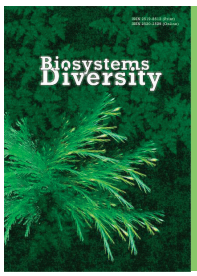

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Climatogenic reaction of *Robinia pseudoacacia* and *Pinus sylvestris* within Northern Steppe of Ukraine

Y. I. Gritsan, S. A. Sytnyk, V. M. Lovynska, I. I. Tkalich

Dnipro State Agrarian and Economic University, Dnipro, Ukraine

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Dnipro State Agrarian and Economic University, S. Yefremov st., 25, Dnipro, 49060, Ukraine. Tel.: +38-067-769-63-29. E-mail: glub@ukr.net

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Climatic changes in the environment are becoming more noticeable each year. Nonetheless, trends in the reaction of radial growth of forest trees to climate change should be studied in different climatic regions due to significant local variability in climatic conditions which are specific for any particular area. We conducted a correlation analysis of the relationship between the parameters of radial increment of black locust (*Robinia pseudoacacia* L.) and Scots pine (*Pinus sylvestris* L.) and meteorological factors of the environment in forest areas located in the northern steppe zone of Ukraine. We performed surveys in plantations of black locust, growing in hill slope and interfluve areas and also in sandy terrace plots of Scots pine. Over the period of intense vegetatative growth, black locust requires moisture 50% higher than the norm, and Scots pine 43% higher than the norm. It was determined that maximum increment for the studied plants occurred under the influence of a combination of factors involving reduction of the air temperature by 2.6–2.7 °C below the norm for black locust and by 2.3–2.5 °C for Scots pine. During the period of lower vegetative activity, Scots pine demonstrated lower sensitivity compared to black locust. This paper provides a statistical characteristic of the radial increment of trees in the conditions of changes in meteorological factors which limit their growth. The article provides data on multiple correlation of radial increment of the tree stands in relation to growth locations; demonstrates correlation dependency of radial increment of the studied trees on the precipitation and mean monthly temperatures over different time periods and during particular months. Radial increment of Scots pine exhibited most positive correlation with the total of precipitations throughout the period. For the stands of black locust, correlation coefficients were higher and distinguished by both positive and negative values. In the current increment of this species, a negative correlation relation was observed with the total precipitation in July, August and September, and positive correlation with the remaining months of the year. By contrast, radial increment of black locust and Scots pine positively correlated with air temperature during all time periods and particular months.

Keywords: correlation analysis; radial increment; black locust, Scots pine, steppe zone.

Introduction

Climatic factors of the environment are determinants of the growth of trees (Franke et al., 2017). One or another growth period is characterized by particular environmental conditions influencing the final sizes of mechanical and assimilating organs of woody plants (Kukhta, 2003; Panthi et al., 2018). There is a general pattern of duration and energy of growth of trees in relation to annual weather conditions (Smiljanić & Wilmking, 2018). Over the first half of the vegetative growth period, when the soil contains sufficient reserves of moisture, the increment depends on the total of positive temperatures, and over the second half of the vegetation period, when water content in the soil is low, it depends on the precipitations (Antonova et al., 1999). According to Holdridge (1967), temperature and atmospheric precipitations are essential for functioning of vegetation, though within each climatic zone, plants can be affected by other environmental factors, such as type of soil, exposition (Gustafson et al., 2017). The borders between the zones of moisture are determined by critical relationships between the amount of precipitations and potential evapotranspiration, and the latter depends on the temperature (Tie et al., 2018).

The interaction of the main elements of the productive process – photosynthesis, respiration and growth – throughout the vegetative period leads to the formation of the value of total and practical productivity, and therefore increment, the highest possible values of which are definitely a subject of interest (Laroque & Smith, 2005; Castagneri et al., 2014; Teets et al., 2018). Researchers use various criteria for determining the beginning and the end of the radial growth of tree plants (Vaganov & Shashkin, 2000; Yeh et al., 2000). In general, the beginning of radial growth is associated with increase in size of cambial cells and appearance of first mitoses in the cambial zone; division of cells to form phloem and appearance of first tracheids in the cambial zone (Antonova, 1983; Tonn & Greb, 2017). The end of the radial growth is usually associated with the end of mitotic activity and increase in the number of cells, end of formation of the cellular wall (Antonova, 1983, 1999).

The territory of northern steppe of Ukraine is characterized by environmental factors which limit the growth of tree species (Faly & Brygadyrenko, 2014, 2018). As is well known, the further one moves south, the more the conditions of humidity are the external limiting factor for distribution of forest ecosystems as one approaches closer to the steppe biome (Brygadyrenko, 2014; Jankowski et al., 2014). Steppe is a habitat with insufficient amount of air humidity, and therefore soil humidity, which leads to inhibition of growth processes, and also of geographic distribution of ecological ranges of tree species. Forests in this geographic zone are mostly plantations created using forest species. The exceptions are places with heightened moisture – sandy terraces, interfluves, bairaks (hillside forests in the steppe zone), where tree species can renew in a vegetative way or through self-seeding.

Woodlands in the steppe zone are places of active economic activity of humans, and experience different types of anthropogenic impacts, including uncontrolled felling. The places where the

felling is performed most often lack the environmental conditions needed for the growth of plants, which leads to decrease in their productivity. All this requires organizing a system of restoration of these forests, which should take into consideration the ecological patterns of formation of the wood. Such knowledge would allow one to predict the productivity of tree plants, which could be assessed by the increment in the radius (radial increment) in the trunk at 1.3 m height.

The impact of environmental factors on the radial increment can be assessed using the coefficients of correlation, at the same time using monthly mean values and totals of the factors over a month (Feliksik & Wilczynski, 2000; Oberhuber & Kofler, 2000).

For creating forest plantations tolerant to the environmental factors in the conditions of northern steppe zone of Ukraine, as the main forest-forming coniferous species, a native species is used – Scots pine, while the main broadleaved species is the black locust, a species introduced from North America.

Scots pine (*Pinus sylvestris* L.) and black locust are the most important species in Europe and within Ukraine. Together with other species, they dominate the forest landscape from Northern and Eastern Europe to the Mediterranean mountains in Southern Europe (Stanners & Bourdeau, 1995). These species are not capricious in terms of the conditions of humidity, richness of nutrients in the soil, and thermoresistant plants.

The objective of this study was correlation analysis of the impact of climatogenic factors of the environment – air temperature and precipitations – on the formation of the radial increment of Scots pine and black locust trees, growing in the conditions of the north steppe zone of Ukraine.

Materials and methods

The experimental material was obtained on experimental plots located in Dnipro region. All the experimental plots in physical-geographic aspect are the part of the northern steppe zone of Ukraine. The oblast territory has a low extent of afforestation (3.8%) and is characterized by insufficient humidity. The climate of the studied region is distinguished by insignificant amount of precipitations (average annual amount – 480 mm). The average annual temperature in the region equals 9.0 °C. Relative air humidity on average over the year is 74%, being lowest in August (61%), and highest in December (89%). The coefficient of moisture (relation of precipitations to evaporation), calculated using the formula of I. E. Buchinsky (Hensiruk, 2002) applied for Dnipro region, equals 0.50–0.75, which indicates insufficient humidity of the region of the observations. In general, the climate in the region is moderate, with mild winters and warm (sometimes hot) summers and is characterized by large daily and seasonal fluctuations of meteorological parameters. Over the last 100–120 years, the air temperature in the region of the studies, as well as on the Earth on the whole, has tended to increase. During this process, the annual mean air temperature has increased at least by 1.0 °C.

Analysis of meteorological conditions in the region of studies was conducted using the material of tables from the archive of the Ukrainian Regional Center of Hydrometeorology and Monitoring of the Environment, and also the Archive of the Prysamarsky International Biosphere Station of Dnipro State University. In the study, we used data of hydrometeorological stations of Ukraine by maximum series of observations in the interval of 60 to 150 years under different variants of averaging the data (month, seasonal, annual). The materials were analyzed according to average monthly temperatures of air, air humidity, and total of precipitations.

The studies were performed for the black locust which grows in slope and interfluve habitats, and also for the Scots pine, the growth location of which is limited to sandy terrace areas. The density of the crowns in plantations of black locust, where the model trees for further research were selected, equaled 0.6–0.7 (for the slopes), 0.5–0.6 (for the interfluve). The density of the crowns of Scots pine in the sandy terrace areas was 0.2–0.4. We collected samples of cores and cross sections of 40 black locust and 50 Scots pine trees.

The collecting of samples in the woodlands was carried out by obtaining cross sections of trees, performed at 1.3 m height. The samples of wood from the trunk were cut out off its peripheral part on the south side. In the regions with limited forest resources and in the places with nature protection regime, we performed extraction of cores from the area of root collar using a bore, diameter of which equaled 4 mm. After selecting model trees, we set the places for boring on the trunk, and the number of cores from one tree was determined after extraction of the first core. The bore was set and perpendicularly introduced into the trunk as near to the root collar as possible, so the loss of annual layers was minimal, and the obtained series of measurements maximally approximated to the true age of the model trees. After the introduction of the bore into the tree trunk to the needed depth, a receiver (spoon), which divided the core at the cutting edge, was put in. The reverse movement of the collar, the core was separated and extracted to the outside. Into the hole, a solid cap of wood of the needed diameter was hammered at the level with the trunk for reducing the seepage of resin of Scots pine and secretion of sap from the hole. Cores (2–3) of each model tree were tied using thread. The tied cores were put into a solid container for further transport. The cross sections were wrapped into thick paper for slow and uniform drying and prevention of ruptures.

For measuring, the cross sections were treated with a sharp knife along the directions where the measurement lines were to be, prior to which the layers were divided according to decades (for the control). The measuring of width of annual rings was made under the MBS-1 and MBS-9 microscopes in the units of scale of ocular-monometer with 0.01 mm accuracy. Measuring was conducted on the samples of the cross sections, samples and cores from the periphery to the center of the trunk along the line of the highest increment. The cores extracted using the bore were measured in such a way that the line of the measurement would be perpendicular to the border of the annual layer.

The obtained dates were statistically verified using Statistica 10 program (StatSoft Inc., 2011). Correlation coefficient, relative standard deviation and standard error were calculated. Significance of difference between average values in increment in the studied species was established using one-way analysis of variance and F-test for 95% confidence level.

Results

Plants in the northern steppe zone suffer significant deficiency of moisture and warmth, and the areas of opposite anomalous processes of dendrological climatograms of the species in this zone have great differences (Gritzan et al., 2018). Maximum increment, both for coniferous and broadleaved plants, is associated with increase in precipitations. Plants are especially demanding in terms of increase in precipitations over the summer months, for during the period of intense vegetation, black locust needs humidity 50% above the norm, and Scots pine – by 43%, and their maximum increment was observed in combination with reduction of air temperature by 2.6–2.7 °C below the norm for black locust, and by 2.3–2.5 °C for Scots pine.

In relation to winter humidity, Scots pine demonstrated lower sensitivity compared to black locust, which for realization of maximum increment in the following season requires increase in the amount of moisture by 45% above the norm (Lovelius & Gritzan, 1998). It should be noted that black locust had higher reaction to moisture.

The statistical characteristic of the increment demonstrates that the analyzed species of trees react similarly to the change in factors which limit their increment (Table 1). In turn, the variability of the values of increment of black locust is characterized by larger amplitude of fluctuations, compared to Scots pine. Growth of tree stands correlates with the amount of precipitations over the vegetative period. Increment in tree species is usually determined by precipitations of the current season of the vegetative period. However, the second half of the vegetative period is often essential for the formation of the increment in the following year. Due to this fact, distinguishing long time periods for assessment of external impact within a calendar year is not practical. Formation of vegetative organs and their initiation takes place over the vegetative season, but these are different temporal processes.

The correlation relationship between the increment and the mentioned meteorological elements over particular periods was observed to be significant and in general quite significant for the analyzed species.

Discussion

The data provided in this article demonstrate that the relationship between the annual increments and precipitations was the closest at the following consequent record: July-September of the previous vegetative season; October – December, February of the first half of a current hydrological year and May – June of current vegetative season of the second half of the hydrological year. Such temporal period, which we call a dendrological year, most effectively reveals the complex pattern of impact of environmental factors on the studied species and does not contradict the biological essence of the processes. Determining the meteorological conditions of which part of the year have the greatest effect on the increment of the tree stand was the object of these studies. Using the correlation analysis, we demonstrated the dependency of the radial increment on precipitations and mean temperatures over different time periods and over particular months (Fig 1, 2).

Table 1
Characteristic of increment of analyzed sample trees

Growth location	x ± SE*	Fluctuations of increment, mm	RSD, %
Robinia pseudoacacia L.			
Slope	3.671 ± 0.289	1.590–6.431	37.3
Interfluve	3.990 ± 0.365	1.592–7.271	37.4
Pinus sylvestris L.			
Sandy terrace	2.554 ± 0.099	1.901- 3.198	27.2

Note: * x ± SE – mean value of the studied parameter ± standard error, RSD – relative standard deviation; n = 40 for black locust, n = 50 for Scots pine.

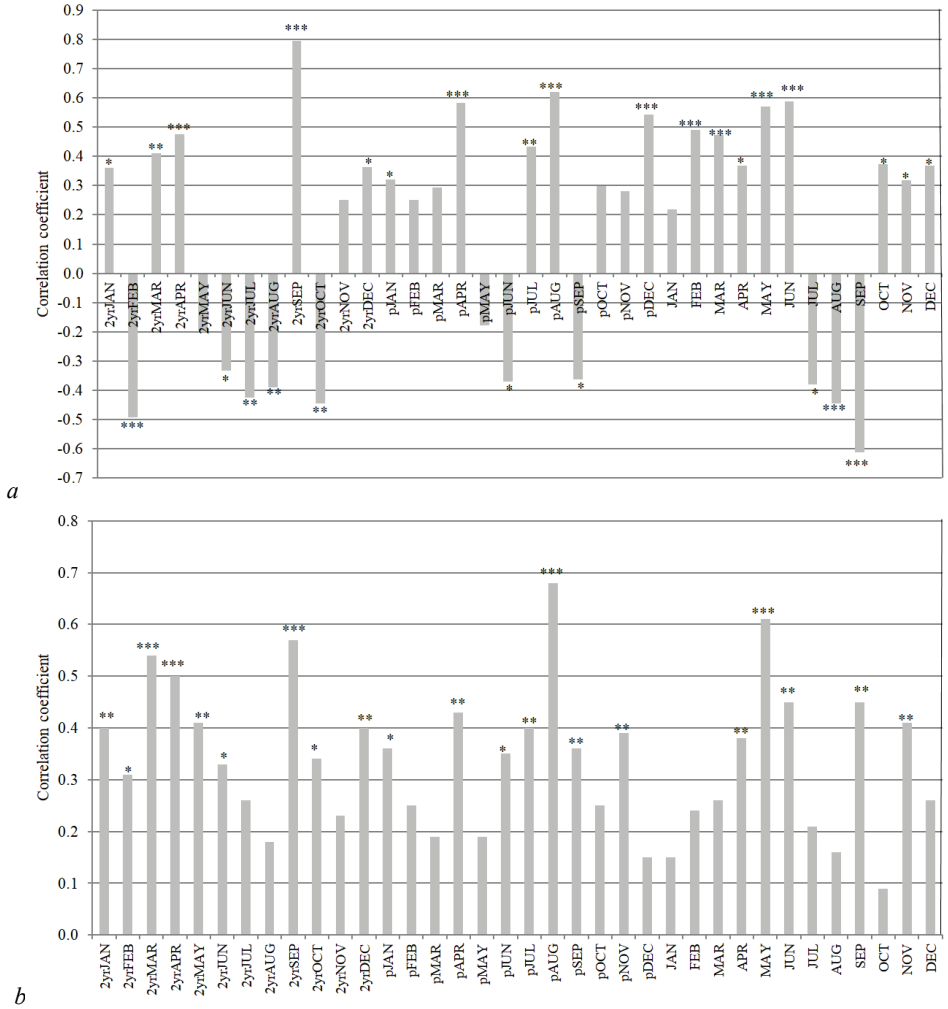

Fig. 1. Correlation coefficients between monthly total precipitation and radial increment for black locust (*a*) and Scots pine (*b*) from previous two years (January (2yrJAN), previous January (pJAN) to current December (DEC) for the investigated period): n = 40 for black locust, n =50 for Scots pine; * – P < 0.05, ** – P < 0.01, *** – P < 0.001

The coefficient of correlation between the total of the precipitations during the three mentioned periods and annual increment of both black locust and Scots pine proves a highly significant positive relationship (Fig. 1). Integral consideration of the temperature factor in such temporal range is not practical, which is proved by the low correlation relationship of both species due to different course of temperatures over the year (Fig. 2).

Realization of maximum increment of trees requires optimum meteorological conditions in each of three distinguished periods, and not in some particular period. Such attempt of generalizing data allows better demonstration of the significance and the role of meteorological elements in the following periods: reproductive development (process of development of specialized organs); cumulative conditions (summing up the effect of environmental factors for realizing increment); assimilative development (process of formation of assimilative apparatus and annual ring) of tree stands. Over the assimilative period, at maximum increment of the annual ring, the optimum value of the air temperature was on average 17.0 ºC. For the reproductive period, the temperature of 18.9 ºC was more favourable on average. Over the years of maximum increment of the annual ring, the humidity was 1.4–1.5 times higher than over the years with minimum increment. Thus, mean optimum amount of precipitations for the generative period equals 138.3 mm, 168.5 for cumulative and 131.1 mm for assimilative (Lovelius & Gritsan, 1998). Taking into account the well manifested reaction of tree stands to May precipitations, we provide their mean efficient value –

71.4 mm. Distinguishing the meteorological parameters which affect the growth of plants and which cause their manifested rhythms, we should note that the precipitations perform the role of indicatory factor for the studied territory, only the optimum proportion of warmth and moisture determines better conditions for growth of plants (Messaoud & Chen, 2011). At sufficient moisture, lack and excess of warmth cause not insignificant disorders in the mechanism of plants' growth, which corresponds to the postulates proposed by Shelford (Lindner, 2010).

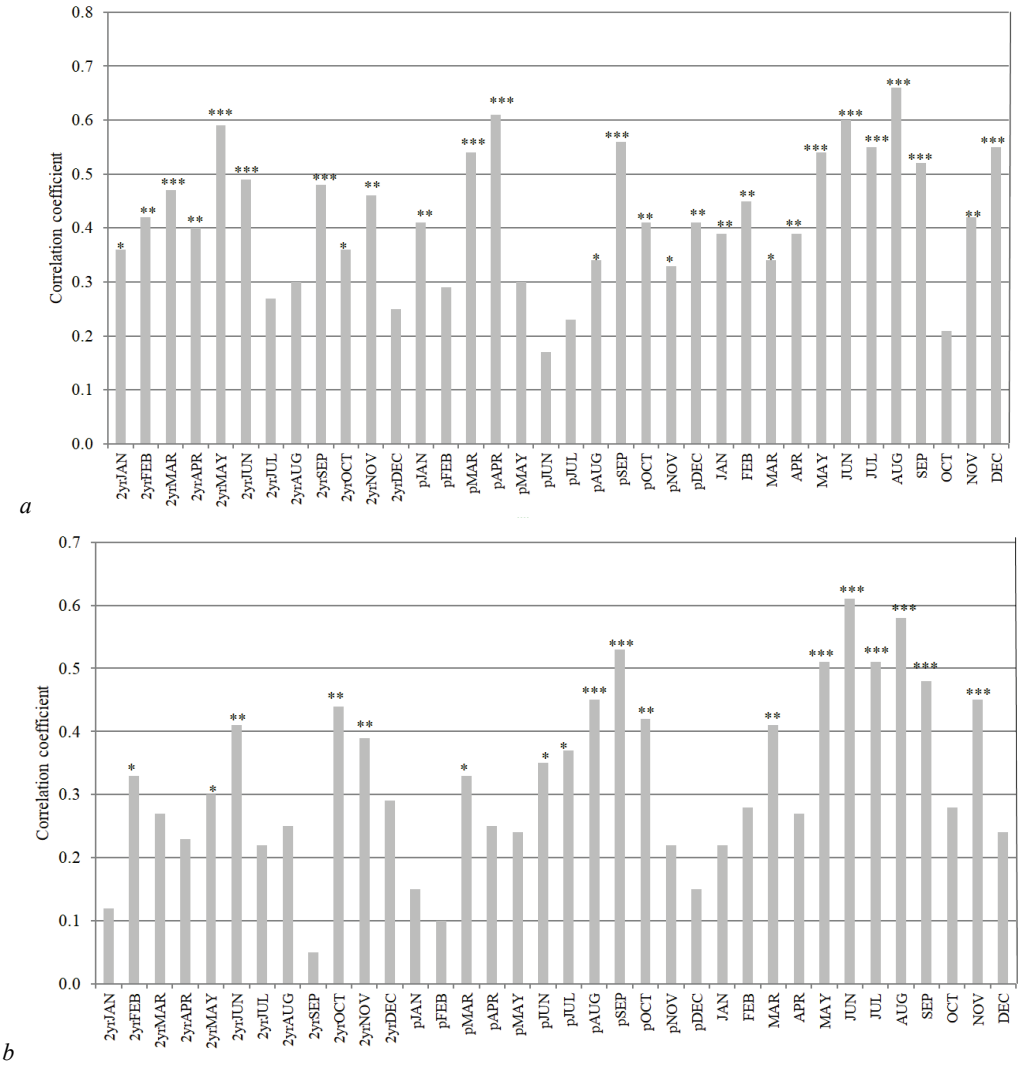

Fig. 2. Correlation coefficients between monthly mean temperature and radial increment for black locust (*a*) and Scots pine (*b*) from previous two years (January (2yrJAN), previous January (pJAN)) to current December (DEC) for the investigated period): n = 40 for black locust, n = 50 for Scots pine; * – P < 0.05, ** – P < 0.01, *** – P < 0.001

For the two species we studied, the dendrological year, regardless of the growing locations of the plants, lasted from August of the previous year to July of the current vegetative season. Precipitations over the cold part of the year were observed to be quite effective for timely prediction of increment. For the spring-summer period, the improvement of increment was related to precipitations in May and June. Meteorological conditions of July – September determine the increment of the following vegetative season. According to Williams (1938), in temporal development, all life conditions of plants are absolutely equally valuable. This is completely applicable to the determined periods. Accordingly, one cannot state that the maximum effect of increment could be obtained only at normative manifestation of a complex of meteorological factors in some of them. Therefore, only a combination of favourable climatic conditions in each phenological phase of growth and development of plants condition the highest increment in the annual ring (Campoe et al., 2016; Carlón-Allende et al., 2018).

Organogenesis, development and growth are the processes which take place in accordance with the genetic programs and are modified under the impact of the environment (Foster & Brooks, 2001; Chen et al., 2010). Interaction of internal and external factors leads to division of the life cycle of plants into phases of development. For example, taking conditions of the hydrological year as the basis of influence on the vital activity of plants, one can distinguish the following periods: the first in October – March and the second in April – September. The importance of the second period is uncertain for current growth of trees. Within the second period, it is practical to distinguish an interval from May to June, which plays a significant part in the formation of current growth. The interval from July to September influences the growth of the following season, which occurs due to the initiation of the reproductive organs. The significance of morphometric peculiarities of the buds for growth and development of plants in the following vegetative season is indicated by Rusalenko (1986), who demonstrated the dependence of the length of the shoot on the length of the buds. It can be presumed that the main cause of such relation is explained by better development of the assimilating apparatus which provides higher biological productivity under favourable climatic conditions.

Conclusions

The obtained results demonstrate the unity of the reaction of growth processes of coniferous and broadleaved plants to global changes in the factors of terrestrial and cosmic origin. In most cases for both species, air temperature of the studied region over the winter months signifi-

cantly affected the variability of growth. Using correlation analysis, we determined that the most significant relationship is that between radial increment and moisture. At the same time, the precipitations of the winter period are predictive for the increment of black locust, and precipitations in the autumn season – for Scots pine. Such an approach to understanding the processes of growth and development of trees is an important condition for organizing correct and effective care for forest species in the conditions of Ukraine's steppe zone.

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