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THE EFFECT OF AIR TEMPERATURE, PRECIPITATION AND HUMIDITY ON RING WIDTHS IN THE BLACK LOCUST (*ROBINIA PSEUDOACACIA* L.) GROWING IN URBAN CONDITIONS

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ABSTRACT

This study characterizes the basic biometric traits of the black locust growing in urban conditions of the city of Wrocław (south-western Poland) and sets out the relationship between annual tree ring widths and air temperature, air humidity and precipitation. Materials consisted of 54 wooden discs taken from felled straight-trunked trees at four sampling sites at a height of 1.3 m from the ground in the area of a defunct garden established at the turn of the 20th century. Meteorological indicators were calculated based on daily data obtained from the Wroclaw meteorological station, part of the national atmospheric monitoring network. Tree ring widths were determined separately in heartwood and sapwood using LINTAB^{TM} 6 and TSAP-Win software, to an accuracy of 0.01 mm. Just over 85 % of the analyzed trees were at least 61 years old. In the heartwood layer the average tree ring width of 2.44 mm was about 1.08 mm wider than in the sapwood layer. Results confirmed the significant effect of warm winter and cool July on the ring widths of the black locust. The greatest demand for water was statistically proven in the period June to August in the year preceding the formation of the tree ring, and in the months January and September in the year of the tree ring formation.

KEYWORDS: Dendroclimatological analysis, heartwood, sapwood, urban areas, meteorological indicator, south-western Poland.

INTRODUCTION

There are few studies on non-native species of trees that have an especially adverse effect on the biodiversity and functioning of native hyloecosystems (Dzwonko and Loster 1997, Krízsik and Körmöczi 2000, Call and Nilsen 2005, Motta et al. 2009, Gassó et al. 2012). In Poland, one example of such a species is the black locust from central and eastern North America (McAlister 1971, Boring and Swank 1984, Motta et al. 2009). This species is characterized by intensive growth at an early age, a developed root system strongly penetrating the topsoil, intense vegetative propagation and seeds with a long lifetime (Węgorek and Kraszkiewicz 2005, Passialis and Voulgardis 2007, Sitzia et al. 2012, Zajączkowski and Wojda 2012). Outside of forests, the back locust grows in urban gardens and parks as an ornamental tree with abundant inflorescences, as well as in residential areas and roadsides (Sjöman and Nielsen 2010, Yang et al. 2012). The wide range of the black locust, even in poor soil and climatic conditions, is due to its wide range of ecological tolerance (Rédei et al. 2008, Enescu and Dănescu 2013, Vítková et al. 2015), as well as the properties of its wood (Adamopoulos et al. 2010, Oltean et al. 2010, Kraszkiewicz 2013, Stolarski et al. 2013) and flowers (Kasper-Szél et al. 2003, Walkovszky 2008, Marghitas et al. 2010, Kropf et al. 2010, Giovanetti and Aronne 2013). Still, urbanization and climate change (Szymanowski 2005, Kalbarczyk and Kalbarczyk 2009, Szymanowski and Kryza 2012, Kutnar and Kobler 2013, Walawender et al. 2014) may significantly alter the course of growth and development of this tree species (Nowak et al. 2006, Dmuchowski et al. 2011, Nowak et al. 2012, Chatzistathis et al. 2015).

The aim of this study was to investigate the structure of the basic biometric traits of the black locust in urban areas and determine the impact of air temperature, air humidity and precipitation on the annual tree ring widths.

MATERIAL AND METHODS

The research material was collected at the site of a former garden from the turn of the 20th century in Pilczycka street in the northwestern part of Wrocław (a city in south-western Poland) (Fig. 1). The discs cut from the black locust were obtained during a planned felling of the trees due to redevelopment of the land, in accordance with the local development plan, all the required arrangements and administrative decisions. Analysis concerned 54 discs taken at a height of 1.3 m from the ground from healthy and dominant black locust trees.

Fig. 1: Location of sampling sites (WP) and IMGW-PIB stations (MS).

Before logging, all selected straight-trunked trees were described using the following parameters: trunk circumference (Tc, cm), tree height (Th, m) and crown spread (Cs, m). The discs, dried and planed in order to increase the contrast between the rings, were used to determine the tree ring widths, separately in the heartwood and sapwood. Measurements were performed in duplicate in the directions of bark to core and core to bark, using LINTAB™ 6 and TSAP-Win software, to a precision of 0.01 mm. The two measurement directions determined on the surface of the discs served to determine individual sequences of tree ring widths, which were then assigned WP codes.

The correctness of measurements was tested by establishing a graphical compliance of dendrograms, as well as with Pearson's correlation coefficients and Student's t tests. The sequences that were least similar to the others were excluded from the regressions and correlations. The seven sequences were rejected due to the shorter age of the trees (WP2, WP12, WP25, WP49, WP50, WP51, WP53), were not used to build the real chronology and were not included in the comparison of standard and residual sequences.

The biometric traits of all 54 individual sequences of black locust growth rings were described using basic statistical indicators: mean ($\bar{x}$), standard deviation (SD), minimum (min) and maximum (max), and also based on the annual incidence of tree rings in one millimeter intervals in heartwood and sapwood. We also determined the incidence of tree rings that were wider or narrower than in the preceding year in an individual sequence.

The residual influence of air temperature, air humidity and precipitation on the annual tree ring width of the black locust, was assessed on the basis of the following meteorological indicators: air temperature (T, °C), relative air humidity (Rh, %), the number of days with air humidity higher than 75 % (Rh>75 %, day) and lower than 75 % (Rh<75 %, day), rainfall (Rf, mm), the number of days with rainfall (nRf, day) and without rainfall (nRf0, day), number of days with rainfall higher than 1 mm (nRf>1, day) and higher than 3 mm (nRf>3, day), the indicator of rainfall – the quotient of the total rainfall and the days in the month (IRf, mm), and the average thickness of the snow cover (Sc, cm).

All monthly meteorological indicators were calculated based on daily values obtained by the Wrocław IMGW-PIB weather station, operating within the national air-monitoring network (Fig. 1). In the regression analysis describing the dependence between the weather and tree ring width, tree ring width was a residual dependent variable, while monthly or periodic meteorological data in the period 1954-2014 served as independent variables.

The multiannual period was selected based on the greatest number of measurements of tree ring widths in individual sequences in a given year. All analyses of air temperature, air humidity and precipitation on the dynamics of the tree ring widths were conducted between June in the year preceding the formation of the tree ring to September of the year of ring formation.

RESULTS

Biometric features of sequences between individuals

The average age of the analyzed 54 black locust trees was about 63 years and ranged from 23 to 90 years (Tab. 1). Trunk circumference at 1.3 m from the ground was highly variable and ranged from 61 cm to as much as 206 cm. The average height of the trees in the former garden in the northwestern part of Wrocław was 16.2 meters, with the highest tree reaching 19.0 meters. The crown spread averaged 6.5 m, with the maximum spread at 10.0 m. Among the primary biometric traits (Ta, Tc, Th, Cs), the highest variability was observed for trunk circumference (v=25.8 %, SD=30.3 cm) and then crown spread (v=23.6 %, SD=1.5 m), while tree height variability was the lowest (v=12.5 %, SD=2.0 m).

Tab. 1: Statistical indicators of biometric traits of real chronology of the black locust.

Biometric features n=54	Indicators			
	$\overline{x}$ ±sd	min	max	v (%)
Tree age (Ta, years)	62.5±11.2	23.0	90.0	17.9
Trunk circumference at a height of 1.3 m (Tc, cm)	117.3±30.3	61.0	206.0	25.8
Tree height (Th, m)	16.2±2.0	9.0	19.0	12.5
Crown span (Cs, m)	6.5±1.5	3.5	10.0	23.6

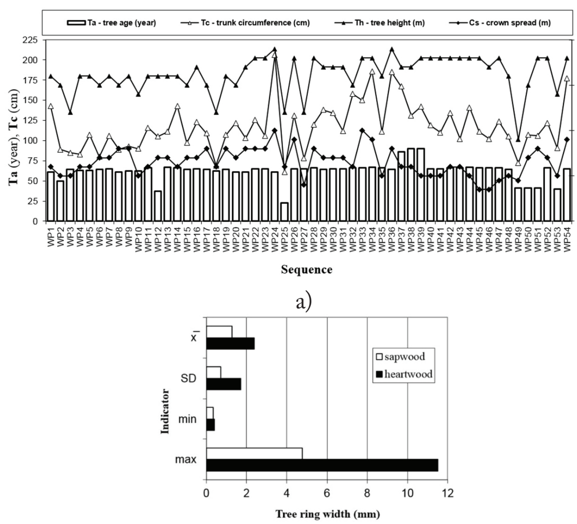
Explanation: $\overline{x}$ – mean, sd – standard deviation, min – lowest value, max – highest value, v – variation coefficient, number of degrees of freedom.

Average tree ring width (Rw) in each of the 54 individual sequences ranged from 1.35 to 4.00 mm (Fig. 2a). The largest Rw was found in tree WP12 (Rw=4.00 mm, Ta=37 years, 1978-2014), followed by WP51 (Rw=3.75 mm, Ta=41 years, 1974-2014), WP36 (Rw=3.64 mm, Ta=64 years, 1951-2014) then WP42 (Rw=3.58 mm, Ta=66 years, 1949-2014), while the narrowest was recorded in tree WP27 (Rw=1.35 mm, Ta=65 years, 1950-2014).

The variability of the black locust tree rings described by the standard deviation was very high. As might have been expected, the lowest SD was found in the youngest tree WP25 (SD=0.59 mm, Ta=23 years, 1992-2014), slightly higher in the almost three times older tree WP47 (SD=0.84 mm, Ta=66 years, 1949-2014), with the highest in WP42 (SD=2.37 mm, Ta=66 years, 1949-2014), WP36 (SD=2.34 mm, Ta=64 years, 1951-2014) and WP35 (SD=2.32 mm, Ta=66 years, 1949-2014).

The minimum tree ring widths ranged from 0.35 mm for WP27 to 2.27 mm in the youngest tree WP25 (23 years). The range of the maximum ring widths compared to the minimum was greater, ranging from 4.54 mm (WP46, Ta= 66 years, 1949-2014) to 11.52 mm (WP24, Ta=61 years, 1954-2014). The average range was 6.73 mm, with the greatest in WP24 (10.6 mm, Ta=61 years, 1954-2014).

Detailed analysis showed that the average tree ring width in heartwood was 2.44 mm, about 1.08 mm more than in sapwood (Fig. 2b).



a)

b)

Fig. 2: Statistical indicators ($\overline{x}$ - mean, SD - standard deviation, min - the lowest value, max - the highest value) for the annual tree ring width for the individual (a) and site (b) chronology.

Wider tree ring widths in the heartwood of the black locust and their greater temporal variability were confirmed by other statistical indicators – minimums, maximums and standard deviation. In the individual sequences the number of tree rings in heartwood was more than 10 times greater than in sapwood and averaged as many as 57 years (Fig. 3). Sapwood rings never exceeded 8 years and did not exceed 4 years in 17 out of 54 analyzed trees.

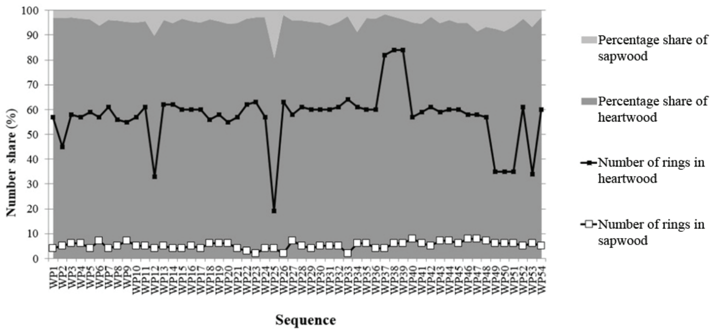


Fig. 3: Characteristics of tree rings in sapwood and heartwood of the black locust.

The percentage of heartwood in the wood ranged from about 80 to as much as 98, with an average of 95 %. The width of the sapwood layer correlated inversely with age. Approx. 20 % content of sapwood was found in the 23 year old tree WP25 (1992-2014), while 1.5 % in the nearly four times older tree WP37 (1929-2014).

Tree ring widths were most frequently (more than 36 %) recorded in the range of 1-2 mm, and then in the ranges of 0-1 (21) and 2-3 mm (over 19 %) (Fig. 4). Definitely less frequent were the ranges 3-4 mm (approx. 9), 4-5 mm (approx. 6), 5-6 mm (approx. 4) and >6 mm (5 %). The frequency of rings in heartwood was similar to the distribution throughout the wood. In sapwood, which was on average only five years old, the rings were usually 0-2 mm wide (over 87 %), with more frequent 1-2 mm rings (approx. 44). The >2 mm rings in sapwood were recorded at a frequency of approx. 12 and rings with >3 mm were only at a frequency of approx. 4 %.

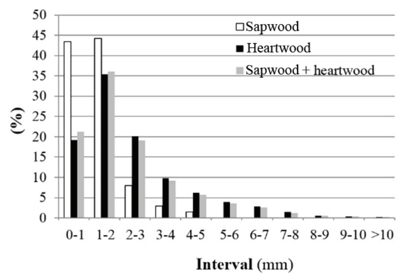


Fig. 4: The incidence of rings in black locust heartwood and sapwood in one-millimeter intervals.

The prevalence of rings that were wider or narrower compared to the previous year varied. On average, narrower rings were recorded a little bit more often (approx. 53 of all cases) (Fig. 5).

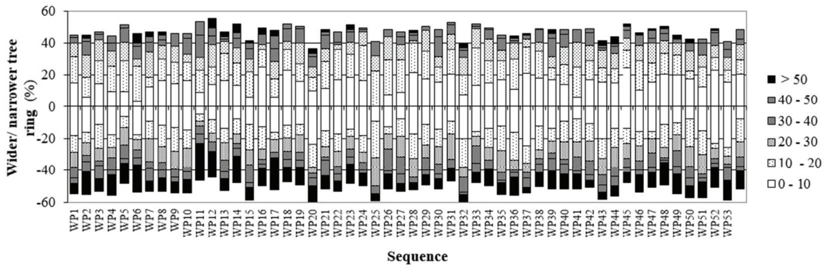


Fig. 5: The incidence of rings that are wider and narrower compared to the preceding year.

These rings were most often 0-10 % narrower (approx. 14 % of rings), then 10-20 % narrower (approx. 11) and 20-30 % narrower (approx. 9 %). The distribution of wider rings was similar; the 0-10, 10-20 and 20-30 % intervals were observed respectively in 15, 14 and 9 % of all rings.

The >50 % interval was found more often for narrower rings (approx. 10 %) than for wider ones (1 %). In the individual sequences, the distribution of narrower and wider rings was often quite different in the studied discs. For example, a tree ring width reduction of more than 50 % compared to the previous year, occurred in more than 20 % of all rings in trees WP11 and WP17.

Real chronology

The site chronology was 90 years, formed on the basis of 47 individual sequences out of the 54 examined sequences (after the removal of the outlying youngest trees), from 1925 to 2014, with the oldest trees labeled as WP38 and WP39 (Fig. 6). In the period 1954-2014, both average and individual tree ring widths varied. In the period 1954-1959 average tree ring widths were as large as 4-5 mm, in the period 1960-1989 they were mainly in the 2-3 mm range and in the period 1990-2014 mainly in the 1-2 mm range. Obviously, the distinct negative trend in annual tree ring widths was related to the aging of trees.

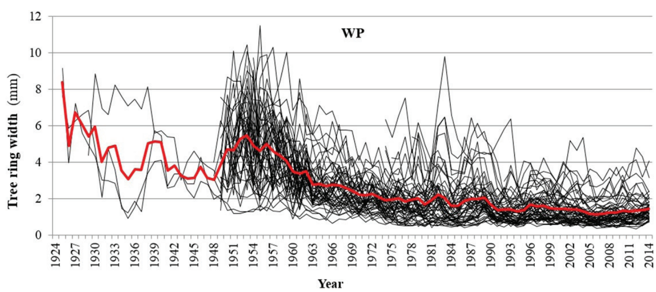


Fig. 6: Correlated dendrochronological curves for individual sequences (-) and for site chronology (–) of the black locust WP.

Dependencies between weather and tree ring width

The tree ring widths in the analyzed black locust significantly depended on the air temperature, air humidity and precipitation (Tab. 2). Air temperature (T) had a significant positive effect in winter, especially in January (r=0.29, P≤0.05) and February (r=0.28, P≤0.05), while a negative effect in July (r=-0.33, P≤0.05).

Wider rings were formed in the years in which the relative humidity (Rh) was higher than the long-term average. Rh in the period from June to October of the preceding year and in the September of the current year had a significantly positive effect on the ring width, with the correlation coefficients ranging from 0.21 in July (P≤0.1) to 0.32 in June (P≤0.05).

The next two indicators describing the content of water vapor in the atmosphere, i.e. the numbers of days with a relative humidity >75 and <75 %, confirm the significant correlation between Rw and Rh (except July of the preceding year), with Rh<75 % having a negative effect. The impact of precipitation, described by total rainfall (Rf) and the indicator of rainfall (IRf), on the black locust's ring width was significantly positive for rainfall in the period from June to August in the preceding year and in January of the current year, and negative in February of the current year.

Tab. 2: Significant correlations between residual site chronology of black locust WP and meteorological elements describing the precipitation and humidity 1954-2014.

Year	Month	Indicators										
		T	Rh	Rh>75	Rh<75	Rf	nRf	nRf>1	nRf>3	nRf0	IRf	Sc
Previous	6		0.32[2]	0.27[2]	-0.26[2]	0.33[2]		0.21[3]			0.34[2]	n.s.
	7		0.21[3]			0.31[2]		0.24[3]	0.25[3]		0.31[2]	n.s.
	8		0.33[2]	0.25[3]	-0.24[3]	0.25[3]					0.23[3]	n.s.
	9		0.28[2]	0.32[2]	-0.32[2]							n.s.
	10		0.29[2]	0.25[3]	-0.26[2]							n.s.
	11						-0.23[3]			0.23[3]		
	12											
Current	1	0.29[2]				0.26[2]			0.28[2]		0.25[3]	-0.25[3]
	2	0.28[2]				-0.29[2]	-0.28[2]	-0.29[2]	-0.24[3]	0.31[2]	-0.27[2]	
	3											
	4											n.s.
	5											n.s.
	6							-0.26[2]				n.s.
	7	-0.33[2]										n.s.
	8											n.s.
	9		0.29[2]	0.24[3]	-0.23[3]				0.28[2]			n.s.

Explanation: T – air temperature (°C), Rh – relative humidity (%), Rh>75 – number of days with air humidity higher than 75 % (day), Rh<75 % – number of days with air humidity less than 75 % (day), Rf – total rainfall (mm), nRf – the number of days with rainfall (day), nRf>1 – number of days with rainfall higher than 1 mm (day), nRf>3 – number of days with rainfall less than 3 mm (day), nRf0 - number of days without rainfall (day), IRf – indicator of rainfall (mm), Sc – average thickness of snow cover (cm), n.s. – not studied, 1 correlation significant at P>0.01, 2 correlation significant at P>0.05, 3 correlation significant at P>0.1.

Not only the amount of precipitation, but its frequency measured by the number of days with rainfall (nRf), including those with rainfall above the thresholds nRf>1 and nRf>3, significantly influenced the tree ring width, while in February it had a negative influence. For example, the formation of a wide tree ring was correlated with the nRf>3 in July of the previous year (r=0.25, P≤0.1) and in January and September of the current year (both r=0.28, P≤0.05), while the narrow tree rings – in February (r=0.24, P≤0.1) for the current year. The number of days without rainfall (nRf0), which describes atmospheric drought, significantly positively determined Rw in November of the preceding year (r=0.23, P≤0.1) and in February of the current year (r=0.31, P≤0.05). Also, snow cover (Sc) in the period of November-March had a significantly negative effect impact on tree ring width (r=-0.25, P≤0.1).

Temporal distribution of meteorological elements

In the analyzed multiannual period, the average annual air temperature was 8.7ºC; it ranged from -1.2ºC to 0.4ºC in winter months and from 16.8ºC to 18.5ºC in summer months. Similar to the whole of lowland Poland, Rh in Wrocław ranged from over 82 % in the autumn and winter months to less than 74 % in the period April-July (Tab. 3). The highest rainfall was recorded in the period May-August, while the lowest in the period December-March, with a minimum in February (Rf=26.0 mm). In the period 1954-2014 Sc was recorded from October to May, with the thickest cover observed in January (Sc=5.7 cm) and February (Sc=5.8 cm). Similar to air temperature, the greatest standard deviation of atmospheric humidity was typically recorded in the spring and summer months, unlike nRf, nRf0 and Sc.

DISCUSSION

There have been no studies on the basic biometric traits of the black locust and the impact of humidity and precipitation on tree ring widths, especially in the warm temperate and changeable climates of Central Europe. Previous studies on the black locust concerned economic evaluation of its use for heating purposes (Kraszkiewicz 2010), the intensity of its growth in linear planting (Węgorek and Kraszkiewicz 2005) or in crop plantations (Zajączkowski and Wojda 2012).

Hungarian research showed that in the black locust, the culmination of growth in height occurs within the first five years, while the diameter at breast height culminates in the first 10 years (Rédei 2003). Under the optimal habitat conditions of Hungary, at the age of felling (35-40 years) the black locust achieved 23-27 m height and 26-32 cm trunk diameter at breast height (Rédei 2003).

In the forests of western Poland, the black locust can reach a height of about 18m to as many as 35 m (Feliksik et al. 2007). In Wrocław, tree height was significantly lower, ranging from 9-19 m, which can be explained by the poorer habitat conditions (Urban 2008, Sjöman and Nielsen 2010, Nowak and Greenfield 2012, Yang et al. 2012, Ziemiańska and Suchocka 2013). In turn, in the forests of the Greek Halkidiki peninsula, the height of 18-37 year old black locusts ranged from 14.5 to 21.0 m (Adamopoulos and Voulgaridis 2002).

In the period 1946-2006 in the mixed fresh forests of western Poland tree ring widths of the black locust averaged 2.24 mm and ranged from 1.10 to 5.05 mm (Feliksik et al. 2007), which was similar to the black locust analyzed in Wrocław. Chemical analysis showed juvenile wood formation in the black locust in the first 10-15 years of cambium growth (Latorraca et al. 2011).

In young heartwood, the content of phenolic compounds and flavonoids is lower than in the older heartwood and therefore it has a lower resistance to degradation caused by *Coniophora puteana* and *Coriolus versicolor* (Latorraca et al. 2011). In the black locusts from the Wołów and Mieszkowice populations in western Poland, the greatest tree ring widths were observed on the southern and eastern sides of the trunks (Klisz et al. 2014). This regularity can be caused by the initiating effect of day length and air temperature on the initial cambium activity in the black locust.

According to Feliksik et al. (2007) low rainfall during summer, especially in June and July, are among the most important factors affecting tree ring width. South-western Poland often experiences droughts, on average every 4-5 years (Kalbarczyk 2010).

Literature data show that low rainfall in autumn of a previous year and February of the current year have a negative impact on the width of tree rings in the black locust (Feliksik et al. 2007). Similar results were obtained in the present study, confirmed by the analysis of correlation between the widths of tree rings and the precipitation and humidity. The effect of low precipitation in February of the year of the ring formation in the period 1954-2014 was statistically significantly. In that month, below-average precipitation resulted in narrower tree rings, unlike the same period in the ecosystems of south-western Poland (Feliksik et al. 2007).

Our analysis of a relationship between air temperature and annual tree ring widths in the years 1954-2014 party confirms the results published by Feliksik et al. (2007) in which T in winter months had a significant positive effect on the ring widths. The observed negative effect of the snow cover in the fall-winter period (from November to March) on the tree ring widths can be explained by its cooling effect on the ground-level air temperature, as shown by (Żarnowiecki 2008). Any heat is first used to thaw the snow, and only then to warm the soil and air to make the growth of plants possible. This is also the season of the year with the alternating periods of thawing and cooling, which may also contribute to the reduction in tree ring widths.

CONCLUSIONS

The average age determined from the individual sequences of tree ring widths of the black locust was 63 years and ranged from 23 to 90 years. Slightly more than 85 % of all the analyzed trees were at above 61 years old.

Among the basic analyzed biometric sequences, the highest variability was observed in trunk circumference, with the lowest for tree height.

In the period 1925-2014, the average tree ring width of individual sequences was in the range 1.35-4.00 mm. In heartwood, rings averaged 2.44, 1.08 mm wider than in sapwood.

Both narrower and wider rings relative to the previous year were most frequently in the 0-10 % of width range (14 and 15 % of all cases, respectively).

In the climatic conditions of Wrocław we demonstrated a significant impact of air temperature, relative air humidity and precipitation (rainfall and snow cover), on the black locust tree ring width.

Above-average air temperature in winter and below-average air temperature in July resulted in the formation of wider tree rings.

The greatest demand for water of the black locust was observed in the period June-August of the year preceding the formation of the ring, as well as in January and in September in the year of the ring's formation, with the most significant correlations found between tree ring widths and relative air humidity.

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