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Research Article

EFFECT OF THERMAL CONDITIONS AND PRECIPITATION ON GROWTH RATE OF SCOTS PINE

Małgorzata Biniak-Pieróg[1], Andrzej Żyromski[1], Roman Rolbiecki[2], Stanisław Rolbiecki[2], Marcin Żyromski[3], Romuald Żmuda[1]

[1] Institute of Environmental Protection and Development, Wrocław University of Environmental and Life Sciences, Plac Grunwaldzki 24, 50-363 Wrocław, Poland, e-mail: malgorzata.biniak-pierog@up.wroc.pl, andrzej.zyromski@up.wroc.pl, romuald.zmuda@up.wroc.pl

[2] UTP University of Science and Technology in Bydgoszcz, Department of Land Reclamation and Agrometeorology, e-mail: rolbr@utp.edu, rolbs@utp.edu.pl

[3] Department of Crop Production, Wrocław University of Environmental and Life Science

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ABSTRACT

The aim of the experiment presented in this paper is to assess the relationship between the height and diameter increase rate and the thermal conditions and precipitation during its growth. The experiment was carried out in the Agro- and Hydrometeorology Observatory of the Wrocław University of Environmental and Life Sciences in 2013–2015. The height and diameter measurement was made each time on the same 43 plants, randomly selected at the stage of setting up the experiment in 2012 and specially marked. Plants included in further analyses were divided into 5 classes and the classification criterion was their height in the 3rd year of cultivation. Initially, an analysis of relationships of selected morphological parameters of Scots pine was carried out, i.e. of the heights and diameters against the changing weather conditions, i.e. precipitations and air temperatures. Subsequently, an effect of the thermal conditions and the amount of precipitation on growth of Scots pine was assessed with the use of the two meteorological parameters mentioned above. These parameters were used as their accumulated sums, calculated as of the dates of biometric measurements, made at the end of each month (the last ten days of a month) in the summer half-year period. Multiple regression analysis was applied to evaluate the effect of thermal conditions and precipitation on the growth of Scots pine in both variants and the significance of the relationships under study was examined with the use of an adjusted coefficient of determination R^2. The analyses and calculations indicate a close significant relationship between the height of pine trees and their diameter at the base on any measurement date. Analyses of different measurement periods indicated a decrease in significance of the relationships between the height of pine trees and their diameter at the base. A decrease in these relationships is becoming more and more pronounced with the age of the trees. Of the two weather parameters, i.e. total air temperature and total precipitation, the precipitation dominates in the relationship with the trees height and air temperature – with the trees diameter.

Keywords: Scots pine, growth dynamic, thermal conditions, precipitation

INTRODUCTION

In line with the aims of the ecological, economic and social policy in Poland, efforts have been made to increase forest resources, mainly by afforestation of land which is not economically effective [Koreleski 2003, Gawroński 2004]. Coniferous trees are the mainly used in planting forest enclaves. They have a considerable effect on the environment and they contribute to improvement of water retention in the areas where they grow, they change the microclimate in a way favourable to humans and they intercept considerable amounts of air pollution. Forests are planted in order to increase the afforestation rate on poor soils [Durło 2012]. It is believed that Scots pine (*Pinus sylvestris* L.) should be the main species planted on poor soils [Kocjan 1997, Durło et al. 2015]. Successful cultivation of forests on degraded or fallow land largely depends on preparation of good quality planting material, which is resistant to potentially damaging agents, such as pathogenic fungi [Oszako and Rakowski 2000]. It must be borne in mind that one of the conditions of success of forest planting on difficult land is to use seedlings with abundant and diverse mycorrhiza [Aleksandrowicz-Trzcińska 2004, Grzywacz 2009]. The condition of soil organisms in nurseries and on land where trees are planted may have deteriorated, especially where such land was intensively used earlier, which in consequence decreases the quality of seedlings produced in such nurseries and decreases the chances of success of planting. The biological condition of soils can be improved by enriching nurseries in organic matter, e.g. by mulching with forest ectohumus [Klimek et al. 2011]. Szołtyk and Hilszczańska [2003] claim that enriching of soil in forest nurseries with ectohumus results in increased mycorrhisation of seedlings by as much as 80%, which greatly improves the success rate of planting seedlings on difficult lands.

Apart from soil, climate is another factor which affects productivity of Scots pine biomass; this is usually characterised by two parameters varying from year to year: air temperature and total precipitation in the area where forest is planted. Because of the simple method of measurements, these two parameters are easily accessible, so linking these weather factors with the results of selected biometric measurements of Scots pine can allow one to make an assessment of a possibility of estimation of the growth rate of these plants.

The aim of the experiment presented in this paper is to assess the relationship between the height and diameter increase rate and the thermal conditions and precipitation during its growth.

MATERIAL AND METHODS

The experiment was carried out in the Agro- and Hydrometeorology Observatory of the Wrocław University of Environmental and Life Sciences in 2013 – 2015. Age of trees covered by the study included individuals between the ages of 3 to 5 years, so the trees in the young forest stand. Pine seedlings were planted in early spring 2012. They were planted in the 1.4 m x 0.8 m setup, which yielded the planting area of about 155 m^2.

In the area of the Observatory, small-grained loamy sands are most frequent in the soil surface horizons . In deeper layers they change into weakly loamy sands and loose sands with thin interlayers of loamy sands and sandy loams. Their underlying substrate is boulder loam, mainly small-grained sandy. For several months in a year the soils in the object are totally saturated with water at the depth of 100–120 cm. Typologically they are alluvial soils proper. In the international classification FAO-WRB [IUSUS 2006] the cultured soils with preserved features of alluvial deposits are most often classified in the group of Phaeozems (Fluvic Gleyic Phaeozems (Anthric, Arenic)). Soil density is the lowest in the surface horizons, where its values oscillate around 1.4 g cm^{-3}, while in the underlying layer of loam the density is about 1.55 g cm^{-3}. Total porosity is ca. 40–45%, while capillary porosity is lower and falls within the range of 20–30%. The soils in the object are characterised by low water retention capacity, and the field water capacity at suction force corresponding to pF=2.0 is very low, within the range of 6–12.5% (v/v) [Żyromski et al. 2016].

During the subsequent years of the study, between May and October, at the end of each month (the last ten days of a month), measurements of the height and diameter of the trunks just above the root crown were made. The height measurement was made each time on 43 plants, randomly selected at the stage of setting up the experiment in 2012 and specially marked (Figure 1).

Measurements of the diameter of each of the selected plants were started at the beginning of the measurement period in 2013. However, considerable difficulties were encountered as they grew. As plants became closer and closer to one another, it became increasingly difficult to measure the diameters because of hindered access to the trunk. This was the reason why 34 plants were taken into account in the analysis of this parameter. Lack of year-to-year continuity of measurements was a factor which eliminated some plants.

Plants included in further analyses were divided into 5 classes. The height of plants in the fifth year of the experiment – 2015, which was also the third year of making biometric measurements – was the classification criterion. The following classes of height were adopted:

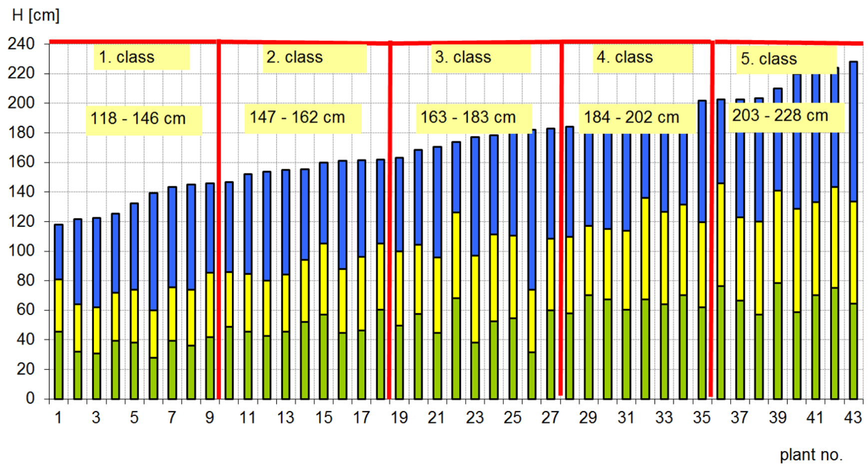

Fig. 1. The structure of the height growth of pine trees covered by biometric measurements

- *class 1*: from 118 to 146 cm;
- *class 2*: from 147 to 162 cm;
- *class 3*: from 163 to 183 cm;
- *class 4*: from 184 to 202 cm;
- *class 5*: from 203 to 228 cm.

Initially, an analysis of relationships of selected morphological parameters of Scots pine was carried out, i.e. of the heights and diameters against the changing weather conditions, i.e. precipitations and air temperatures.

Subsequently, an effect of the thermal conditions and the amount of precipitation on growth of Scots pine were assessed with the use of the two meteorological parameters mentioned above. These parameters were used as their accumulated sums, calculated as of the dates of biometric measurements, made at the end of each month (the last ten days of a month) in the summer half-year period. Accumulated increments of the height and diameters of the pine trees for these dates were used in the analyses. The calculations were made for two variants. The first one took into account the accumulated totals of precipitation and air temperature and increments as calculated from the beginning of the measurement period at the end of May (after 20 May) to the date of a biometric measurement at the end of each of the subsequent month (after the 20th day of a month) of the summer half-year period. The other variant took into account the accumulated weather parameters and increments of height and diameters of tree trunks from the last 10 days of May to the last 10 days of October. Measurements were interrupted in August in 2015 because of very intensive growth of trees in the plantation, which hindered making them in a reliable manner; the height measurements were carried out until the end of October.

Multiple regression analysis was applied to evaluate the effect of thermal conditions and precipitation on the growth of Scots pine in both variants and the significance of the relationships under study was examined with the use of an adjusted coefficient of determination R^2.

RESULTS

Characterisation of the thermal conditions and precipitation during the period of study

At the first stage, a comparative analysis was carried out of the thermal conditions and precipitation during summer half-year periods when measurements of pine trees growth were made. The thermal conditions were characterised on the basis of the deviations of ten-day mean air temperatures from the normative values of the multi-year period of 1981–2010 according to the IMGW-PIB (National Research Institute). Precipitation was characterised by the Relative Precipitation Index [Łabędzki and Bąk 2014].

Each summer half-year period in the years 2013–2015 was warm, with the average temperature between 15.9°C in 2013 and 16.4°C in 2015. Warm and medium-warm ten-day periods were the most frequent (Figure 2).

In 2013 they occurred mainly between July and October. May and June contained ten-day periods both with an average temperature below and above the norm, with cold ten-day periods being the most frequent in 2015. The half-year total precipitations in the years of the study were 241 mm in 2015 (a very dry half-year period), 472 mm in 2014 and 541 mm in 2013 (very humid half-year periods). The ten-day period variability of the amount of precipitation in 2015 distinguished it from the other years, because extremely dry periods occurred between the last ten days of July and the end of October, except for two ten-day periods, with 3 such periods with not one day with rainfall. There were ten-day periods in 2013 with above-norm amount of rainfall and those with the amount of rainfall below the norm. Humid, very humid and extremely humid ten-day periods were the most frequent in 2014 (Figure 3).

The analyses carried out for the study employed accumulated total temperatures and precipitation, presented in Figure 4 and 5. The accumulated total air temperature for the whole half-year period was 2401°C in 2013, 2584°C in 2014 and 2532°C in 2015, so they were quite similar, which is indicated by the thermal classification of the whole half-year periods. Their changes over time in 2013 and 2014 was almost identical, with a marked difference at the end of June and the whole summer half-year period. The year 2015 was different, with considerably lower accumulated total in July and higher – in August and September.

An increasing total precipitation was each time characterised by their different course (Figure 5); it must be stressed that the precipitation curve for 2013 lay distinctly above the levels for the other years. There was a nearly linear increase in total precipitation observed in 2014 between consecutive dates of pine trees growth measurements. The year 2015 – a very dry one – can be divided into two periods: the first one until July, with an increasing total precipitation up to 134 mm and the other – from August to October with poorly marked increase in the total precipitation by merely 76 mm, whereas such increase during the same period of the other half-year periods was by over 200 mm.

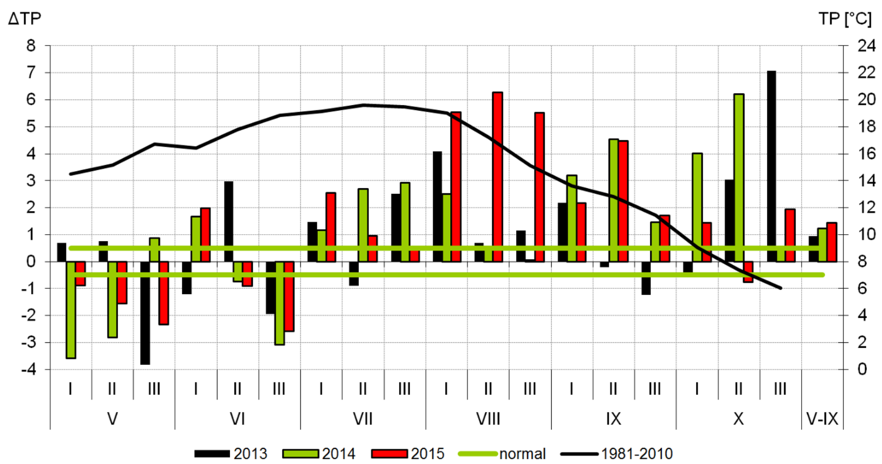

Figure 2. Deviations of decadal (ten-day period) air temperature averages (ΔTP) in the years 2013–2015 from the multi-year values 1981–2010 adopted as normal (TP)

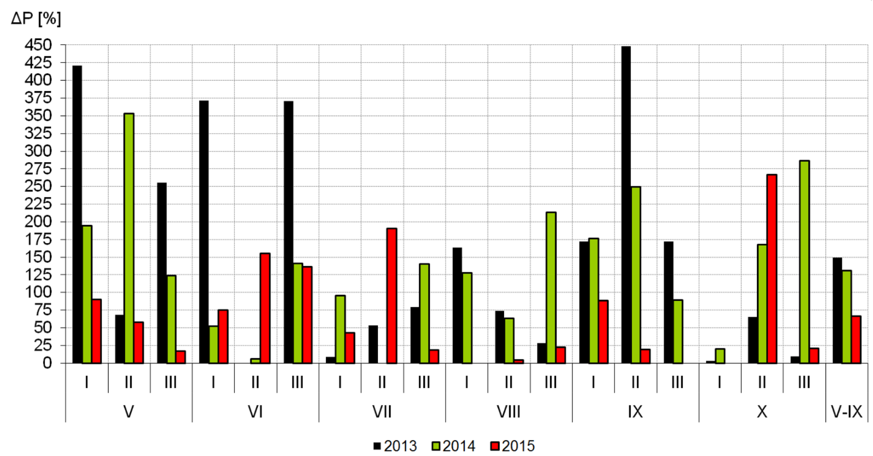

Fig. 3. Deviations of decadal (ten-day period) precipitation totals (ΔP) in the years 2013–2015 from the multi-year values 1981–2010 adopted as normal (TP)

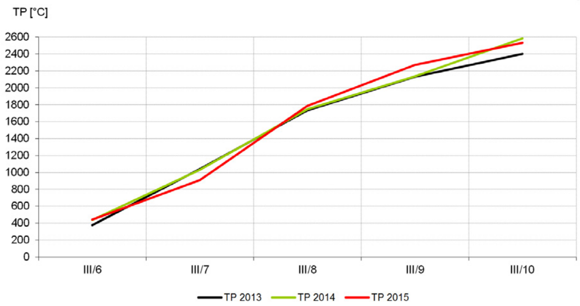

Fig. 4. The course of accumulated totals of air temperature calculated on the dates of plants biometric measurements in the 3rd decade (ten-day period) of the month from June to October in the years 2013–2015

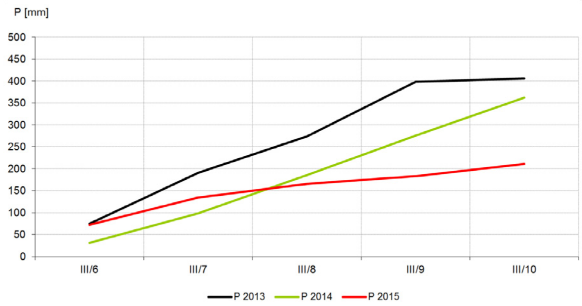

Fig. 5. The course of accumulated totals of precipitation calculated on the dates of plants biometric measurements in the 3rd decade (ten-day period) of the month from June to October in the years 2013–2015

The effect of the thermal conditions and total precipitation on selected morphological features of Scots pine

An analysis of increments of Scots pine for the five adopted classes of height during the whole half-year period during the first year of the biometric measurements – 2013 – indicates certain comparability; highly similar increments were observed in classes 1–3 (about 7 cm) and 4–5 (about 12 cm). The increments in different classes during the second year of measurements – 2014 (4-year-old plants) – varied and ranged from 14 cm in class 1 to 31 cm in class 5. Class were seen to cluster in terms of the increments in the third year of the pine cultivation: in class 1 and 2 they were about 25 cm, in class 3 and 4 – about 30 cm and in class 5 – slightly more than in the previous year, i.e. 39 cm.

The characterisation of the diameter increments in the whole summer half-year periods was narrowed down to the years 2013–2014, because considerable growth of plants in the plantation prevented the measurements. No such repeatability was observed in this morphological feature like in an analysis of the height increments. Average diameter increments ranged from 6 mm in class 1 to 11.8 mm in class 3 in 2013; in the following period – 2014 – from 6.1 mm in class 1 to 13.4 mm in class 5 and – except for class 3 – they were each time greater than in the first year of measurements (the 3rd year of the pine trees' lives).

Both the weather parameters adopted by the authors, i.e. the air temperature and the total precipitation, affected the growth of pine trees in all the years. The results of this effect were visible, for example, in that despite the identical age of the trees and identical thermal conditions and amount of precipitation, the parameters indicated considerable variability. This is indicated by a division of the trees in the experiment into classes. At the same, the authors used only two morphological features, i.e. the results of measurements of the trees height and their diameter at the base and they decided to determine the relationships between the two indexes against the changes of the weather parameters. Considering this, the relationships between these features were determined in monthly intervals during the consecutive years of the experiment. Examples of the relationships for one of the measurement dates in 2013 are presented in Figure 6. The results obtained in consecutive years of the measurements allowed for a conclusion that the greatest diversity of the coefficients of determination R^2 for different measurement dates was obtained for the year 2013.

Their changes over time are presented in Figure 7. It was found that as the trees grew in consecutive years, the relationships decreased, with their simultaneous equalising. Despite this, the coefficients of determination were statistically significant because they considerably exceeded the critical values of R^2, which ranged from 0.0976 to 0.1029 [Krzysztofiak and Urbanek 1981] for n-2 degrees of freedom. The diversity of the critical values of coefficients of determination was a consequence of different numbers of trees covered by the measurements. The diversity of the relationships between these two morphological features can be attributed to the fact that older trees became increasingly insensitive to thermal conditions and amounts of precipitation.

Since it was not possible to make measurements of all the diameters in the third year of the measurements, i.e. in 2015, a comparative analysis was carried out on the basis of similar peri-

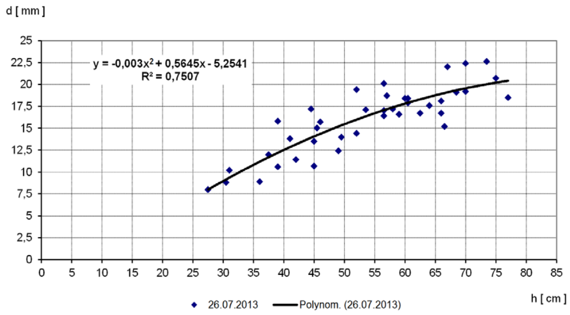

Fig. 6. The relationship between the height *h* [cm] of pines and their diameter *d* [mm] on one of the terms of measurement

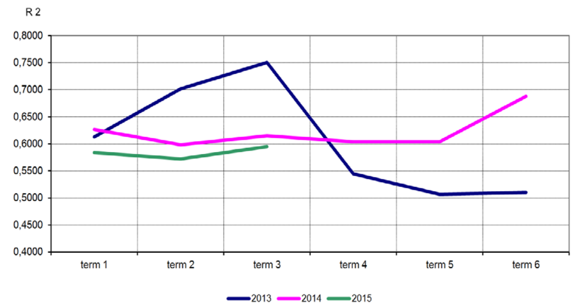

Fig. 7. Variability of coefficients of determination R^2 for the relationship between height of pines and their diameter in the subsequent years of the experiment

ods in different years. And so, three periods from 2013 were used in the comparative analyses: from 31 May to 26 July, in 2014 – from 20 May to 22 July and in 2015 – from 22 May to 19 July. These periods lasted 56, 63 and 58 days, respectively. During these periods, the 24-hour total precipitation and 24-hour average air temperature was added up. The relationships were also determined for these periods between the heights of pine trees and their diameters at the base. The analyses were supposed to show whether there is a relationship between selected biometric parameters and the way the selected weather parameters change in time. The results are shown in Figure 8. The relationships indicate that neither the sum of air temperatures nor the sum of precipitation during similar periods had any significant effect on the relationship between the height and diameter of the pine trees at the base.

An analysis for abbreviated periods beginning with: 21 June in 2013, 22 June in 2014 and 26 June in 2015, i.e. 25, 30 and 23 days of consecutive years, confirm this regularity, with the calculated coefficients of determination R^2 being greater (Fig. 9).

Another analysis involved an assessment of comprehensive effect of air temperature and precipitation; the analysis was carried out separately for the height and the diameter of the pine trees. It was carried out for the height classes described in the methodology part, using the method of multiple regression analysis. Its application allowed one to assess the contribution of precipitation and temperature. Adjusted coefficients of determination R^2 for these relationships were the qualitative criterion.

The results were diverse in regard to the biometric parameter. In analyses conducted for the accumulated increments of pine trees height at the end of consecutive months of the summer half-year periods, the largest R^2 – 0.4840 – was calculated for class 3, which included trees with the height ranging from 163 to 183 cm. Comparable values were obtained for the tallest trees, classified as class 5 – R^2 = 0.4769 and as class 1 – 0.4729, which included the shortest trees. In this variants of the analyses, much better results were obtained for similar relationships with the diameters measured at the root crown for class 2 as well as 4 and 5, which in-

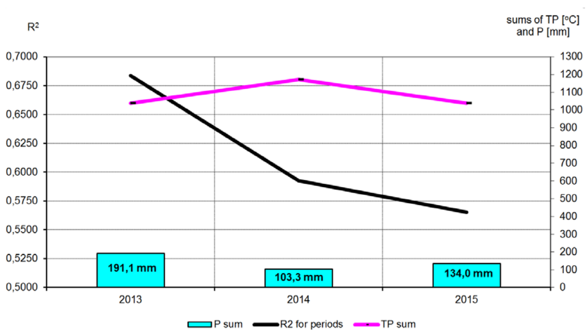

Fig. 8. The variability of atmospheric precipitation and air temperature sums and the coefficients of determination R^2 for the relationship between the height and diameter of the pines – longer periods

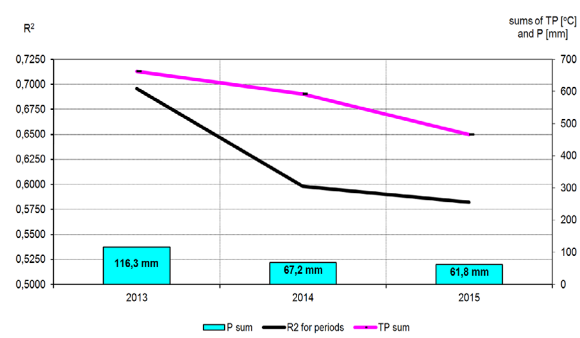

Fig. 9. The variability of atmospheric precipitation *P* [mm] and air temperature *TP* [°C] sums and the coefficients of determination R^2 for the relationship between the height and diameter of the pines – shorter periods

Table 1.The results of multiple regression: list of variables entering into equations and the values of the corrected coefficient of determination R^2

Specification	Class	Variant			
		The end of the month		The end of the summer-half year	
		hight	diameter	hight	diameter
Variables significant*)	1	P*, TP*	TP*, P*	P*, TP*	-
	2	P*, TP*	TP*, P	P*, TP*	TP*
	3	P*, TP*	P*	P*, TP*	P*
	4	P*, TP*	TP*	TP*, P*	TP*
	5	P*, TP*	TP*, P	P*, TP*	TP, P
R^2	1	0.4729	0.3288	0.8219	-
	2	0.4371	0.6913	0.6839	0.6259
	3	0.4840	0.4095	0.7414	0.3161
	4	0.4305	0.7538	0.6772	0.6267
	5	0.4769	0.6530	0.7856	0.4063

cluded trees with the height of 184 to 228 cm (Table 1). The analyses of the relationship between accumulated increments of the pine tree heights and accumulated air temperatures and precipitations at the end of a summer half-year period showed that the coefficients of determination R^2 for the height of pine trees – regardless of the class of height – were nearly twice as large as those calculated for the variant which included the monthly periods. They ranged from 0.6772 for class 4 to 0.8219 for class 1. Extending the periods of accumulation of the weather parameters decreased their values for diameters in classes 3 to 5.

The results of the regression analysis also provided the information about which of the parameters under analysis had a statistically significant effect on the measured biometric features of pine trees (Table 1).

The analyses for the variant which included monthly periods showed that those were accumulated precipitation and accumulated air temperatures, regardless of the class of trees height. Each time, the precipitation supplied more information about increments of the pine trees to the equations of regression. Identical analyses for increments of diameters in this variant of calculations indicated that except for class 3, which included pine trees with the heights ranging from 163 to 183 cm, each time the air temperature was statistically significant and the largest coefficients of partial correlation were obtained for it. In most cases, these results were confirmed by analyses carried out for the variant which included half-year periods of accumulating of precipitation and average 24-hour air temperatures.

CONCLUSIONS

These assessments and analyses indicate that there are relationships between increments of pine tree biomass and the air temperature and precipitation. A three-year period may be too short, but observations made during it and the results of the study allow for some conclusions:

1. The analyses of the starting materials in a form of the air temperature and precipitation and the relationships determined from them indicated that sums of 24-average temperatures are a better thermal parameter than just average temperature.
2. The analyses and calculations indicate a close significant relationship between the pine trees height and their diameter at the base on any measurement date.
3. Analyses of different measurement periods indicated a decrease in significance of the relationships between the height of pine trees and their diameter at the base. A decrease in these relationships is becoming more and more pronounced with the age of the trees.
4. Of the two weather parameters, i.e. total air temperature and total precipitation, the precipitation dominates in the relationship with the trees height and air temperature – with the trees diameter.

The information obtained on the relationship between the thermal conditions and precipitation and active growth of Scots pine can be useful for the scientific community and practitioners in identifying mechanisms that significantly affect the growth of Scots pine biomass.

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