DYNAMICS OF RADIAL INCREMENTS OF OAK DUE TO CLIMATIC FACTORS EFFECT

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Abstract

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Dynamics of radial increments in the growth process of sessile oak trees in dependence on climatic factors was studied in the work. There was selected oak stand, in Central Slovakia, about 5 km to the south-west from climatic station Sliač, where increments probes were taken from 25 trees. All orders of annual rings were synchronized and dated. From absolute increments there were calculated increment indexes as their proportions to equalled age increment trend. This trend was derived by two ways – regression equalling according to fluent mathematical function and as moving averages. Correlation analysis was used for detailed examination of the effect of average monthly temperatures and monthly precipitation totals on increment indexes of trees. The results show that increment indexes calculated from moving averages are more suitable for studying the effect of climatic factors in increments. For 60% of studied trees statistical test confirmed significant positive linear dependence of increment indexes on monthly precipitation totals in vegetation months May until July. Significant positive correlation dependence on spring and late summer monthly temperatures is only for 4–8% of trees. At the same time this dependence is negative for about the same number of trees.

Key words: oak, radial increment, dendro-ecology

Introduction

Seasonal deposition of radial increment of wood on the whole surface of wood mantle of trees is generally known for the growth process of forest tree species in moderate climatic zone. In last years the research of this process has been very intensive. It is aimed at clarifying elementary regularities of its formation and dynamics. In connection with climatic changes also the dynamics of radial increments in dependence on climatic factors has been studied intensively. After publishing the encyclopaedia on dendrochronology by Fritts (1976) and Schweingruber (1983) several authors started to deal with this issue. Recently the research has been aimed mostly at coniferous tree species. Ots, Rauk (1999) as well as Vita, Bitvinskas (1998) studied pine and spruce in Lithuania. Mäkinen (1998) studied pine in Finland. Feliksik, Wilczyński (1999a, b, 2004) studied Austrian black pine and eastern white pine in Poland. Rolland et al. (1998) carried out a long-term dendrochronologic research of spruce, larch and Swiss stone pines in French Alps, Anfodillo et al. (1998) in Italian Alps, while Oberhuber, Kofler (2000) conducted research with the same tree species in Austrian Alps. In Germany Knott (2004) studied seasonal dynamics of radial increment of fir and beech, and Gruber (2001) only of beech. Vejpustková et al. (2004) studied in detail the effect of climatic factors on radial increment of spruce in the Czech Republic. Ďurský, Pavlíčková (1998) dealt with the issue of climate and pine increment, and Šmelko, Miková (1999) with spruce and Turkey oak increment in floodplain forest in Slovakia. All authors studied in detail mainly the effect of monthly temperatures and precipitation on radial increments of trees. They stated that their importance depends on concrete growth conditions of the studied tree species. The monthly temperatures are more remarkable in cold regions and on the contrary precipitation in warmer ones. Correlation dependence of radial increments on studied climatic factors is very different. Mazepa (2000) and Esper et al. (2004) dealt in Switzerland with the use of dendrochronology for retrospective determination of the climate in Siberia.

The aim of our research was to collect empirical material and on the basis of this material to study interrelations of the dynamics of climatic changes and increment changes in the growth process sessile oak as well as to derive models of the effect of climatic factors on their increment.

Materials and methods

Empirical material was collected in sessile oak stand situated near Zvolen and climatic station Sliač. Trees for increment sampling were chosen in the vicinity of permanent research plot that is located in this stand. It was established for the research of forests production and construction of national yield tables in 1969. The altitude of the stand is 400 m and its site can be classified into the group of forest types *Fageto-Quercetum*. There were taken 25 probes from 25 co-dominant and dominant trees with diameters 28–36 cm, heights 27–32 m and age 91–104 years. Increment probes were taken by Pressler's gauge, 1 probe per tree at the height 1.3 m above the ground with direction to the core of stem to cover as most annual rings as possible. We measured the width of annual rings by digital position meter with the accuracy ± 0.01 mm. On the basis of the data we constructed annual rings curves, which we synchronized and dated. We used simple method of graphical comparison of significant points as the highest increments minimums and maximums but mostly the method of parallel increments trends as given by Schweingruber (1983). Jačka (1989) as well as Petráš et al. (1993, 2000) completed these methods and used for the comparison of annual increment trends of increment curves of individual trees with standard curve of the studied stand. Standard increment curves were constructed as mean ones based on the choice of increment curves of trees that had the highest percent of parallelism. Regarding the fact in boring annual ring probes it was difficult to observe their accurate direction towards the core of stem, only last 50 years were used for synchronization. Five curves were selected for standard annual ring curve, which had the highest parallelism of 82–90%. Based on them there was constructed average, it means standard curve and it was used for comparing with all 25 curves. Their parallelism with standard curve was within the range 66–90%, on the average 78.2%. We can state with regard to a high percent of parallelism that all increment curves are very similar to standard curve. In addition to, that trees in concrete stand respond by their increment trend to growth factors very similarly, they reach in most of cases also the highest minimums in the same calendar years, as for example, are precipitation minimums. In Fig. 1 standard annual ring curve demonstrates that it was in the years 1923, 1947, 1962, 1974, 1993 and 2000. At the same time also increment minimums in pine stands were recorded in Slovakia according to Petráš et al. (2000).

Following synchronization annual ring increment orders were standardized into increment indexes. We proceeded in a way that absolute increment orders were equalled by regression functions in dependence on the age of tree as age increment trends and based on them there were calculated increment indexes I_i as the proportions of the value of actual i_a and equalled increments i_e at particular age according to the formula:

$$I_i = \frac{i_a}{i_e} \tag{1}$$

Besides regression functions there were calculated for annual rings orders also their moving averages from four values following each other and based on them also increment indexes according to the formula 1. Increment indexes derived by both methods were analysed in detail and studied by means of correlation dependence on basic climatic factors. They were namely monthly precipitation totals for the years 1901–2003 and average monthly temperatures for the years 1931–2003. These data were taken from climatic station Sliač being distant only 5 km to northwest from the examined stand. Fig. 2 illustrates the development of these data. Namely they are precipitation totals for the whole calendar year and for the month May until August, as well as average annual temperatures and average temperatures for the month May until August.

Results and discussion

Increment trends and indexes

The increment of each tree is being influenced, besides studied climatic factors, also by many other factors. These effects reflect in increments, in form of certain increment trends, in shorter or longer time intervals. Life trend is the basic one that after quick culminating of increment already at young age drops slightly. As it is illustrated in Fig. 1 it is possible to

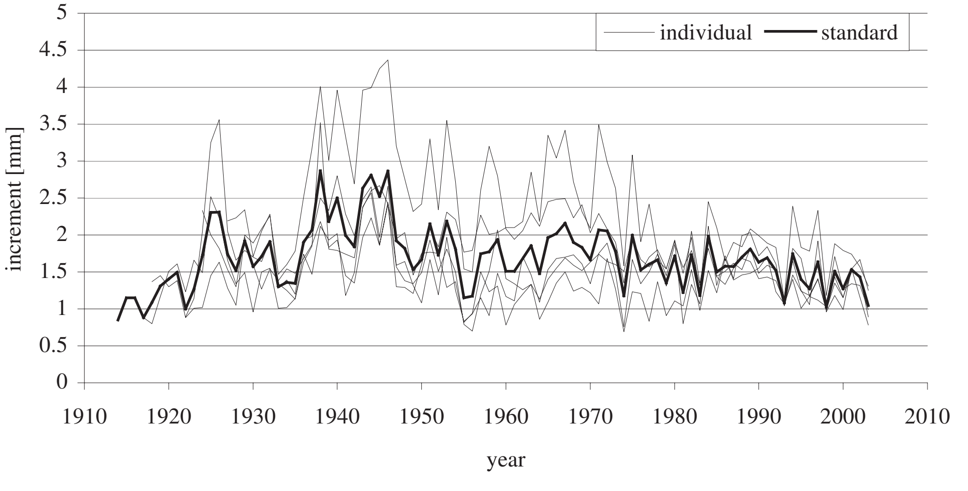

Fig. 1. Individual curves and standard (average) curve of radial increments.

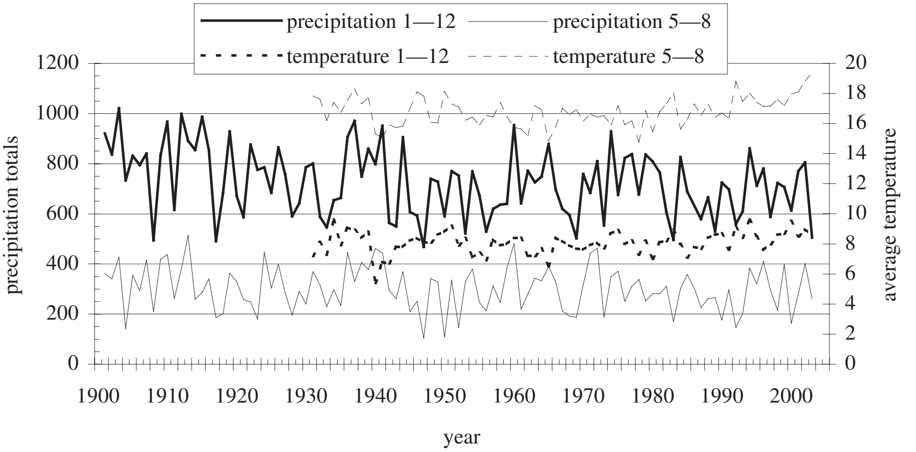

Fig. 2. Precipitation totals and average temperatures at meteorological station Sliač for the years 1901–2003.

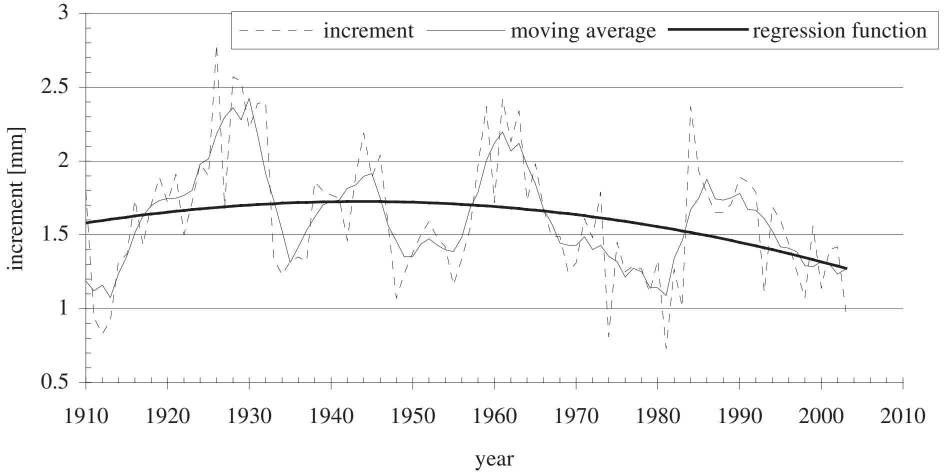

Fig. 3. Adjustment radial increments of the tree No. 19 by means of moving averages and regression function.

identify on increment curves also the trends in shorter intervals, which can be a response of trees on the changes in its closest growth space. Not only climatic changes may be the reason. To confirm our assumption we equalled the curves of radial increments of individual trees by two methods, namely by mathematical function and moving averages. Fig. 3 illustrates such an equalling for the tree No. 19. Radial increments have very high variability, within

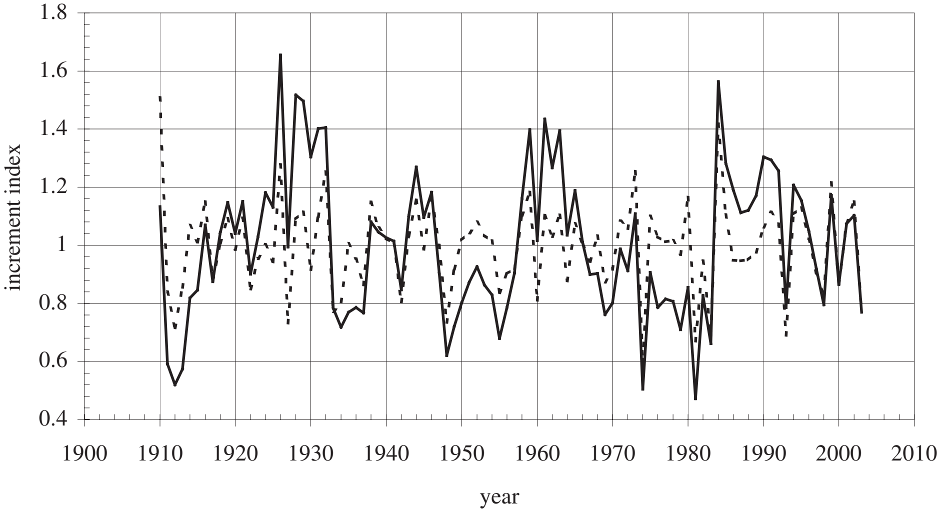

Fig. 4. Development of increment indexes calculated according to equalled regression function (solid line) and moving averages (dash line).

the range 0.5–2.8 mm. Though life trend is relatively balanced, increments oscillate in cycles around this trend in the intervals 10–15 years.

Fig. 2 illustrates the development of precipitation totals and average monthly temperatures at meteorological station Sliač for the whole year and for vegetation months May–August. Precipitation totals for vegetation months ranged from 100 mm to 500 mm in lower parts. According to these values as well as other data it is obvious that climatic characteristics have not such marked cyclic fluctuations as tree increments in Fig. 1 and Fig. 3. Fig. 3 shows that climatic factors cannot cause marked cyclic changes of tree increments but there are also other effects. This finding encouraged us to calculate increment indexes according to the formula (1) as the proportion of actual and equalled increments using both methods. In one case increment trends were equalled by continuous mathematical function and in the second one by moving averages, which reflect their cyclic changes very well. They are illustrated in Fig. 4 and we can state from their comparison that indexes calculated from regression function still oscillate cyclically around the value 1.0 and they have greater range of values than the indexes calculated from moving averages.

Similarly, there were calculated also precipitation indexes from precipitation total for the months from May until August and they are given altogether with increment indexes calculated from moving averages of the tree no. 19 in Fig. 5. When we compare them it is obvious that precipitation indexes have greater dispersion around mean value 1.0 than increment indexes. At the same time they have, similarly to increment indexes, very low rate of cycles, reaching the average value of about 1.0. It only confirms that our procedure in the calculation of increment indexes by means of moving averages was correct.

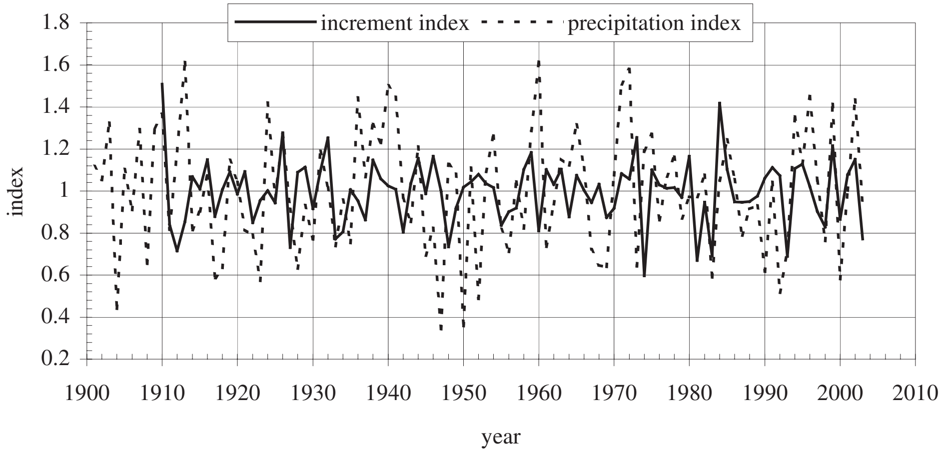

Fig. 5. Development of increment and precipitation index.

Effect of climatic factors on radial increments

This effect was studied in detail on increment bores of all 25 trees by means of correlation analysis, namely by means of pair correlation coefficients that measure linear dependence only for pair of variables. In our case they express the intensity of the dependence of annual increment indexes on monthly precipitation total and average monthly temperatures according to all 12 months of actual year, it means the year when the studied increment was formed but also for last 8 months of previous year. The significance of the difference of correlation coefficient from zero was evaluated by statistical test at the level of significance – = 0.05. For studied trees n equalled 62–94 increment indexes. Then the number of the degrees of freedom is n–2.

Figs 6–9 illustrate percentage proportion of the number of trees for which the effect of studied climatic factor was statistically significant. Fig. 6 documents the effect of monthly precipitation totals on increment indexes of trees derived by the proportion of actual increments to age increment trend according to regression function. Almost 30–50% of trees influence positively and significantly precipitation totals in May and June of current year. Their correlation coefficients range from 0.21 to 0.51. The effect of precipitation in other months, including the months of last year, is insignificant according to correlation coefficients or significant only with a small number of trees. Fig. 7 presents the proportion of trees, whose increments significantly influence average monthly air temperatures. Positive effect of higher temperature appears only with 4–8% of trees, especially in spring and late summer months of current year. It is negative with 4–12% of trees, mainly in spring and summer months of current year and in summer and late summer months of previous year. Based on the value of correlation coefficients that range from –0.24 to –0.35 and 0.24 to

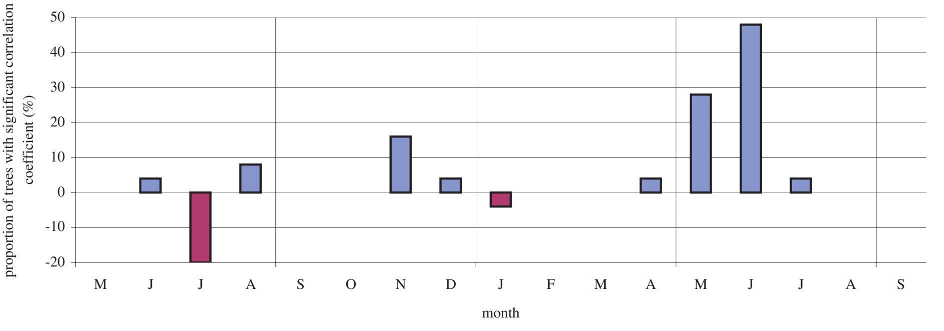

Fig. 6. Proportion of trees with significant effect of precipitation on increment index according to regression function from May of previous year until September of current year.

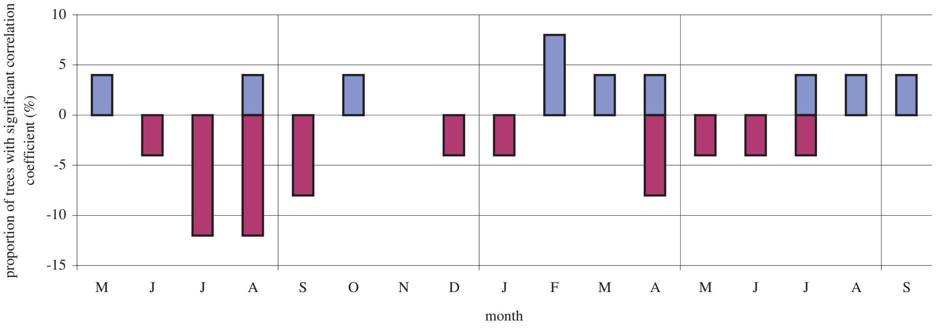

Fig. 7. Proportion of trees with significant effect of temperature on increment index according to regression function from May of previous year until September of current year.

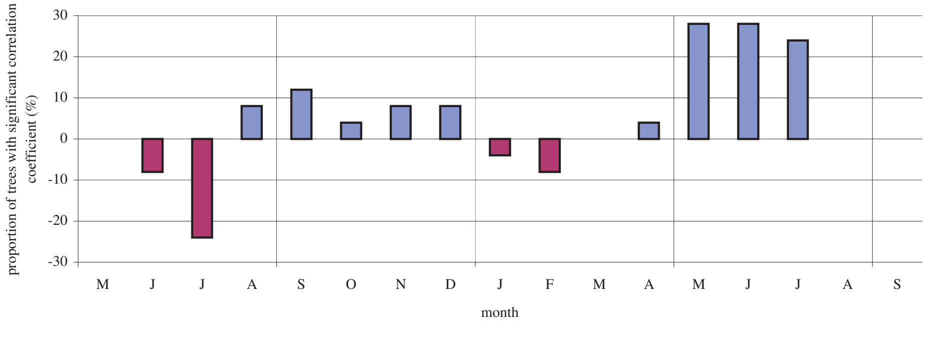

Fig. 8. Proportion of trees with significant effect of precipitation on increment index according to moving averages from May of previous year until September of current year.

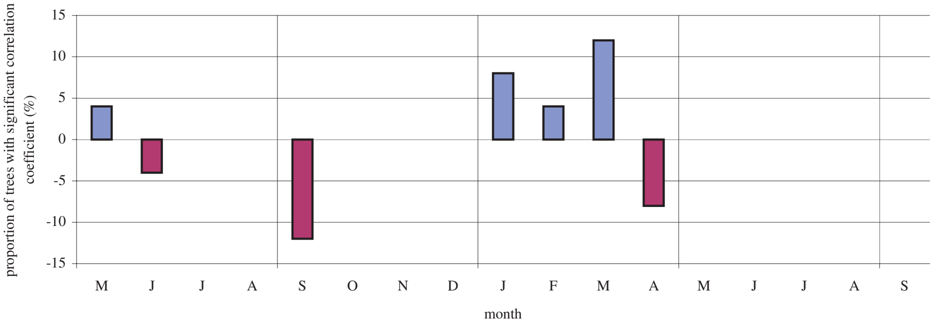

Fig. 9. Proportion of trees with significant effect of temperature on increment index according to moving averages from May of previous year until September of current year.

0.35 we can state that also the intensity of dependence on monthly temperature is lower than with precipitation.

Figs 8–9 present the same information as Figs 6–7 but for increment indexes derived by the proportion of actual increments to equalled ones according to moving averages. We can see in fig. 8 that about 25–30% of trees are influenced positively by precipitation totals in May until July of current year with correlation coefficients 0.23–0.48. Precipitation totals in August until December of previous year are significant only for about 5–10% of trees with correlation coefficients 0.22–0.28. There are only few cases with statistically significant negative effect of precipitation. We can see in Fig. 9 that statistically more significant correlation coefficients of the effect of monthly temperatures on increments are in January until March of current year. We are unable to explain logically this effect. Negative effect of higher temperatures on trees increments was confirmed only in April of current year and in September of previous year.

After detailed analysis of all pair linear correlations we can state, what concerns climatic factors, that precipitation totals in summer months from May until July of the current year influence the most radial increment indexes of trees. Due to this reason we summed up their monthly totals into one total for three months and calculated its pair correlation to increment indexes. For increment indexes calculated on the basis of regression function 48% of trees have statistically significant correlation with the values of correlation coefficients in the range 0.23–0.40. For increment indexes calculated on the basis of moving averages almost 60% of trees have significant correlation with correlation coefficients within the range 0.23–0.54. Following this comparison we can state that increment indexes of trees derived by the proportion of actual increments to age increment trend according to moving averages have more significant and closer correlations than the indexes of trees derived by the proportion of actual increments to age increment trend according to regression function.

According to gained results we can state, that similarly to many others, we also confirmed the existence of statistically significant correlation dependencies between annual radial increments of trees and basic climatic characteristics as average monthly temperatures and precipitation totals. We must note that also with statistically the most significant and strongest dependencies, when correlation coefficients reach the values 0.23–0.54, it is not necessary to make them absolute. After their calculation to the coefficients of determination we can conclude that studied climatic factors explain only about 5–30% of total annual variability of radial increments. Remaining 70–95% of variability must be explained by other reasons. According to on our knowledge it is impossible with correlation dependencies to deal with them in statistical details as well as to include into total correlation model all factors, only statistically significant ones, and of them only those, we are able to justify their significance logically.

Many authors listed in references put greater significance to precipitation in Slovakia's climatic conditions only in lower and middle locations, where, in general, consumption of soil moisture for evapotranspiration is high during vegetation period. Any high supplies of winter or spring moisture are insufficient to cover high consumption in summer months. It is natural that also concrete site conditions, particularly soil conditions including concrete forest stand, can modify this balance more significantly. More significant effect of monthly temperatures on radial increments was confirmed in our research only occasionally and disputably. Some authors emphasize their greater significance only in cold climatic regions or in high mountainous areas, where there is a permanent excess of precipitation and soil moisture also in vegetation period. Though the results of the research in oak stands are not so frequent, our knowledge are approximately the same as the results for other tree species.

Conclusion

We studied dynamics of radial increments in the growth process of sessile oak trees in dependence on climatic factors. In the region of C Slovakia, about 5 km to southwest from climatic station Sliač, we have chosen oak stand and took increment bores from 25 trees. All annual rings orders were synchronized and dated. From absolute increments we calculated increment indexes as their proportions to equalled age increment trends. This trend was derived by two methods, regression equalling according to continuous mathematical function and as moving averages. Correlation analysis was used for detailed analysis of the effect of average monthly temperatures and monthly precipitation totals on increment indexes of trees. Obtained results show that increment indexes calculated from moving averages are more suitable for studying the effect of climatic factors on increments. For 60% of the studied trees significant positive linear dependence of increment indexes on monthly precipitation totals was confirmed by means of statistical test in vegetation months May–July. Significant positive correlation dependence on spring and late summer monthly temperatures is only for 4–8% of trees but at the same time this dependence is also negative for about the same number of trees.

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