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Conference Paper

Dynamics of Branch and Stem Apical Growth in the Progenies of Plus Pine Trees (*Pinus sylvestris* L.)

S. A. Shavnin[1], A. A. Montile[1], A. I. Montile[2], and D. Yu. Golikov[1]

[1]Institute Botanic Garden, Ural Branch of the Russian Academy of Sciences, 620130 Ekaterinburg, Russia
[2]Ural State Forest Engineering University, 620049 Ekaterinburg, Russia

Corresponding Author:
S. A. Shavnin
sash@botgard.uran.ru

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Abstract

The relationship between the characteristics of the linear growth of branches and stems was studied, as well as the possibility of distinguishing between various Scots pine (*Pinus sylvestris* L.) genotypes. The objects of research were experimental plantations of the half-sib progenies of pine plus trees aged 10–11 years. The annual increments of the stem and differently oriented branches were measured. Correlation, regression and data analysis methods developed by the authors were used. The time dynamics of the obtained values were studied by comparing the regression line slopes describing the interrelation of axial increments and by analysis of the frequency spectra of the Integral Parameter of Characters Sequence applied earlier. The analysis of the obtained results has shown the existence of a significant relationship between auxiblast linear growth within the two adjacent years and a weak interrelation of the characteristics of branch and stem morphogenesis. The possibility of distinguishing Scots pine half-sib families by comparing the dynamics of branches and stem apical growth is described.

Keywords: Scots pine, apical growth of branches and stems, genotypic and phenotypic variability, impact of environmental factors on growth, morphogenesis of woody plants, growth modeling

1. Introduction

The morphogenesis of woody plants, including apical and radial growth, is controlled by genome, physiological and biochemical mechanisms (redistribution of carbohydrates and hormones) and environmental factors [1–3]. At the same time, their interrelation has not been studied enough; also, branch and stem growth are usually considered separately. It is known that the activity of apical and lateral meristems during the vegetation period of Scots pine does not coincide in time: the leading ones are the apical meristems [4]. There is a sufficient number of studies of branch [5–8] and stem [9–11] growth which indicate a significant dependence on genome. As a rule, in the study of stem and branch growth the integral characteristics (height, diameter, length) are used, but their rate dynamics over several years are not considered. It should be noted that the impact of environmental factors on growth depends on climate variability over years [4, 12] and the influence of weather conditions. The reaction of plants to the impact of these factors is also under genetic control [13]. Thus, the dynamics of the growth of different *Pinus taeda L*. genotypes over several years also differs [6]. This allows us to suggest that studying the changes in branch and tree stem growth rates over a number of years will make it possible to distinguish genotypes and to assess their potential productivity, as well as to get additional information on the relationship of these growth processes during morphogenesis.

The objectives for this research were to (1) study the interrelations between characteristics of the linear growth of the axial auxiblasts of branches and stems and (2) assess the possibility of distinguishing between half-sib families in the progenies of different Scots pine plus trees with the use of these parameters.

2. Methods

The object of the study was the comparative sylvicultures of Scots pine, created in the territory of the Sysert Forest district in the 1990s (Sverdlovsk Region, Russia). Two groups of descendant families of plus trees (3 families in each) were examined. In groups 1 and 2, family numbers corresponded to the registered numbers of plus trees – 11, 1, 52 and 38, 50 and 56, respectively. Each family consists of 24–29 trees. In group 1 (the age of the trees was 10 years), the length of axial auxiblasts over 4 years (2001–2004) on branches (6 years old) of the southern, southeastern and eastern exposures were measured on each tree. In group 2 (the age of the trees was 11 years), the annual increments of branches of the southern exposition and the axial increments of the stem over the last 7 years (1999–2005) were measured on each tree. The accuracy of the measurements was 1.0 mm.

When analyzing the data obtained, the methods of cluster and regression analysis [14, 15] were used (STATISTICA v 8.0). In the analysis of phenotypic variability, we used the method of determining the frequency spectra of the Integral Parameter of Characters Sequence (IPCS, previously described as IPCMS [16]). This allows one to describe the polymorphism of plants according to the complex (in a given sequence) of characters using the series of IPCS frequency values in the groups under study.

A particular spectrum is a set of IPCS values for a set of objects. The frequencies of value occurrence in the graphic display are indicated by the gradation of color (in shades of gray). For the analysis, the informative parameters were the IPCS positional arrangement and the frequencies.

3. Results

Data analysis of axial increments of differently oriented branches in group 1, as well as of separate branches and stems in group 2, has shown a significant reliable correlation between them in two adjacent years. This indicates the influence of the processes determining one-year increments on the next year's axial growth. This dependence is observed in branches of each exposure and in their sum set. Thus the effect of orientation is not significant. The regression analysis of branch auxiblasts growth within two years (2001–2002) in group 1 confirms the existence of a linear connection between annual increments. For families 1, 11 and 52, the regression equations are: $y = 5.3739 + 0.8697 * x$ ($r = 0.882$); $y = 16.3372 + 0.448 * x$ ($r = 0.634$); $y = 5.725 + 0.8268 * x$ ($r = 0.811$), respectively ($P < 0.0001$). In the equations: y – growth for 2002, x – growth for 2001 and the coefficient at x characterizes the slope of the regression line. The relationship between the growth of both branches as stems for two adjacent years exists for each family and for the whole group. Comparison of the results of the correlation and regression analyses of axial increments of branches and stems for two adjacent years (Table 1) indicates a significant difference in their interrelationships. This is also confirmed by the absence of reliable correlation between one-year growth values of the stems and branches, and also by the absence of a nonlinear interconnection between them.

Following the assumption that growth characteristic dynamics are inheritable, a comparative analysis of the regularities of branch and tree stem growth of families in group 2 was carried out for the whole studied time interval (1999–2005). The restoration of the linear relationship between increments in two adjacent years revealed, as evidenced by a comparison of the slopes of the regression lines (Table 1), the significant differences in the growth dynamics for individual families. These data analyses also have shown that within a single period of time families can be distinguished by the use of slope coefficient values, but during some periods different families may react in the same way. Because of this, for a more correct and reliable distinguishing

Table 1: Correlation coefficients (r at $P < 0.05$) and slope coefficients of regression lines (a) for axial annual increments of branches and stems of Scots pine plus trees half-sib families in group 2.

Years	Family Number					
	38		50		56	
	r	a	r	a	r	a
Branches						
1999–2000	0.281	0.642	–	–	–	–
2000–2001	0.741	0.938	0.019	0.018	0.649	0.566
2001–2002	0.950	0.881	0.640	0.653	0.764	0.876
2002–2003	0.321	0.175	0.625	0.643	0.833	0.724
2003–2004	0.600	0.591	0.761	0.614	0.773	0.683
2004–2005	0.751	0.745	0.791	0.316	0.722	0.620
Stem						
1999–2000	0.778	0.519	0.671	0.372	0.776	0.731
2000–2001	0.825	0.790	0.650	0.861	0.765	1.004
2001–2002	0.562	0.443	0.706	0.485	0.790	0.871
2002–2003	0.489	0.590	0.476	0.755	0.741	0.752
2003–2004	0.378	0.337	0.407	0.487	0.455	0.453
2004–2005	0.562	0.568	0.679	0.473	0.472	0.468
Source: Authors' own work.						

between families it is necessary to analyze the dynamics of changes in axial increments over a period longer than two years. For the trees from one family, the coefficients significantly 'coincide' for all or almost all pairs of years in the selected period. It should be noted that the parameters related to the specific heredity are not annual increments of the branches or stems, but the characteristics of the dynamics of their changes, described by the slope angle of the regression line.

In addition to the approach described, a new method for analyzing the dynamics of growth characteristics, based on the determination of IPCS spectra, was used to distinguish individual families. To characterize the half-sib families, samples consisting of trees from an individual family (3 samples, 9 trees with mismatched numbers in each) were used. The characters used annual axial increments of branches or stems for the studied period of time. During the intermediate analysis of data, the identifiers of the resulting IPCS were established as branch increments of recent years, and for the stems – increments at the beginning of measurement period. The final analysis has shown that the IPCS frequency spectra for axial increments of branches and stems do not coincide both with respect to the arrangement of lines in the spectra and to the sequences of samples from individual families. The latter were established after calculations and are shown on the horizontal axis of Figure 1. It should be noted that the number of lines in the spectra corresponds to the number of characters (annual increments).

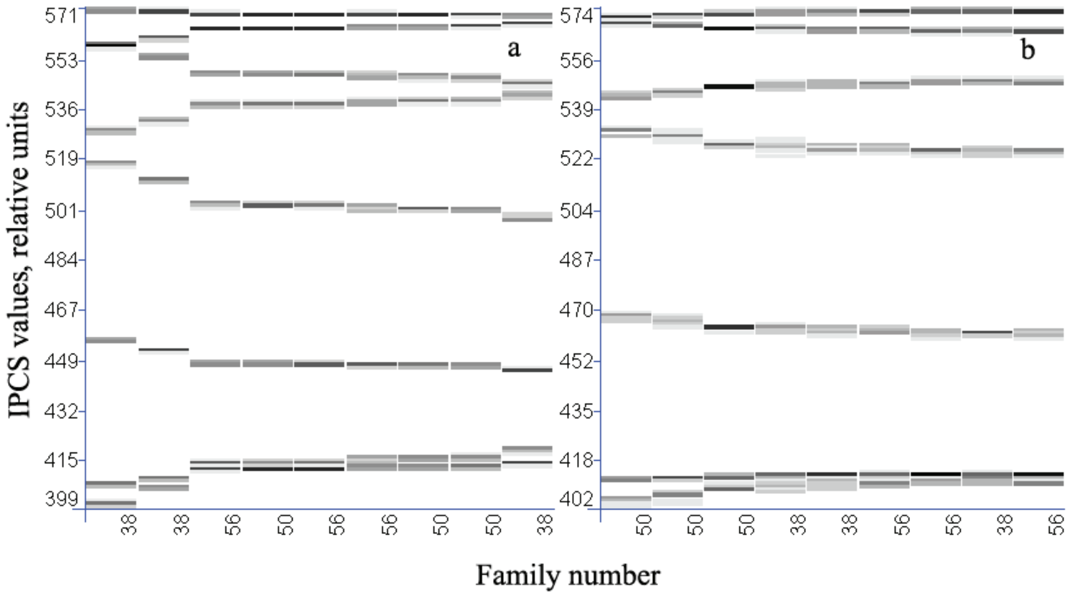

Figure 1: IPCS frequency spectra (higher frequency values are darker) of samples taken from families of group 2 (numbers 38, 50 and 56), calculated according to the annual axial increments values of the stems (a) and branches (b). Source: Authors' own work.

The position of the line (the value of IPCS) and the frequency (line color intensity) characterize the individual manifestation of a particular character in the sample. The compact arrangement of samples from one family in the sequence indicates a relatively low variability of growth characteristics in the family. In this case, the spectra obtained by processing data about branches (Figure 1(b)), in comparison with the spectra for stems (Figure 1(a)), show a more reliable distinction of families. Thus families 50 and 56 are maximally separated in the sequence of samples from each other and only a small mix of samples from families 56 and 38 is observed. The comparison of branch and stem axial increment values with the use of the IPCS frequency spectra revealed their essential difference, which is corresponds to the conclusion obtained after correlation and regression analyses, that the growth processes of branches and stems differ.

4. Conclusion

The analysis of the results obtained from the study of auxiblast axial growth of Scots pine trees allows us to conclude that there is a linear relationship between the apical growth of both branches and stems for two adjacent years. It is also revealed that despite the existence of the same patterns in the morphogenesis of the stems and branches, the relationship between their annual increments is weak. It has been established that to distinguish half-sib families from the plus trees' progeny is more effective not to use the absolute values of growth characteristics but rather their dynamics over several years. To describe the latter, coefficients of the regression equations of the interconnection of axial annual increments of both branches and stems can be used, as well as the new independent approach – comparative analysis of the frequency spectra of the Integral Parameter of the Characters Sequence values, calculated for a set of families.

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References

[1] Kozlowski, T. T. and Pallardy, St. G. (1997). *Growth Control in Woody Plants*. Academic Press.

[2] Pallardy, St. G. (2008). *Physiology of Woody Plants* (third edition). Academic Press.

[3] Zimmerman, M. H. and Brown, C. L. (1971). *Trees: Structure and Function*. Berlin: Springer-Verlag.

[4] Pietarinen, I., Kanninen, M., Hari, P., et al. (1982). A simulation model for daily growth of shoots, needles, and stem diameter in Scots pine trees (*Pinus sylvestris*). *Forest Science*, vol. 28, no. 3, pp. 573–581.

[5] Wang, Q., Little, C. H. A., and Oden, P. C. (1997). Control of longitudinal and cambial growth by Gibberellins and Indole-3-Acetic acid in current year shoots of *Pinus sylvestris*. *Tree Physiology*, vol. 17, pp. 715–721.

[6] Quesada, T., Parisi, L. M., Huber, D. A., et al. (2017). Genetic control of growth and shoot phenology in Juvenile Loblolly Pine (*Pinus taeda* L.) clonal trials. *Tree Genetics and Genomes*, vol. 13, no. 65, pp. 1–15.

[7] Isik, F., Isik, K., Yildirim, T., et al. (2002). Annual shoot growth components related to growth of *Pinus brutia*. *Tree Physiology*, vol. 22, pp. 51– 58.

[8] Clair, J. B. St. (1994). Genetic variation in tree structure and its relation to size in Douglas-Fir. II. crown form, branch characters, and foliage characters. *Canadian*

Journal of Forest Research, vol. 24, no. 6, pp. 1236–1247.

[9] Emhart, V. I., Martin, T. A., White, T. L., et al. (2006). Genetic variation in basal area increment phenology and its correlation with growth rate in loblolly and slash pine families and clones. *Canadian Journal of Forest Research*, vol. 36, pp. 961–971.

[10] Gwaze, D. P., Bridgwater, F. E., Byram, T. D. et al. (2001). Genetic parameter estimates for growth and wood density in loblolly pine (*Pinus taeda* L.). *International Journal of Forest Genetics*, vol. 8, pp. 47–55.

[11] Clair, J. B. St. (1994). Genetic variation in tree structure and its relation to size in Douglas-Fir. I. biomass partitioning, foliage efficiency, stem form, and wood density. *Canadian Journal of Forest Research*, vol. 24, no. 6. pp. 1226–1235.

[12] Gavrikov, V. L. and Sekretenko, O. P. (1996). Shoot-based three-dimensional model of young Scots pine growth. *Ecological Modelling*, vol. 88, no. 1–3, pp. 183–193.

[13] Almeida, M., Graner, E. M., Brondani, G. E., et al. (2015). Plant morphogenesis: Theoretical bases. *Advances in Forestry Science*, vol. 2, no. 1, pp. 13–22.

[14] Rencher, A. C. and Christensen, W. F. (2012). *Methods of Multivariate Analysis. 3-Rd Ed.* New Jersey: John Wiley & Sons, Inc.

[15] Gan, G., Ma, Ch. and Wu, J. (2007). *Data Clustering: Theory, Algorithms, and Applications*. Alexandria, Philadelphia: ASA-SIAM. 2007.

[16] Neuimin, S. I., Shavnin, S. A., Montile, A. A., et al. (2016). Variability of characters in reproductive organs of three taxa within *Agropyron* Gaertn.: Mathematical analysis. Skvortsovia, vol. 3. no. 1, pp. 4–19.