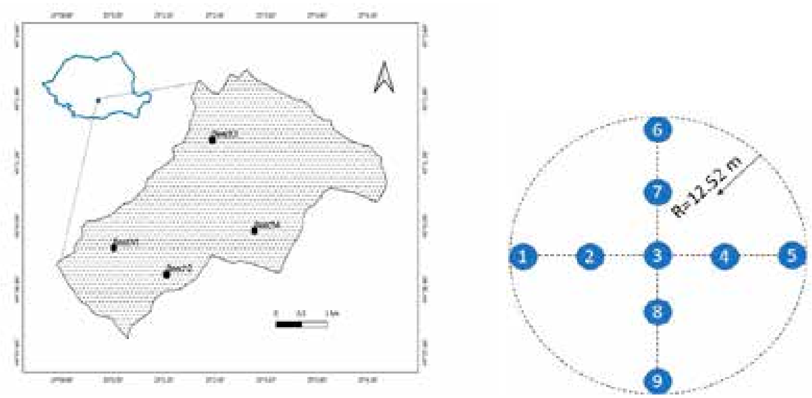

Figure 2. The location of soil microclimatic sites and sampling design (filled blue circles) within a 0.05 ha plot

According to Köppen and Geiger, the climate for all experimental sites is characterized by temperate continental, classified as *cfb*, with a mean annual temperature of 9.5°C and mean annual precipitations of 867 mm, respectively. July is the hottest month with an average temperature of 20.1°C and January is the coldest month with -1.7°C. The rainiest month is June (117 mm) and the driest month is February (44 mm) (estimates calculated using climate-data.org) (Figure 3).

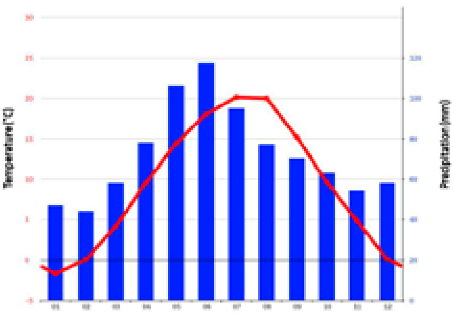

Figure 3. Climate-diagram of air temperature (red line) and precipitations (blue column) of Mihaești region (climate-data.org)

The mean elevation is 525 m, ranging from 509 to 541 m above sea level (Table 1), with small modification of topography, with the most common landscape elements being hills. According to the FAO World References Base (Târziu and Spârchez, 2013), the most frequent soil type is Eutric Cambosols (clay loam), covered with mull type, developed on a sandstone with marls parental material (Braga and Spârchez, 2014; Heres et al., 2021). The forest cover of the studied region is highly heterogeneous, both tree species composition and stand structure vary among the stands. The dominant tree species in the region is beech (*Fagus sylvatica* L.), although other tree species may also be present: sessile oak (*Quercus petraea* Matt. (Liebl) and peduculate oak (*Quercus robur* L.), hornbeam (*Carpinus betulus* L.), sweet cherry (*Prunus avium* L.) or sycamore (*Acer pseudoplatanus* L.). The European beech trees within the study stand differ by site, from younger (main age at 10 years) to adult (main age at 120 years), which allows to consider it as an even aged forest stand by each site, with the oldest stand being mature for harvest. All the stands in the present study, within a 1 km radius, had reached canopy closure and were characterized by a nearly heterogeneous herbaceous vegetation. The age of beech stand was provide by the forest administration (Management Plan of Experimental forest district Mihaești). According to the general protocol (Braga and Sparchez, 2014) forest structure around each soil microclimate measurements (500 m^2 area) were inventoried: the diameter of breast height (DBH, cm) and total height of the tree, (H, m). After that, we determined the tree density (N, stem ha^{-1}), the basal area (BA, m^2ha^{-1}) and the volume (V, m^3ha^{-1}) within a 12.52 m radius (R) based on the stem mapping database of the all 4 stands age (Table 1, formula 1 and 2).

$$BA = \frac{\sum_i^n \left(\left(\frac{1}{2}\right) \times DBH_i \right)}{R^2} \qquad (1)$$

$$\log V = a_0 + a_1 \log DBH + a_2 log^2 DBH + a_3 \log H + a_4 log^2 H \qquad (2)$$

where: a_0, a_1, a_2, a_3, a_4 represent the regression coefficients for each tree species (Giurgiu et al., 2004).

Soil microclimate measurements (temperature and moisture) were carried out in two perpendicular transects within a 12.62 m radius (500 m^2) of each stand age. Within 500m^2 plots, a series of nine points at 6.26 m were permanently marked per stand for soil microclimate measurements (Figure 2).

Table 1. The main characteristics of each site (Geographic coordinates, A - stand age, DBH - diameter of breast height, N - number of trees per ha, BA - basal area, V - volume of trees per ha.). The stand age was provided by the forest administration and the rest of date was determined

Site	Latitude (N)	Longitude (E)	Altitude (m)	A (years)	DBH (cm)	N (N/ha)	BA (m^2/ha)	V (m^3/ha)
Beech1	44.9930	25.0002	509	10	3.2	4438	9.2	23.1
Beech2	44.9846	25.0209	517	30	8.6	1237	18.3	77.6
Beech3	45.0271	25.0389	553	80	32.5	532	27.3	456.5
Beech4	44.9984	25.0554	541	120	44.8	323	33.2	346.8

The soil temperature (Tsoil) was measured to a depth of 10 cm in all 9 measurement points per each plot, using a specific device (CEM DT 131, UE). Simultaneously to the Tsoil measurements, the soil moisture (Usoil) was measured to a depth of 20 cm at the same positions, using the time domain reflectometry technique with *a FieldScout TDR 300 (Spectrum Technologies Inc., USA).* All soil microclimate measurements were done, in general, bimonthly throughout all unfrozen season (from April to December).

Statistical analysis

In order to test the hypothesis that mean values of the dependent factors (soil temperature and soil moisture) differ for each type of forest site (stand age), one-way analysis of variance (ANOVA) was used. Assumptions were examined by Levene's test for homogeneity of variances (Snedecor and Cochran, 1980). The analysis was run independently for every sampling period (Spring, Summer, Fall and Winter) for all variables. When groups were significantly different, ANOVA were followed by Tukey's HSD test. When p value < 0.05, examined values were expressed to be significantly different. All statistical analyses were performed using Statistica 7.1. (Statsoft, Inc., 2005).

RESULTS AND DISCUSSION

Seasonal variability of soil temperature (Tsoil) and soil moisture (Usoil)

As we expected, both soil microclimatic dependent variables (i.e., Tsoil and Usoil) followed a different pattern during the study period (Table 2, Figure 4).

On the one hand, Tsoil accomplished large seasonal changes, culminated during the summer embracing its minimum during the winter (Table 2, Figure 4A).

Furthermore, values of soil moisture accomplished less seasonality, reaching a minimum during summer, but being more stable and similar for the rest of the year (Table 2, Figure 4B).

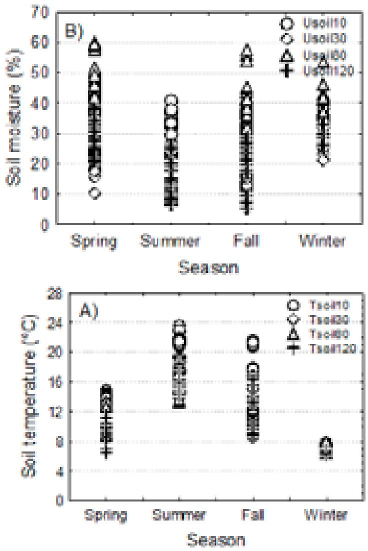

Figure 4. Seasonal (i.e. spring, summer, fall and winter) pattern of A) soil temperature and B) soil moisture for 10, 30, 80 and 120 old stand

Relationship between soil microclimate variables (Tsoil and Usoil) and stand age

In spring, the lowest value of soil temperature at 10 cm depth was recorded at the 120-year-old stand and the highest value was recorded in the youngest stand (Table 2). Besides, the highest value along all period of measurements, was recorded in summer (20.41±1.91˚C), in the rest of site being recorded relatively similar values.

Moreover, the same trend was reported during the fall. As expected, the lowest soil temperature, was recorded in the winter season, and the value between plots was relatively similar.

Soil moisture determined in the first 20 cm of the soil profiles experienced less seasonality, with the lowest value recorded in summer 3.21±3.37%, 30-year-old stand) and the highest value recorded in spring time (46.10±6.07%, 80-year-old stand). However, throughout all periods of measurements, the 30-year-old stand averaged soil moisture significantly lower in comparison with the rest of the stands (Table 2).

Table 2. Mean and standard deviation values of soil microclimate (soil temperature and soil moisture) for ich season in each site (n = sampling dates in which an average of 9 points per site were sampled)

Season	n	Soil temperature (°C)				Soil moisture (%)			
		10-year old	30-year old	80-year old	120-year old	10-year old	30-year old	80-year old	120-year old
Spring	3	13.47±1.16	11.80±1.54	10.57±1.33	9.26±1.78	31.22±5.75	27.05±6.36	46.10±6.07	27.66±4.12
Summer	6	20.41±1.91	16.45±1.88	16.79±2.16	16.33±1.57	21.02±7.13	13.21±3.37	32.18±8.17	13.60±4.63
Fall	5	15.17±4.13	12.71±2.97	12.90±3.15	12.69±3.12	20.86±6.23	14.68±5.71	33.70±9.62	16.59±7.61
Winter	1	7.28±0.33	7.27±0.29	7.27±0.53	6.56±0.23	30.69±3.80	27.60±4.89	42.58±4.94	28.71±2.18
Annual	15	16.21±4.57	13.55±3.35	13.42±3.75	12.81±3.87	24.12±7.88	18.03±8.00	36.78±9.93	18.99±8.24

Note. The above-mentioned statistics have been calculated both at the seasonal level (i.e., spring, summer, autumn and winter) and over the four seasons combined (i.e., annual).

Soil temperature (Tsoil) and soil moisture (Usoil) measured at each site were compared with the one obtained at their references sites by mean one-way repeated-measures ANOVA.

In spring time, when performing soil microclimate measurements, throughout all plots, we found significant differences in mean soil temperature, between the 10-year-old stand and the rest of the plots ($p < 0.05$, Figure 5A). Not the same thing happened in the rest of the year, where only the 10-year-old plot recorded differences between the others plots in summer and fall seasons (Figure 5B and 5C). In addition, in the winter season, only the 120-year-old plot recorded significant differences on soil temperature from the rest of plots ($p < 0.05$, Figure 5D).

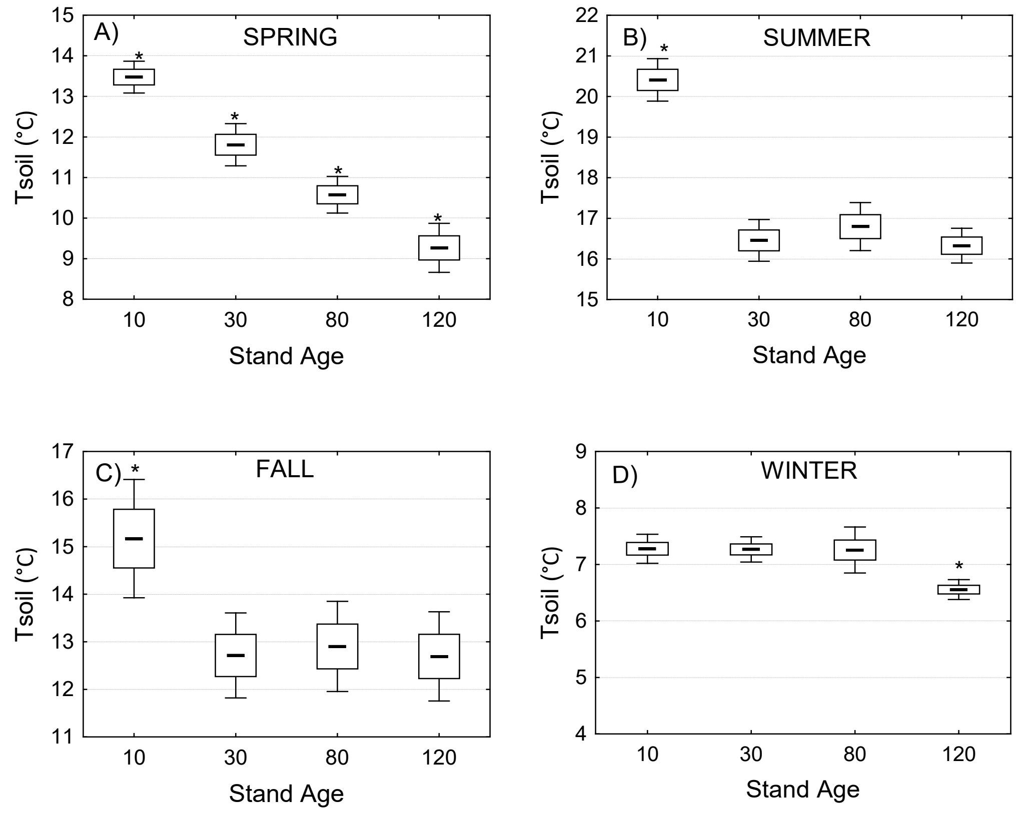

Figure 5. Seasonal variation of soil temperature in the different stand ages. Box-plots represent the mean value and error bars are standard errors of the means. Asterisk (*) symbol denote significant correlations at the $p < 0.05$.

On the other hand, we found a similar trend by significant differences ($p < 0.05$) of the soil moisture pattern for Spring, Summer and Fall season (Figure 6A, B, C), where the 10-year-old and the 80-year-old recorded significant differences compared with the other plots ($p < 0.05$), the 30-year-old and the 120-year-old. In winter (December), the seasonality of Usoil followed a pattern similar with the rest of the seasons (year), but the mean value of Usoil recorded a significant value only for the 80-year-old stand ($p < 0.05$, Figure 6D).

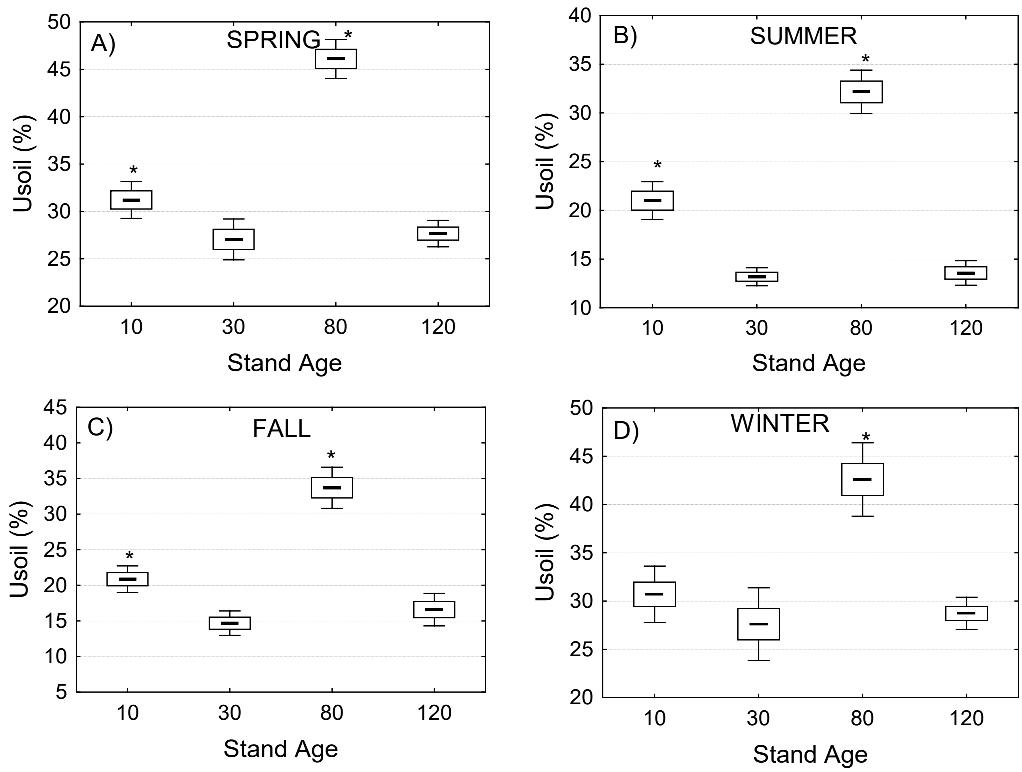

Figure 6. Seasonal variation of soil moisture in the different stand ages. Box-plots represent the mean value and error bars are standard errors of the means. Asterisk (*) symbol denote significant correlations at the $p < 0.05$

As we expected, seasonal variation (April to December) of soil microclimate in beech forest developed a similar trend for all sites (Figure 4) and was much larger in soil moisture heterogeneity than in soil temperature variability, between stands age (Table 2, Figure 5, Figure 6). Our results demonstrate the influence of stand characteristic (i.e., age stand), but they also suggest that the importance of tree age is lower than we had expected. The limitation may be attributed to the variability of other soil characteristics, such as soil porosity, local topography, thickness of litter, forest structure (Kovacs et al., 2016; Ni et al., 2019; Onet et al., 2019). The analysis of the experimental plots (different age stands) showed a decrease of soil temperature with stand age in the spring season and a similar decreasing trend in the summer and the fall period (Figure 3). A possible explanation for the fluctuation of soil temperature between the studied sites can be done by the amount of the litter layer, which is larger in older stands (Braga & Sparchez, 2014). The soil temperature under the youngest stand (10-year-old) recorded the highest value for the vegetation season (Spring, Summer and Fall) and insignificant differences between sites in December. Indeed, the annual litterfall quantity can act as a buffer zone which regulates the particularity of the soil temperature regime (Fekete el al., 2019). As we expected, in colder periods of measurements (i.e., December period), the influence of age stand on soil temperature was insignificant, with the exception of the 120-year-old stand where the mean value determined was much lower (Table 2, Figure 6). An explanation for the frozen period (cold December) can be given by the low activity of the trees due to a very weak metabolism of the fine roots. Indeed, the soil temperature reduction could limit the growth vegetation (Alvaria Uria & Korner, 2008). Furthermore, the roots expansion of most plants could stop at temperature below 5°C (Vapaavuori et al., 1992; Ni et al., 2019), even if in our study the soil temperature values recorded in December was much higher than this threshold (Table 2). Moreover, the thickness of the litter layer can have an isolating response on the soil temperature regime (MacKinney, 1929) by delaying freezing in temperate zone (Sayer, 2006). On the other hand, the soil temperature regime can be influenced by a soil biochemical process. Through the decomposition of organic matter and soil biota activities, a significant amount of heat can be released, with substantial repercussions on the soil microclimate regime (Holst et al., 2004; Fekete et al., 2016; Onet et al., 2019). As more sunlight reaches the ground, the range of soil surface temperatures increases and moisture balance are altered (Zheng et al., 2000), with implications in regulating the hydrological process (Ni et al., 2019). The 80-year old stand was the most significant driver in the maintenance of soil moisture microclimates, while the 10-year-old stand was the most significant driver in the maintenance of the soil drought. One cause can also be attributed to the presence and thickness of the litter layer, one of the factors that highlight the extent of the canopy, especially mature trees that have similarities in maintaining certain climatic conditions. On the other hand, the 80-year-old stand was not affected by natural perturbation (windbreaks or insect attacks) or anthropic interventions (silvicultural practice) in the last decade, confirmed by the forest management plan. In this case (i.e., Beech80 site), characterized by high-density trees with a big crown, the forest canopy intercepted all the water content from precipitation events at low intensity (< 10 mm), but allowed infiltration during larger rainfall (James et al., 2003). At the same time, for younger trees (Beech10 and Beech30 sites) the balance between interception and evaporation of water at soil surface from precipitation events was more or less different, with implications in the hydrological process (Figure 5). Furthermore, the litter horizon (e.g. dead leaves, bark, twigs) allows more or less the infiltration of water to high depths in the soil profile and reduces the evaporation from the mineral horizon of soil while absorbing a fraction of the rainfall. These facts strongly suggest that the soil water regime acts as a bridge between deficits in precipitation and failures of plant growth (Shinoda & Nandintsetseg, 2011).

Although the maximum value of the trees volume (Beech80 site) linked to the close canopy, recorded throughout all growth vegetation, the highest value of Usoil compared with others sites. However, there is a level of canopy density, which is probably correlated to site specific soil water availability. One the other hand, the canopy density was much lower in early spring and only reached high values after leaves were fully developed, with repercussions on the soil climatic regime (Georg von Arx et al., 2013).

The local conditions (Mihaești region) confirm the variability of the phenology during a year, namely the beginning and the end of the beech phenology (when the leaf begins to develop until the moment it falls at the end of autumn). There is a difference in phenology in terms of the stand age. Spring young trees start the foliage sooner compared to old trees. The end of the phenology shows the opposite situation, when leaf fall in old trees takes place later than in young trees (young tree leaf sooner and lose the leaf faster while the old trees' leaf later on and lose the leaf later) (Sidor, 2014). Further, the onset of phenological phases in the first part of the year is generally controlled by the total value (sum) of effective air temperatures preceding the phase (Bednarova &Merklova, 2007) even if the start of the phenophase can substantially differed by approximately half a month among individual trees, under different density canopy (Schieber, 2006). Additionally, the phenological pattern of Fagus sylvatica can be different among trees, especially if they possess a different age. Indeed, the seedlings leafed out almost a month earlier than the adult tree, and an ontogenic effect might be responsible for this discrepancy (Gressler et al., 2015). Furthermore, the photoperiod duration, the temperature intensity and the amount of precipitation are the most climatic variables which control the phenological process of each individual trees (Schieber, 2006).

However, even though the soil temperature variable is controlled by the full verticality of the vegetation cover (Aussena, 2000), the effects of forest characteristics (i.e. structure, age) on soil moisture may be difficult to determine, as reduction in canopy cover may lead to more evaporation from the soil surface, but less transpiration loss (Abd Latif, Z., & Blackburn, G. A., 2010; Sparchez et al., 2017). Shifting balances between soil temperature and soil moisture along all seasons suggest potential changes in soil features and the complexity of terrain, with interaction with plants activities and the architecture of forest cover, particularly by amplitude of leaf area index in forest (Bequet et al., 2012). Besides, young trees situated below the main canopy, increase humidity by stronger shading and by reducing wind speed, filling the trunk space with variously dense foliage, thus creating a more moderate microclimate (in Kovacs et al., 2017).

CONCLUSIONS

The present study evaluated the implications of age stand on soil microclimatic conditions in an even aged beech forest. Due to the fact that the determination period was relatively short, only about one year, we consider that it was not possible to evaluate very well these forest-climate responses in the soil, compared to an analysis situation over a multi-year period. According to our results, the stand age influences the variability of the soil microclimate. On the one hand, the canopy of the forest, as an expression of the crown biomass, can regulate the dynamics of the soil climate. On the other hand, the soil activity and soil characteristics can influence the spatiotemporal variability of soil climatic parameters. A long-term assessment will be useful to investigate the particularities of forest ecosystems, such as the influence of the stand age on the variability of soil climate regimes.

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