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Dendroclimatological analysis of the radial growth rings for oak in Moldova plateau

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Abstract By using the dendroclimatological method we have analyzed the climate influence upon the tree growth. Since the annual growth ring can be differentiated on intra-annual growing periods, respectively earlywood and latewood, the climate analysis was done with an intra-annual resolution, but finally reported to the total annual growth. The studied statistical parameters are the most representative for the definition of the analyzed relationships respectively the correlation and the response functions. In order to check the obtained results we will calculate the event years for the series of growth indexes of annual rings (RW). To understand ecosystem response and variety consequences of environmental changes I have built three oak tree ring chronology with a significant sensitivity to the climate. The importance of this study comes from the need to know the adaptation way of the tree to the climate factor, which is mostly essential for the long term evolution of wood species.

Key words

dendrochronology, oak, response functions, earlywood, latewood

Lately, a great number of studies have analyzed the influence of climate upon trees, in Romania (Popa, 2003; Popa & Kern, 2008; Nechita & Popa, 2012, Levanič et al., 2012), and also abroad (Čufar et al., 2008; Fonti et al., 2007; Dagmar et al., 2008). The increasing interest for this topic is due to the current climate changes. Scientists around the world succeeded in creating a large number of dendrochronological series based on radial growth rings for long periods of time. The longest created series goes back to year 8480 B.C. and it belongs to Stuttgart, Köln and Göttingen universities (Friedrich et al., 2004). The analysis of climate for such a long periods of time was done by climate reconstructions based on meteorological data before and after the little ice age.

Based on these studies, forecasts and modeling of future climate were done (Christensen et al., 2007). According to the IPCC 2007 forecasts more climate changes can be observed for the next decades respectively the planet surface will warm up due to the warming up of the troposphere and the chilling out of the stratosphere. At high latitudes the relative warming up will be higher, the cooling effect of the tropospheric aerosols moderates both global and local warming which induces a rise of air temperature at the level of the earth shell. According to these studies the soil warming up will be more pronounced than the oceans'.

Due to the increase of temperature at the soil level behavior changes for the species that live at the inferior limit of the vegetation levels can occur, oak being an important part of this category. The study of their adaptability to the climate changes is extremely important for the near future of this species (Nechita & Popa, 2012).

The obtained results emphasized a strong correlation between the average radial growth and the main climate factors studied, respectively precipitations and temperatures. The interpretation is done by taking into account that the trees of this studied area, even though they vegetate in optimum climate, they obviously respond to the precipitation action during the period of forming the radial growth ring and to the temperatures at the beginning of the vegetation season. The evidence of the climate having continental influences is done by negative correlations obtained at the beginning of the vegetation season.

Material and Method

The study area is located in Moldova Plateau near Podu Iloaiei city (47°06′23″N, 26°56′32″E; 215 m altitude). The trees introduced in this survey are very large, reason for which they are considered to be remains of some older forest. Nearby there are several lakes, these local conditions ensuring a plus of humidity in atmosphere and soil.

We have introduced a number of 37 trees in the study, their choice being made according to the dendrochronological principles (Fritts, 1976; Cook &

Kairiukstis, 1990). The growth samples were taken at 1.30 m high from the ground. The taken samples have been dried out and then assembled on standard wooden plates. For a good visualization of the growth rings they were polished with abrasive tapes with different granulations. The measurement of the width of the annual ring was done by a digital positioning table LINTAB 5 and the computer program TSAP Win (Rinn, 1996). The measurement accuracy was of 0.001 mm, the records being saved in Tucson format (*rwl, **.).

The measurement accuracy was tested by the computer programs TSAP Win and Cofecha (Holmes, 1983). By running the computer routines of the ARSTAN Win program (Cook, 1985) the series of annual growth values were standardized, obtaining the series of residual indexes (RES) used in this study. For standardization we have used the spline function with amplitude of the interval of 30 years in order to emphasize the medium and low frequency.

The analysis of the event years was done with the statistical program R Gui (R Development Core Team 2009). The method used for determining the event years was that of the statistical analysis of the normalized values in mobile window. The calculation stages of the pointer years are presented below (Cropper, 1979). To start we have calculated the average values and the standard deviations for each mobile window of 5 years fitted in the analyzed year t. The pointer year represents the year in which the radial growth within a growth series is obviously decreased or increased compared to the average value of the annual ring width.

Thus, the establishment of the pointer years by applying a significance limit of 0.75 – which is equal to the width of the annual ring t – is 0.75 local standard deviations higher or smaller, resulting positive or negative event years, as the case may be. The calculation of the percentage of individual series presenting an event year determined also the separation of the ones with representativity higher than 75% of the total number of individual series in year t.

The climate data come from the international database CRU TS3 (Jones & Haris, 2008). The time period covered is of 109 years, between 1901 and 2009, the grid's resolution being of 0.5°. The climate data are characterized by an annual level of precipitations of 553 mm, the multiannual minimum being recorded in February (-21.9 mm) and the maximum value in June (86.1 mm). The average of the multiannual temperatures is of 7.6 °C, the minimum being recorded in January (-5.1°C) and the maximum in July (18.8°C).

The greatest amount of atmospheric precipitations in one year is of 796.7 mm, corresponding to 1941, unlike in 1953 that holds the minimum recorded value of 109 measurements, respectively 379.1 mm. The relation between the climate conditions and growth was determined through the statistical program Dendroclim 2002 (Biondi & Waikul, 2004). The studied time period is between September of the previous year and the September of the current year.

Results

The average length of the individual growth series varies between 67 years and 197 years, with an average of 128 ± 28 years, covering the period between 1812 and 2008. A number of more 10 individual series are recorded only after 1873. The wood average radial growth is of 3.06 mm·year^{-1}, varying between 1.15 mm·year^{-1} and 7.64 mm·year^{-1}. The earlywood has an average growth of 1.37 mm·year^{-1}, between the minimum value of 0.38 mm·year^{-1} and the maximum value of 2.23 mm·year^{-1}. The average growth of the earlywood series corresponds to the value of 2.21 mm·year^{-1}, and varies between 0.42 mm·year^{-1} and 5.85 mm·year^{-1} (Figure 1).

The 1st degree autocorrelation for the series of average growth varies between 0.63 ± 0.16 for the total ring and 0.50 ± 0.14 for the earlywood. The series of indexes are characterized by insignificant values of the 1st degree autocorrelation. The standard deviation is significant for the latewood (1.40 ± 0.37) and the total ring (1.68 ± 0.40), for the RAW series. After the application of the autoregressive model the standard deviation has a maximum value of 0.32 recorded for the summer wood.

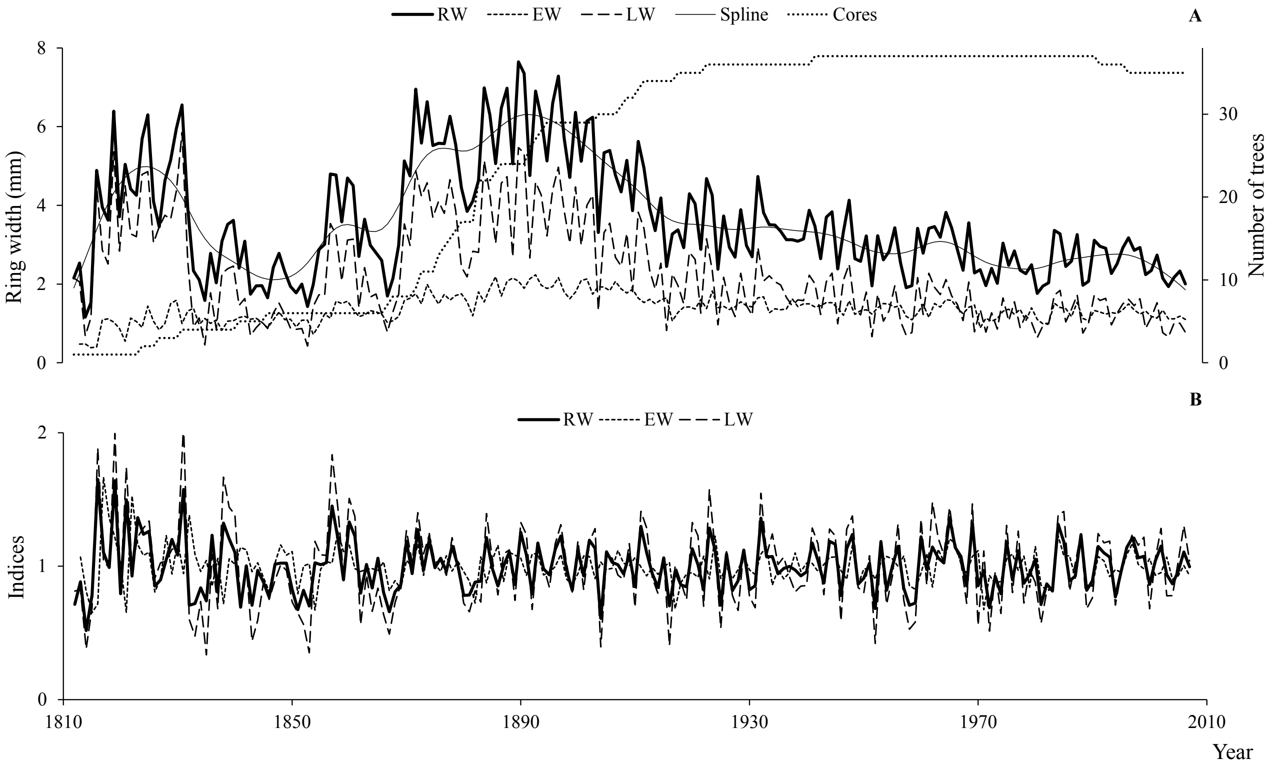

Figure 1. The dendrochronological series for oak in Podu Iloaiei. A – the series of average radial growth for the annual ring (RW – bold continuous black line), earlywood (EW – dotted black line), dashed black line – distribution in time of the number of trees. B – comparison of the residual growth series (RW, EW and LW).

The correlation between the individual series and the average chronology is significant for the latewood (0.66), it reaches the maximum value. The average sensitivity of the series of individual growth for the all chronologies is higher for the latewood 0.48, being followed by the total ring 0.28 and at last by the earlywood 0.23. The correlation value between the index series (rbar) is smaller than for the radial growth series, the greatest values being recorded for the latewood, respectively for the RAW chronologies (0.60) and for the RES value is 0.46. The average EPS statistic is of 0.94, with significance superior to the value of 0.85 after the year 1870 for the indexes series.

The variability explained by the first main component is of 50.37 % for the series of residual indexes of latewood. The smaller value is recorded for the earlywood in the case of both RAW and RES chronologies, respectively 27.22 % and 27.83 %. The proportion between signal and noise is very important for the residual series where we have determined the maximum value for the summer wood (29.73) and the minimum value for the spring wood (10.06).

The climate influence upon radial growth for the studied trees is major both for precipitations and temperature. The annual average precipitations significantly influence the tree growth mainly in the year before the bioaccumulation process. A positive affect is experienced in the months of October (0.17) and November (0.25) for the total wood (Figure 2). The amount of precipitations in November is less important for the earlywood (0.17) compared to the latewood (0.23).

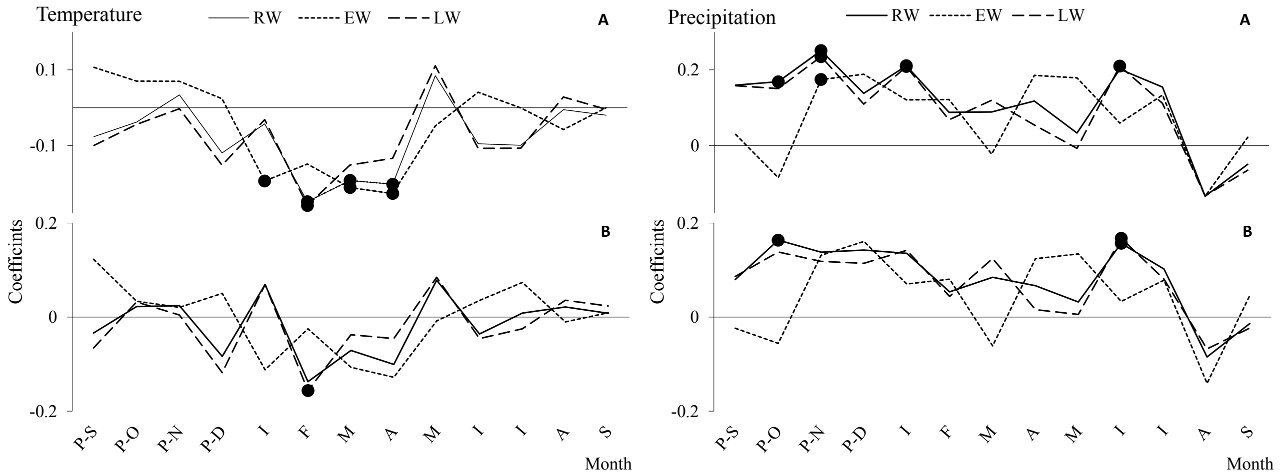

Figure 2. Correlation between the climate parameters and the residual values of the series of indexes. A – correlation between the residual series of total ring (RW), earlywood (EW), latewood (LW) and climate parameters; B – response functions between residual series of total ring (RW), earlywood (EW), latewood (LW) and climate parameters.

Analyzing the obtained correlation values for the current year of forming the radial growth ring we can notice that precipitations in January and June are the only important ones. The need to have a water amount in the soil large enough is given by the positive signal of correlation. Thus we can assert from the obtained results that at the intra-annual level only the latewood is significantly influenced by this parameter.

Unlike the previously studied climate parameter the average temperatures have a strong negative and significant influence upon the bioaccumulation process. The temperatures affect the total ring RW in February, Mars and April. The maximum correlation level is seen in February (- 0.25) while in Mars it drops to -0.19. The month of April, according to the significant correlation with the value of 0.20 shows that these trees are frequently exposed to the late freezing phenomenon.

Intra-annual analysis indicate that only the earlywood is affected by freezing, the maximum correlation value being recorded in April (-0.23) supporting this assertion. The latewood is negatively and significantly correlated with temperatures only in the month of February when the strong frosts with continental influence can harm the trees biological structures (apical or terminal meristems).

The response functions can be interpreted as indicators for the annual climate conditions which determine growth above the average. This parameter is characterized by monthly average temperatures below the mean and average precipitations above the mean of every month. The monthly values dotted in black indicate values with significance above the trust interval of 95%. The response functions show us a significant and negative influence between radial growth and temperature in the month of February of the current year of forming the tree growth ring.

The significant value is found in the series of latewood (LW – 0.16). Higher but insignificant values are found in the characterization of the earlywood (EW) in the months of Mars (0.11) and April (0.13). The values corresponding to the months of September corresponding to the earlywood (0.12) and May for the late and total wood (0.08) suggest the presence of the direct relation between growth and temperatures of these two months.

The results for correlation with precipitations indicate a positive significance in the month of October of the previous year for the total ring; the significance value is of 0.16. The same value is found in the current year for the radial growth ring formation in the month of June. The latewood also presents a value superior to the one for the total ring respectively 0.17 in June. Negative but insignificant values were recorded for the earlywood for the month of October of the previous year and the month of May for the current year, the value being of – 0.06.

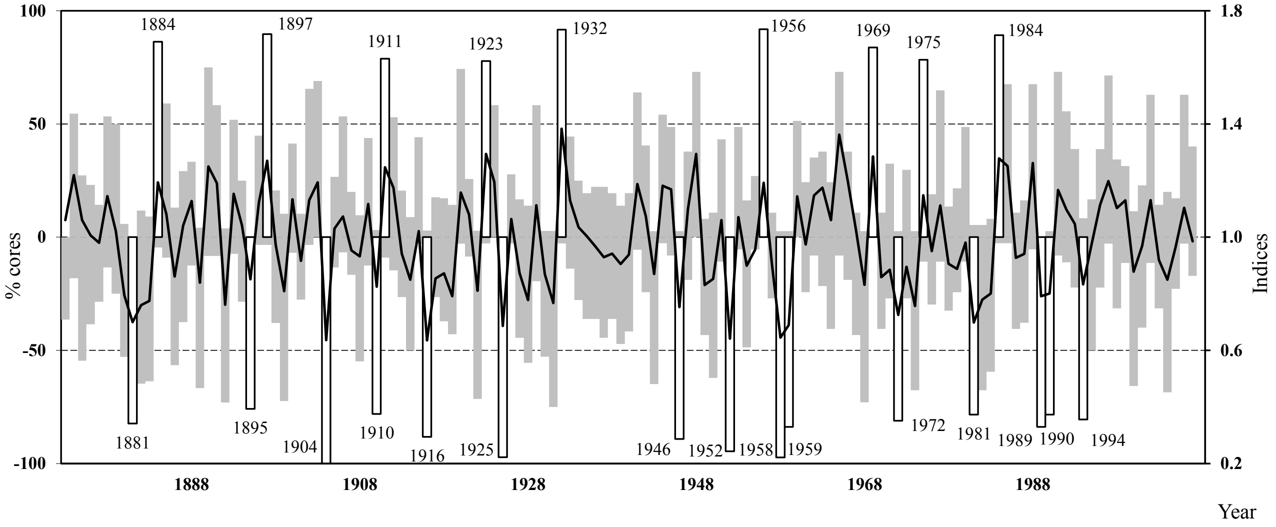

Figure 3. Event years for the dendrochronological series of oak in Podu Iloaiei (grey – percentages of individual series including the event year, the white bars limited by the black line represent the positive and negative event years, the continuous black line represent the dendrochronological series).

The pointer years represent clear references in the crossdating process but moreover they offer precious information regarding the extreme climate conditions they were formed in (Neuwirth et al., 2004). From the calculations made, it results a number of 24 event years of which 15 are positive and 9 negative. We have considered event years the ones with a percentage higher than 75% occurrence in the individual series.

The percentages below 75% of the individual series which include the event year have been represented in the graph as grey bars (Figure 3). The positive pointer years are 1984, 1975, 1969, 1956, 1932, 1923, 1911, 1879 and 1884. The negative pointer years are the following: 1994, 1990, 1989, 1981, 1972, 1959, 1958, 1952, 1946, 1925, 1916, 1910, 1904, 1895 and 1881.

The value of 100 % of the negative pointer year 1904 indicates its unanimous presence in all the individual dendrochonological series. We can notice a very high percentage in 1925 when the value reaches the top of 97.22% and in 1958 with the value of 97.30%. Unlike the negative event years, the positive ones do not include occurrence percentage in the individual series exceeding 95%, the highest value being attributed to the year 1956, respectively 91.89%, followed by the one in 1932 (91.66%).

Discussions and Conclusions

This study suggest a high dendrochronological potential for oak (Quercus robur *L.*) which was explored for the first time in this part of Moldavian Plateau. Its growth rings of erlywood and latewood are well-defined there is a clear climatic signal in the growth ring variability. After approximately 100 years the radial growth it drops from an average of 4.26 mm·year^{-1} to 2.98 mm·year^{-1} for the total ring. The latewood has the same decreasing tendency accentuated after 1914 unlike the earlywood which is relatively constant in time.

The correlation between the individual series and the average growth series is very high, which shows a great homogeneity of the trees where samples were taken. The mean sensitivity has a higher value for the latewood compared to the total ring and the earlywood which determines a major reaction of the trees to the actions of climate factors within the vegetation season. The climate influence explained by the first main component is over 50 % for LW too. The statistical parameters calculated for the dendrochronological series of oak in Podu Iloaiei suggests a strong dependency of the radial annual growth rings to the limitative climate factors.

The calculation of the response functions offers credible information for the tree reaction to the action of climate factors cumulated for several years (Lebourgeois et al., 2004). The differentiated analysis of wood on intra-annual growing periods offers responses for the monthly influence of precipitations and temperatures upon the tree radial growth ring formation.

The analysis of the cumulated correlation with response functions allows us to determine the climate factor that decisively influences growth in a certain month and makes the difference between dendrochronological series with different origins (Fritts, 1976). The event years reported to the existing climate data can offer information on the relation between the two characteristics. The combination of statistical calculation procedures mentioned above represents a very strong and trustworthy instrument used for understanding the dendrochronological information (Rozas, 2001).

We have demonstrated in this study that the radial growth rings of oak in the studied area are mainly controlled by the precipitation regime in the year before bioaccumulation and the thermal regime at the beginning of the current vegetation season. The atmospheric humidity deficit determines a decrease of the biomass quantity accumulated due to the increase of temperature and decrease of the precipitation level (Lebourgeois et al., 2004).

The clearly expressed model of influence of the climate conditions in extreme years shows the same dependency of the radial growth to the level of precipitations in spring cumulated to the terminal months of the previous year. The obtained results are also found in the studies made in other parts of Europe (Lebourgeois et al., 2004; Romagnoli & Codipietro, 1996; Čufar et al., 2008), resulting that precipitations of the previous year are very important in forming the earlywood and the ones in May and June exclusively participate to the formation of the latewood.

It should be noticed that certain years for instance 2003, 2000 or 1953 when minimum values of precipitations were recorded respectively 398 mm/year, 388 mm/year and 379 mm/year the results didn't make these years as event years as we expected. By these results, we can say that the type of linear relation discussed above between precipitations and radial growth is not found in the measured data any time. The explanation is that the biomass accumulation depends on a cumulus of environment factors that constantly and cumulatively influence and they don't limit themselves to the climate factors. In order to put into evidence the most important predictions conditioning the wood formation in trees is necessary to study a much larger number of elements.

As well precipitations shows no temporal stability, phenomenon characteristic for all wood species who have as limitative climatic factor precipitation. The explanation comes from the fact that precipitations have regional character, almost local, without any temporal dependence. By contrast temperatures, who decide the length of the vegetation period at upper limit of vegetation, have effect on a large scale and in most cases can be expected.

Few results referring to the event years can be associated to the results obtained in studies in other European areas. Thus the negative year 1989 is found in France (Lebourgeois et al., 2004) or England (Bridge et al., 1996). Unlike England or France, in Romania the years considered very important in the Western Europe are found to be of special importance. Thus, if abroad 1958 is a positive year, in Moldova Plateau it is a negative year found in more than 97% of the individual series, the same thing being valid also for 1946. On the other hand we can mention the year 1975 in Podu Iloaiei is positive while in the Western Europe it is negative.

Consequently the present study has demonstrated the influence of the climate represented by the average temperatures and monthly average precipitations upon the radial growth differentiated on vegetation seasons. By the measurements done we have emphasized the annual variations of early wood (EW), late wood (LW) and total wood (RW) for the oak in Moldova Plateau for a period of 197 years.

Reported to the measurements made we have proved that early wood is approximately constant all along the series unlike the late wood that brings variability to total wood. For each measured series we have proven the dependence to climate, thus showing a negative influence of temperatures in February and a positive influence of precipitation. In case of precipitations we distinguish two sub-periods respectively the one of the previous year represented by the months of October and November and the one of the current year when the excess of atmospheric humidity in June is strongly experienced by trees.

The obtained results confirm the fact that any of all three chronologies can be used for environmental studies. A very important aspect is that the trees radial growth rings include a great amount of information related to the influence of the environment factors that can offer several pertinent responses for the direct relation between the two component elements of ecosystem. The obtained results can be used to understand the future evolutions of these trees under the climate changes conditions.

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