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DEPENDENCE OF HEIGHT INCREMENT ON THE PRECIPITATIONS AND TEMPERATURE CONDITIONS IN A 24–YEAR PINE STAND

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Dedicated to the memory of Professor Wiktor Oktaba

Summary

The study examined the significance of linear and square dependence between the increments of height, increments of lateral branches of Scots pine and both the temperature and rainfall occurring during the year preceding the year incremental. There was a significant, positive linear relationship between increments and the temperature (of the preceding year). Moreover a negative correlation of rainfall occurring in July. Similar results for the square regression were obtained. However, these relationships are very weak.

Key words and phrases: correlation, increments of the main shoot, increments of lateral branches, backward regression, Scots pine

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1. Introduction

Scots pine is an important tree species in forests of Poland. For many years now multifaceted studies have been conducted on this species. Many scientists have dealt with the effect of atmospheric conditions on diameter increment in trees. In Poland the first such studies were published by Zienkiewicz (1946) and Ermich (1953). The next publications concerned trees growing on different soils, e.g. Jasnowska (1977) and Zielski (1996, 1997) investigated the effect of climatic conditions on radial growth of trees growing on peat soils. Cedro (2001) conducted similar investigations covering the period of 1949–1998 in north–western Poland. Annual height increments of trees are considered as a major dendrometric characteristic since it exerts a direct influence on the determination accuracy of the tree and stand volume increment. It is a variable characteristic and depends on several factors (Beker 1997, Kaźmierczak 2004, 2005; Lemke 1972a, b; Najgrakowski 1998, Rymer–Dudzińska 1997, 1998). The most important of these factors include: tree species, its age, biosocial position, soil and climatic–meteorological conditions.

Each year annual shoots develop from terminal buds formed in the previous vegetation season. The length of the annual shoot, grown in the vegetation season and lignified, does not change, which makes it possible to determine its length at any given time. The length of the annual shoot is a variable trait. Actual annual increment of the height of the tree is unstable and depends on the weather conditions during growth (in the vegetation year) and on the weather conditions in the previous year, particularly in the time from July till September. This time period is very important because buds are formed and reserve substances are accumulated. Next, reserved substances are used for growing the sprouts next year (Assmann 1968).

Scots pine is a tree species with a monopodial type of growth. The main shoot develops from the apical bud and constitutes an extension of the tree axis (Tomanek 1997). Side shoots, forming branches of a tree, grow in verticils. Their number is typically 5 and it decreases with age. Elongation growth results to a bigger or smaller degree in an extension of individual branches, which leads to the formation of the crown. In practice it is usually limited to the determination of growth and increment in height of trees by the determination of elongation growth of its main axis. Scots pine belongs to the northern tree type (boreal–arctic northern) and the mountain tree type. It is found in areas, in which temperature ranges from –60 to +400C. The effect of pine tolerance to changes in temperature was investigated by Białobok et al. (1993), Szeicz and MacDonald (1995) as well as Zielski (1996, 1997). In Poland growth activity of pine covers the period from May to September.

The crown, its size, shape and structure affect the course of tree growth. Characteristics of the crown are also indicators of stand damage. In the determination of health conditions of pines we can use e.g. length and shape of shoots, the type of the apex and branching (Niehaus 1989, Dmyterko 1994, Wójcik, Czarnecka 2001). This criterion, apart from defoliation, is an element in the method used to establish forest damage zones (Instrukcja 2003).

The aim of the study was to determine the dependence between annual increments in length of the main shoot (annual increment in height) and annual increments of lateral branches and the volume of precipitation and temperature in the previous year. Dependencies taking into consideration mean annual temperature, mean temperature from the months of April–September and the mean for the month of July were verified. Analogous relationships were analysed for precipitation in the same three periods. Increments of side branches from the fifth verticil were measured taking into consideration the geographical direction of their location on the tree.

2. Experimental material and methodology

Experimental material was collected from a 0.10 ha mean sample plot located in a 24–year pine stand growing in the fresh mixed coniferous forest (BMśw) in the Zielonka Experimental Forest Division. They are measurement results for 25 mean sample trees, selected according to the principles of the Draudt method. Trees with medium–sized, properly developed crowns were selected (Lemke, 1971). The size of crowns and their health condition were estimated visually. Before felling the social class of tree position in the stand was also identified for the mean sample trees.

Measurements included annual increments in length of the main shoot and all live, properly formed side branches of the fifth verticil. Increment of the main shoot is the increment in tree height. Side shoots were measured taking into consideration the direction of their location on the tree in relation to geographical directions. Between one and six properly formed side branches grew in the fifth verticil. The most numerously represented directions, from which side branches were growing, were the east and west (with 18 trees each), north (15) and south (11). Intermediate directions were characterized by a lower number of branches (7 from the north–eastern direction, 5 from the south–western direction, 4 from the north–eastern direction and 3 from the north–western direction). Annual increments were determined in the increment period of 1994–1998. In the analyzed measurement material relationships were also analyzed between the elongation increment of the main shoot and side branches (Kaźmierczak and Zawieja, 2008).

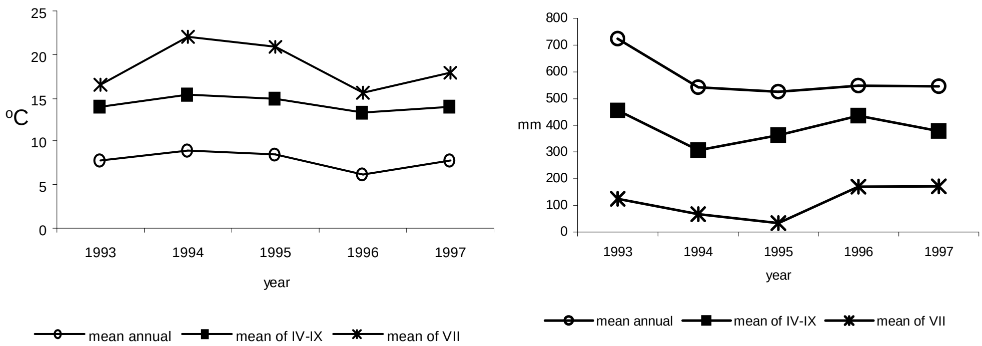
On the basis of observations recorded at the weather station in Zielonka values of mean annual temperature was determined in the months of April–

September and temperature in July (°C). Analogous measurements were taken into consideration in terms of the precipitation total (mm). Weather conditions were considered in the year preceding the increment year, for which annual increments in length were measured for the main shoot and lateral branches.

In order to determine a dependence between annual increments of trees and weather conditions, i.e. precipitation and temperature, linear correlation coefficients were calculated. Annual increments of the main shoot or side branches (in meters) were adopted as dependent variables, while the levels of precipitation (mm) or temperature (°C) were independent variables. Calculations were made for annual increments of all side branches depending on the direction of their location, for mean annual increments of side branches and for the main shoot. Three periods of temperature and precipitation were used: the annual mean, mean from the months of April–September and the mean for July.

3. Results

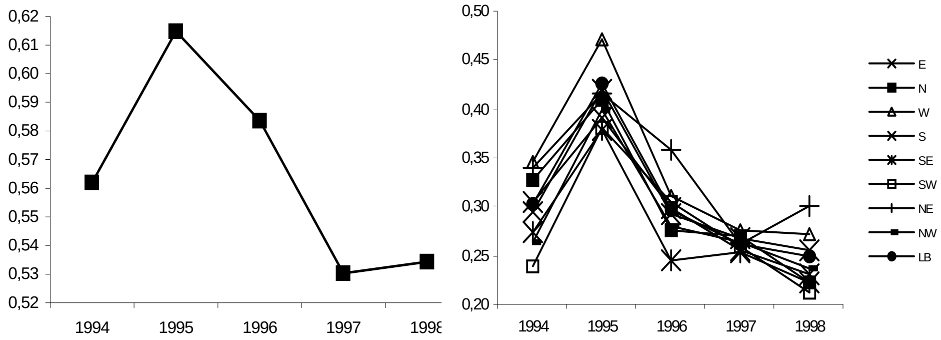
Fluctuations in mean temperature and mean precipitation in the years 1993–1997 are presented in Figure 1. Figure 1a presents changes in mean annual temperature, mean temperature in the vegetation period from April to September and the mean for July. For analogous measurement periods a change was shown in the mean precipitation in Figure 1 b.



a) b)

Fig.1. Fluctuations in mean temperature (on the left) and mean precipitation (on the right) in three measurement periods in the years 1993–1998

The next two graphs (Figure 2) illustrate a change in mean annual increments for twenty five mean sample trees. Fluctuations in increment years observed for mean annual elongation increments of the main shoot (MS) are presented in Figure 2a, while mean increments for lateral branches growing in the eight geographical directions and their means (LB) Figure 2b. Mean increments for lateral branches growing in the eight geographical directions are similar. Moreover, a similar trend may be observed in the course of annual increments of lateral branches and the main shoot. Thus, if in a given year a bigger increment in the main shoot was observed, then increments for lateral branches were also bigger.



a) b)

Fig. 2. Fluctuations in mean increments of the main shoot MS (on the left) and mean increments of lateral branches LB growing in eight geographical directions and the mean of lateral branches (on the right) in increment years

The next graphs present mean annual increments for shoots of the trees (the main shoot MS and the mean for increments of lateral shoots LB), depending on the temperature (Figure 3a, b, c) and precipitation (Figure 3d, e, f). A solid line was used to mark changes in the mean of increments of the main shoot MS, while a broken line marks the mean for increments of lateral branches LB. Annual temperatures and precipitation are presented on the axis of abscissa in the ascending order. In Figure 2a we may clearly see a lack of a correlation between the mean annual temperature and increments of trees. It is also difficult to observe a trend in the dependence of increments on the mean temperature from the months of April–September and for the month of July; however, we may also observe that with an increase in the mean precipitation the increments of shoots decrease (mainly for side branches). The discussed graphs present only a general trend for the means. A detailed analysis may be conducted after statistical calculations were conducted, taking into consideration all measurements for the 25 mean sample trees for the period of five years.

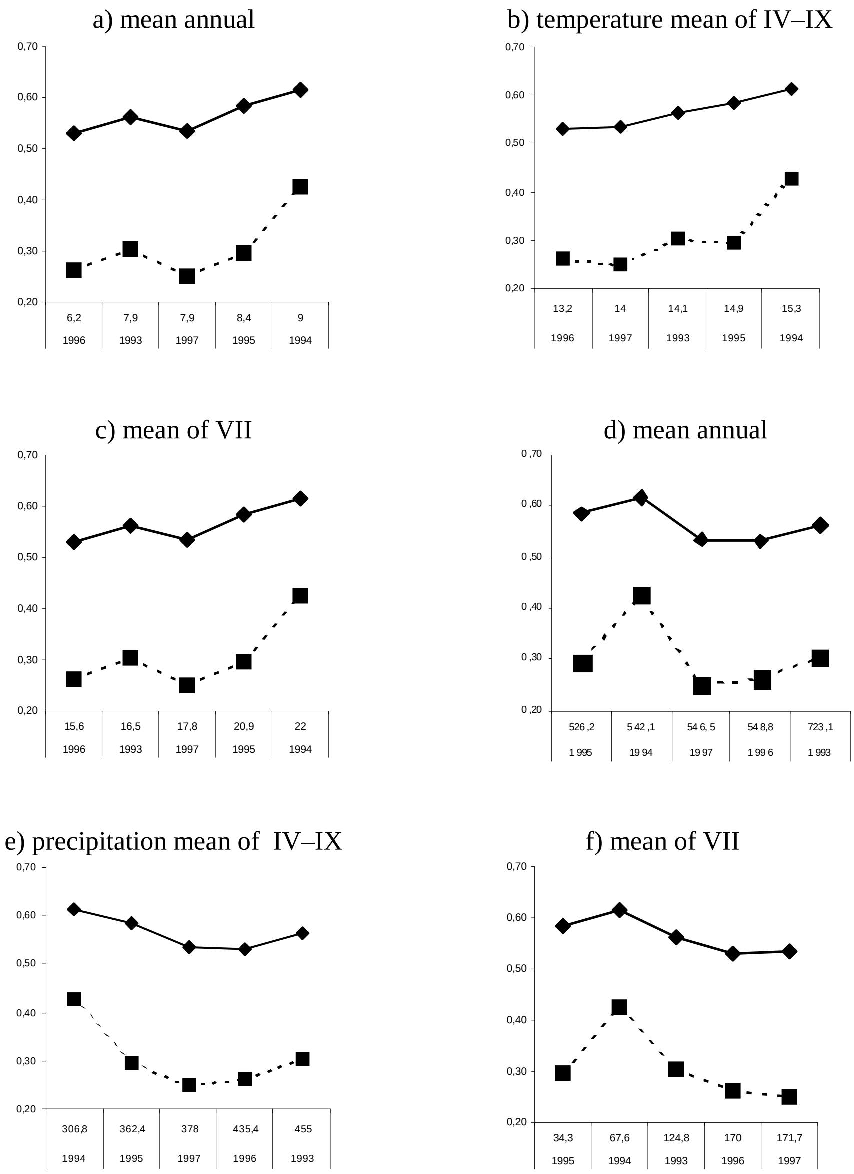


Fig. 3. Fluctuations in mean increments of the main shoot MS (solid line) and mean increments of lateral branches LB (broken line) depending on temperature and precipitation

In order to verify whether there is a linear dependence between increments of lateral branches and the main shoot in the analyzed trees, and temperature and precipitation, correlation coefficients were calculated and their significance was tested. Results are presented in Table 1. Statistically significant coefficients (at the significance level of 0.05) are marked in bold. Temperature in previous year had a significant effect on increments in length. The annual height increment was significantly affected by precipitation in the month of July of previous year.

Table 1. Correlation coefficients for increments of the main shoot (MS), lateral branches growing in eight geographical directions and the mean of lateral branches (LB) with temperature and precipitation

Trait		MS	Lateral branches in the geographical directions								LB
			E	N	W	S	SE	SW	NE	NW	
mean tempe-rature	annual	**0.20**	**0.29**	**0.25**	**0.34**	**0.31**	0.24	0.30	0.28	0.32	**0.36**
	IV–IX	**0.22**	**0.34**	**0.29**	**0.37**	**0.36**	0.28	0.40	0.29	0.39	**0.40**
	VII	**0.21**	**0.32**	**0.24**	**0.33**	**0.32**	0.26	**0.43**	0.26	0.39	**0.37**
mean precipi-tation	annual	-0.02	-0.05	0.09	0.03	0.02	0.00	-0.19	0.00	-0.12	-0.02
	IV–IX	-0.17	**-0.31**	-0.19	**-0.30**	-0.27	-0.26	-0.39	-0.22	-0.39	**-0.35**
	VII	**-0.20**	**-0.25**	**-0.25**	**-0.27**	**-0.32**	-0.20	-0.39	-0.25	-0.31	**-0.30**

Moreover, due to the lack of a visible trend on the graphs, the square regression analysis was conducted for increments on temperature and precipitation. Results are presented in Table 2. In most analyzed cases square regression is not significant (similarly as linear regression, as it is indicated by the correlation coefficients). Significance of square regression occurs for the same dependencies, for which linear correlation coefficients were significant. In order to avoid any ambiguities on what type of dependencies take place between mean increments of lateral branches, and temperature and precipitation, a backward regression (Draper and Smith, 1973) analysis is performed (no such analysis was conducted for increments of the main shoot due to a lack of a dependence either for temperature or precipitation).

It turned out that for the dependence between increments of lateral branches and temperature the linear factor was eliminated, i.e. the dependence is of the $y = b_1 x^2 + b_0$ type. In dependencies between increments and precipitation both regression coefficients turned out to be significant (none of the coefficients was eliminated). Thus regression is of the $y = b_2 x^2 + b_1 x + b_0$ type. All results of a detailed analysis are presented in Table 3.

For the results of individual regression analysis, verified the hypothesis that residuals are normally distributed. Test of Kolmogorov–Smirnov was used in this purpose at significance level 0.01. The values of the test statistics did not exceed critical values, hence there was no reason to reject these hypotheses. However, when Shapiro–Wilk test were used the null hypothesis was rejected. So outliers were rejected and re–performed all regression analysis. It turned out that there was no reason to reject the hypothesis that residuals are normally distributed after the application of both tests. The corresponding *p*–value for both of the tests are given in Table 4.

Table 2. Values of F statistic and *p*–values in the analysis of variance in square regression

F statistic		MS	Lateral branches in the geographical directions								LB
			E	N	W	S	SE	SW	NE	NW	
mean temperature	annual	**3.19**	**9.33**	**6.14**	**10.12**	**5.30**	3.08	**3.87**	0.80	2.17	**19.08**
	IV–IX	**3.31**	**8.17**	**5.27**	**8.50**	**4.97**	2.57	**4.04**	0.79	1.95	**16.70**
	VII	3.00	**8.07**	**6.14**	**8.09**	**4.91**	2.83	**4.12**	0.64	1.97	**16.27**
mean precipitation	annual	0.89	0.14	0.35	0.11	0.39	0.01	0.68	0.18	0.10	0.29
	IV–IX	2.69	**10.43**	**9.92**	**12.97**	**6.06**	**4.04**	3.10	0.63	2.19	**21.94**
	VII	**3.09**	**5.66**	**7.67**	**8.81**	**5.35**	2.13	2.13	0.71	0.97	**13.54**
p–value		MS	Lateral branches in the geographical directions								LB
			E	N	W	S	SE	SW	NE	NW	
mean temperature	annual	0.045	0.000	0.003	0.000	0.008	0.060	0.036	0.465	0.157	0.000
	IV–IX	0.040	0.001	0.007	0.000	0.011	0.092	0.032	0.470	0.184	0.000
	VII	0.054	0.001	0.003	0.001	0.011	0.074	0.030	0.538	0.182	0.000
mean precipitation	annual	0.413	0.865	0.704	0.898	0.680	0.985	0.516	0.839	0.910	0.900
	IV–IX	0.072	0.000	0.000	0.000	0.004	0.027	0.065	0.545	0.154	0.000
	VII	0.049	0.005	0.001	0.000	0.008	0.135	0.143	0.504	0.407	0.000

Table 3. Regression coefficients and their significance (*p*–values) of analysis of backward regression

Trait		MS				LB			
regression coefficients		b_2	b_1	b_0	R^2	b_2	b_1	b_0	R^2
mean temperature	annual	0.002	X	0.444	0.041	0.051	-0.723	2.805	0.260
	IV–IX	0.002	X	0.242	0.049	0.065	-1.786	12.59	0.235
	VII	0.0003	X	0.468	0.044	0.011	-0.382	3.691	0.248
mean precipitation	annual	N	N	N	N	N	N	N	N
	IV–IX	N	N	N	N	0.00002	-0.016	3.536	0.305
	VII	-0.0006	N	0.648	0.046	0.00002	0.003	0.215	0.123
p–values		b_2	b_1	b_0		b_2	b_1	b_0	
mean temperature	annual	0.005	X	<0.0001		<0.0001	<0.0001	<0.0001	
	IV–IX	0.001	X	0.020		0.001	0.001	0.001	
	VII	0.002	X	<0.0001		<0.0001	<0.0001	<0.0001	
mean precipitation	annual	N	N	N		N	N	N	
	IV–IX	N	N	N		<0.0001	<0.0001	<0.0001	
	VII	0.003	N	<0.0001		<0.0001	<0.0001	<0.0001	

X – a given factor was eliminated from regression
N – no stepwise regression was performed

Table 4. *p*–value of conformity tests random errors with normal distribution

Trait		MS		LB	
		S–W	K–S	*S–W*	K–S
mean temperature	annual	0.126	>0,15	0.070	0.074
	IV–IX	0.204	>0,15	0.044	0.031
	VII	0.338	>0,15	0,014	0.139
mean precipitation	annual				
	IV–IX			0,212	>0,15
	VII	0.248	>0,15	0,013	>0,15

4. Discussion and conclusions

In paper by Zielski (1996) significant relationship between radial growth of pine and the temperature in the February and March was concluded. However, the influence of precipitation on increment was greatest in the case of June and July. Similar results were obtained for the pine from the forest areas Dąbrowa Tarnowska (Feliksik 1988). Increments in width of the wood was strongly dependent on the temperature (from January to March) and of precipitation (period April to August). Oleksyn et al. (1993) concluded a significant correlation of radial growth from winter temperatures. Wilczyński (2004) found that warm and short winters with a moist and warm summer caused formation of a wide annual rings, and the years of frosty and long winter, and dry and hot summer resulted in a reduction of increments. Cedro (2001) showed that cold winters and cool spring resulted in a decrease of growth in width. Also, abundant rainfall in June and July and September dry stimulated radial increment during the growing season. Influence of precipitation was weaker than the air temperature. It is clear that weather conditions have a definite impact on radial growth of pine trees.

However, a few publications can be found concerning influence atmospheric condition on the height growth of trees. Salminen and Jalkanen studied height growth of tree from the Arctic Circle up to the northern timberline in Finland. Here are a few conclusions of this paper. The effect of the mean July temperature of the previous year on height increment proved to be very strong at high latitudes (r > 0.7). There was no correlation between height increment and precipitation in any of the sites. The mean November temperature in the year before the previous year had a negative effect on height growth in the tree northernmost stands. Height increment of the two southernmost stands yielded lower correlations to mean monthly temperatures than their northern counterparts.

This study investigated the effect of meteorological conditions on increment in length for shoots of pines in a given vegetation year. Conducted analyses make it possible to draw the following conclusions:

The effect of temperature in July on the volume of annual increment on the length of lateral branches was found. The dependence of increments on temperature was linear in character.

The annual increment of lateral branches was significantly affected by precipitation throughout the entire increment year and in the month of July. This dependence was squared in character.

A positive effect of higher temperature on increments was observed, while when heavy precipitation was observed this effect was negative.

Based on the presented results it was concluded that weather conditions in the preceding year have a effect on crown development. However, these relationships were very weak (very small R^2 values were obtained, primarily for the relationship the main shoot increments from the weather condition). In the light of the above discussion it is easy to see that you need to perform further research on these relationships, to draw more precise conclusions.

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