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# STUDY OF THE TREE SPECIES EFFECT ON THE SOIL BY MEANS OF DISCRIMINANT ANALYSIS

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A multi-sided study of the interactions between forest and soil requires choosing sample plots in such a way when their soil characteristics are as similar as possible but the types of biocoenoses are different. This study employed materials from the database “Soils of Karelia”, which has pooled together long-term data on soils of the Republic of Karelia. The aim of the analysis was to identify the soil traits that are the most sensitive to the type of biocoenosis. The biocoenoses chosen for the analysis were automorphic pine, spruce and birch communities, collectively accounting for 99 % of forest stands in Karelia, growing on podzolic-type Al-Fe-humus soils with sandy texture over sandy or loamy-sand till, which represent the most widespread type of soils in the study area. The analysis was performed for the following soil horizons: forest floor (O), eluvial (E) and illuvial (B). In order to characterize the soil horizons the physico-chemical parameters were used: pH (KCl), total C and N content, labile $P_2O_5$ and $K_2O$ compounds content, and gross content of $SiO_2$, $TiO_2$, $Al_2O_3$, $Fe_2O_3$, MnO, MgO, CaO, $Na_2O$, $K_2O$, $P_2O_5$. Discriminant analysis was employed to determine the traits contributing the most to the differentiation of biocoenosis types. The contribution of the traits to differentiation between groups was measured by Wilks’ lambda. Overall, the analysis has shown that N and C content the most significantly reflect the changes happening under the effect of the forest, both in the organic and in the mineral parts of the soil, as corroborated by the findings of numerous Russian and foreign researchers.

*Keywords*: forest type effect on soil, database, statistical methods.

## INTRODUCTION

The issue of forest effect on soil remains relevant since the time V.V. Dokuchaev, who placed the biological factor on a par with other factors of soil formation, raised it and since the time of the subsequent work of academic V.R. Williams. In the USSR the systematic approach to the problem intensified in the 50–60s of the last century (Zonn, 1954, Remezov, 1962; Shumakov, 1963; Zaitsev, 1964), and even caused a lively debate reflected in periodicals (Remezov, 1953; Zonn, 1954; Rode, 1954). The foreign scientists paid the same a lot of attention to the issue (Ovington, 1954; Kittredge, 1955; Bonnevie-Svendsen, Gjems, 1957). Since the question arose, its study certainly seemed impossible without specifying the wood type and, therefore, to some extend is reduced to the particular influence of specific tree types on soil properties. The researchers note that a huge variety of trees and forest soils are closely related to each other: the development of various tree stand types depends on soil properties which, in turns, are affected by tree cultures. The concepts such as habitat conditions, as well as forest and the biogeocoenose (BGC) often overlap in the literature, so there are conventionally adopted hierarchical (genus-species) relationships between them. Forests and soil interconnections are a constant research topic not only in forestry and soil science. Theoretical and applied aspects of these interconnections are very important in ecology, forest melioration, agriculture and soil protection from erosion and desertification. Both the role of vast forests, shelterbelts, roadsides and even individual trees and windfalls is studied. Water protection role of forests determines hydrological conditions of land use and human habitation. Water protection forest belts optimize the situation in spawning streams.

The whole issue of forest effect on soil can be roughly broken down to several components. One of the main influencing components is the fall which is peculiar for each tree species (Remezov et al., 1959; Rodin, Bazilevich, 1965; Bykovskaya, Evdokimova, 1976; Morozova, 1991). Another integral effect is changing chemical and physico-chemical properties of precipitation passing through the canopy of wood species or leaking on its trunk (Mina, 1967; Karpachevsky et al., 1998; Shiltsova, Swallow, 2006; Pristova, Zaboeva, 2007; Archegova, Kuznetsova, 2011). Next is *root system – soil* interaction: nutritive elements consumption, breathing and root disintegrate properties (Materechera et al., 1992; Angers, Caron, 1998). As a further component one can add a change of lighting, thermal and hydrological regimes under the crowns influence, etc. (Molchanov, 1973; Karpachevsky, 1981; Youssef, Chino, 1984; Augusto et al,. 2002). Apart from the impact of tree stand itself the plants of above-soil layer also participate into the process, accompanying each tree type, they make a contribution to the fall, to the bedding tillage and affect the hydrothermal regime (Ramenskii, 1971; Légaré et al., 1971; Helliwell, 1974). Soil microflora and fauna, which type and quantity are also dependent on the type of wood vegetation and directly affect the rate of litter decomposition and, accordingly, organic matter income in mineral soil part (Gavrilov, 1950; Perel, 1958; Petersen, Luxton, 1982; Cortez, 1998; Menyailo, 2007, 2009). We can continue to list the ways how forest and soil interact.

Some studies consider this issue as a mosaic-like view of forest communities, narrowing the object of study in a particular wood type to elementary soil areas with the most homogeneous soils (Fridland, 1986) or cenobiotic microgroups with the same vegetation type (Ramenskii, 1971), as well as to their combinations, called parcel and tessera (Jenny, 1958; Dylis, 1969; Karpachevsky, 1977; Lukina et al., 2010).

Despite the fact that forest impact on soil is quite easy to detect as well as to evaluate the impact force of a particular component, the main problem is a difficult forecast of the impact and its force on a prolonged period or other similar forest area. This difficulty is a result of the fact that each of the listed components of forest influence on soil is interconnected in a cascade manner with the other and represents a multifactorial non-linear function that varies greatly both in space and in time. Nevertheless, there are a number of successful attempts to model forest-soil interactions (Smith et al., 1997; Chertov et al., 2007).

There are several approaches to the comprehensive study of the question of wood influence on soil. One way is to lay down trial areas on similar adjacent plots with different tree cultures planting on it (Shugalei, 1979; Menyailo et al., 2007; Gurmesa et al., 2013). In the foreign literature this approach is known as *common garden experiments*. The main advantage of this approach is the ability to separate the effects of wood stands from other soil-forming factors. Most often the selected plots have previously been under agricultural crops but there are some experiments to start the trial on a completely artificial soil construct. A drawback of the method lies in the fact that artificially created conditions often involve the impact of previous agricultural activities which also should be considered (Hagen-Thorn et al., 2004). All the changes observed in these conditions will manifest themselves more acutely than in the wild where the growth and the nutrients metabolism are slower. Another important limitation is a small size of the population for global conclusions. When all the repetitions are unified in the frames of one habitat it is statistically supposed a single measurement. The obtained results of the species influence may be present or absent in a natural habitat (Binkley, Fisher, 2013).

Another most common approach to the study of forest type impact on soils is the selection of test areas with similar soil characteristics but different in biocenosis type (Fröberg et al., 2011; Hansson et al., 2011). The obvious benefit of this approach is all the typical advantages of object studying *in situ*. The main disadvantages are the unaccounted initial differences in soil properties, their position in the topography, geomorphologic and climatic differences, etc., which may influence the result and make it difficult to interpret (Binkley, 1998).

Partial solution to these difficulties can be a careful selection of trial plots with a maximum similarity in large number of features. Such selection is possible when there are data on soil and forests properties resulting from large environmental studies, e.g., ICP Forest (Lukina et al., 2013), or while yearly research data are collected into single database. Both in Russia and abroad in recent decades it is getting an urgent task to create soil databases of various sizes – from international to local ones, covering one or more objects of study (Jamagne et al., 2004; Shi et al., 2004; Kolesnikova et al., 2010; Rozhkov et al., 2010;

Novikov, 2017). Large amounts of data enable statistical processing of research materials and evaluation of the results reliability.

## MATERIALS AND METHODS

In this study we used materials of "Soils of Karelia" database, which pool together the long-term data of the soil studies in Karelia (Solodovnikov, 2011). The aim of the study was to determine the soil characteristics which are the most exposed to biocenosis type. Sampling was carried out among the data obtained by the same analysis methods (Arinushkina, 1961; Sokolov, 1975) with the data collected before 2007. For the analysis we chose automorphic pine, spruce and birch biocenosis, collectively forming 99 % of Karelia forest plants growing on alfehumus soils, podzolic type, granulameter composition on the sand or loam moraine, which are the most common soils in the study area. Given the geographic extension of the republic, the materials relating only to the middle taiga subzone were used. Since the influence of forest type is stronger in the upper part of the profile, the following horizons were chosen for the analyses – forest floor (O), eluvial horizon (E) and the following illuvial horizon C (B). In the view of transient horizons and subhorizons selected for analysis we standardized horizon names according to humus content selected as the criterion (Belousova, Meshalkina, 2009).

The resulting selection from the database checked all the signs for compliance with normal distribution both for the whole selection and for each type of BGC separately. The problem of recognition of the values by emissions was solved individually for each value. In many cases the emissions were removed. There were values recognized as typos to which we mostly applied a decrease/increase in grade. If in the line of values there were more than 2–3 emissions we removed the entire line. Another major problem of the database is that a large proportion of their records does not contain the full set of indicators, which makes their statistical processing problematic. In our study we gave up processing of the records relating to the most numerous pine BGC. In the case of small records relating to the spruce and birch

BGC, missing values were replaced with the average on BGC ones (Little, Rubin, 2014). Despite the relatively large volume of the source data, the obtained result selection BGC for pine (n = 11), spruce (n = 5) and birch (n = 7) was too small for direct comparisons of attributes content under various tree stands due to great dispersion data.

Discriminant analysis was used for the analysis of the resulting data set, designed to determine which features are clearly distinctive for object groups. For data processing we used Statistica package (Khalafyan, 2007). The necessary conditions for discriminant analysis are the following: at least two groups of objects; at least 2 objects in each group; k the number of parameters must match k < (n − 2), where n – the total number of objects; the parameters to be measured according to the interval scale and be normally distributed within each group (Klecka, 1980). However, when using this type of analysis, it is recommended, if possible, have the volume of selection more than 10 times greater than the number of parameters, and the number of objects in each group should exceed the number of parameters.

BGC type acted as a grouping factor and the signs were represented by physico-chemical parameters of soil horizon: pH (KCl), total content of C and N, content of labile compounds of $P_2O_5$ and $K_2O$, the gross content of $SiO_2$, $TiO_2$, $Al_2O_3$, $Fe_2O_3$, MnO, MgO, CaO, $Na_2O$, $K_2O$, $P_2O_5$. Fair to assume that the indicators that greatly contribute to the separation of BGC types are the indicators that are most exposed to the influence of the dominant tree stand. Since the roots of the discriminant function show contribution of the properties to the division of only two out of three groups, the evaluation of attributes contribution into the division of all groups was carried out by Wilkes statistics. "Partial Lambda" value (λ) describes the contribution of a single property to the dividing model force and the lower the value the greater the property contribution to the overall discrimination.

## RESULTS AND DISCUSSION

The result of data analysis relating to the litter was the diagram of spreading in two roots of the discriminant function (Fig. 1), which clearly shows the data division into groups on matching the BGC types.

The first discriminant function explains 93 % of the total dispersion. The Mahalanobis squares of distances between the centroids of pine/fir, fir/birch and birch/pine groups account respectively 344 (p = 0.003), 41 (p = 0.26) and 352 (p = 0.001), where p – a magnitude of differences. Despite the visual difference between the groups of fir and birch BGC, a weak significance is, probably, due to the great dispersion of the index in fir BGC at small data selection set. According to Wilkes statistics the greatest contribution to the group separation is done by C ($\lambda$ = 0.17, p = 0.013), $K_2O$ ($\lambda$ = 0.22, p = 0.022), pH (KCl) ($\lambda$ = 0.29, p = 0.044) N ($\lambda$ = 0.35, p = 0.071).

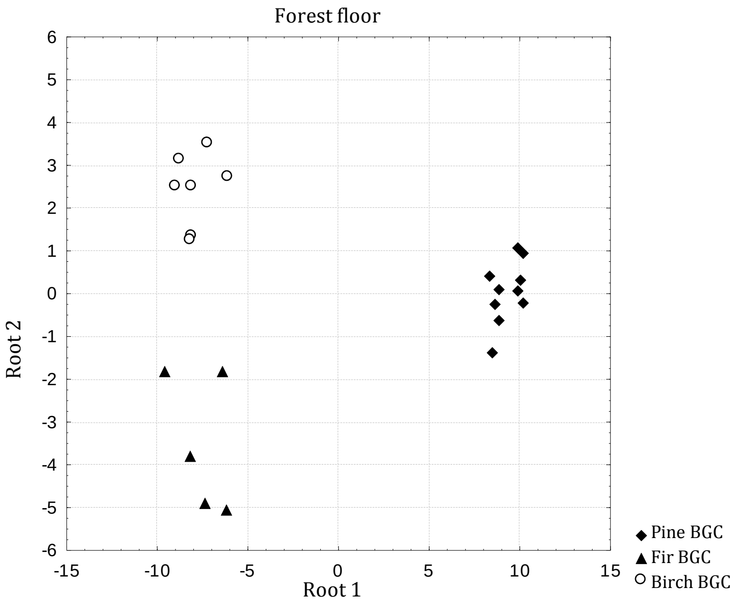


**Fig. 1**. BGC group position in root space of discriminant function of litter parameters.

Nitrogen is a key and most sensitive to the forest type fertility indicator. Some foreign authors (Binkley, 1995; Prescott, 2002) believe that soil enrichment with nitrogen is a result of symbiotic link between tree types and nitrogen-fixing funghi. Research in Karelia (Fedorets, Bakhmet, 2003) have shown that a forest type is mainly due to ammonia nitrogen content which is a result of ammonifiers in the litter, while the total nitrogen content is closely related to soil organic matter. Razgulin (Razgulin, 2008) in his article states that the annual productivity of nitrogen mineralization is greater in deciduous forests than in coniferous. According to the model experiment in Siberia (Menyailo, 2009) it can be concluded that the activity of nitrogen mineralization under the birch is higher than under the pine, which, in turn, exceeds that for the fir. In Sweden, in the study of soils under the pine, fir and birch forests, it was concluded that nitrogen, carbon and exchangeable potassium pools in the litter are in greater amount under fir forests than under birch ones, while pine forests occupy the intermediate position (Hansson et al., 2011; Hansson et al., 2013). These differences are the biggest in litter and significantly lower in soil mineral part. The authors explain the results by differences in litter acidity at different tree stands and, consequently, the differences in the amount of micro fauna affecting the litter decomposition rate, which is supported by researchers from Poland (Błońska et al., 2016). Vesterdal L. (Vesterdal et al., 2007) considers that carbon distribution between litter and soil mineral part more clearly reflects the influence of wood type rather than common carbon reserve. In the studies in the U.S. Binkley, Sollins (Binkley, Sollins, 1990) assert that the differences in soil pH are noticeable only in aqueous solution and insignificantly – in saline one. In addition, Binkley, Fisher (Binkley, Fisher, 2013) argue that soil acidity under different forest types depends primarily on the strength and the degree of dissociation of soil acids, and these both factors, varying, can reduce the impact of forest type on soil acidity.

In the scatter diagram of the data relating to the horizon E (Fig. 2) it is also observed the data separation into groups on BGC types matching.

The first discriminant function explains 64 % of the total dispersion. The Mahalanobis squares of distances between the centroids of pine/fir, fir/birch and birch/pine groups amounted to 124, 176 and 83. The significance of differences between groups is 0.068, 0.045 and 0.087 respectively. According to Wilkes statistics, the largest contribution to group division is made by N ($\lambda = 0.36$, $p = 0.127$), $Fe_2O_3$ ($\lambda = 0.38$, $p = 0.146$), CaO ($\lambda = 0.39$, $p = 0.153$), $Na_2O$ ($\lambda = 0.43$, $p = 0.188$).

The result of the horizon B analysis is shown at the scatter diagram (Fig. 3). The first discriminant function explains 66 % of the total dispersion. The Mahalanobis squares of distances between the centroids of pine/fir, fir/birch and birch/pine groups amount to 94, 82 and 49. The magnitude of differences between groups is 0.022, 0.059 and 0.066 respectively.

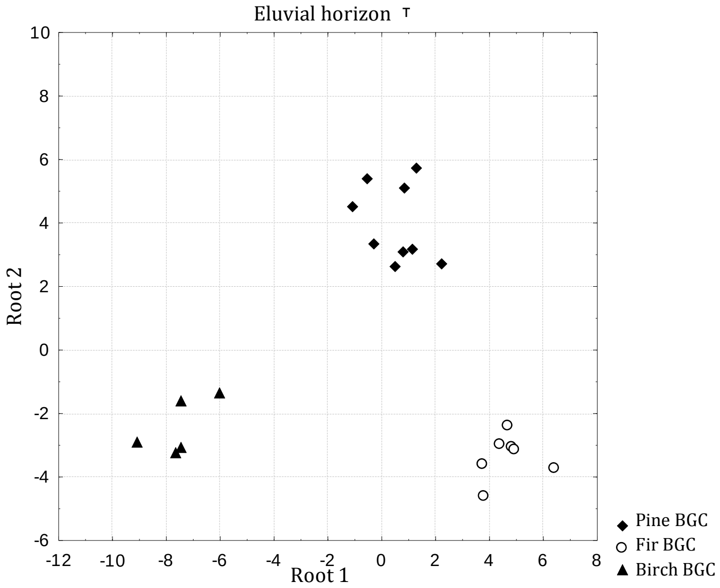


**Fig. 2**. BGC group position in root space of discriminant function of eluvial horizon indicators.

According Wilkes statistics, the largest contribution to the separation of groups is made by C ($\lambda$ = 0.36, p = 0.046), MnO ($\lambda$ = 0.38, p = 0.053), N ($\lambda$ = 0.52, p = 0.145) and labile compounds of $K_2O$ ($\lambda$ = 0.59, p = 0.204).

According to the results it is evident that a majority of highlighted properties for soil mineral part have a weak significance, except for C and MnO. Research in Sweden has shown that soil mineral part contains considerably larger reserves of exchange Na under the fir rather than under the birch tree, and intermediate values –

under the pine tree. Ca exchange values were higher under the fir but not significant. $K_2O$ exchange values under the birch tree were more than under the pine and the fir (Hansson et al., 2011). $Fe_2O_3$ and MnO stocks in a 70-cm layer were smaller under the birch than under the coniferous that coincides with the findings made by Bergkvist, Folkeson (Bergkvist, Folkeson, 1995).

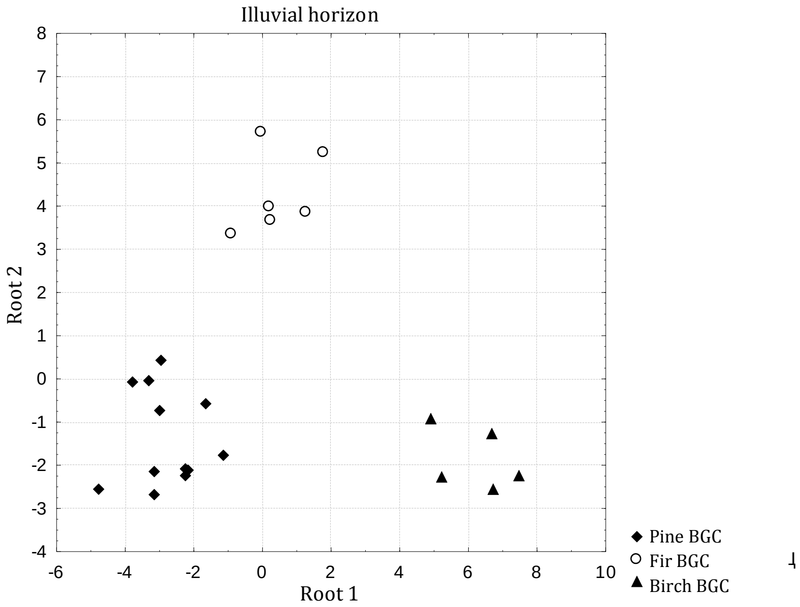


**Fig. 3.** BGC group position in root space of discriminant function of illuvial horizon indicators.

## CONCLUSIONS

Overall, the analysis has shown that greater influence of tree stand type, predictably, falls on the forest floor rather than on the mineral horizons. The published data often demonstrate a significant difference in the content of C, N, $K_2O$ and pH under various biocenosis types, while N and C content best reflects changes occurring under the influence of forests, both in organic and mineral soil part, which is indirectly supported by numerous findings of foreign and Russian

(USSR) scientists. Na, Ca, Fe, Mn content, apparently, depends on the specific composition of the litter of the tree stand species selected for analysis, and the characteristics of their interaction with soil rhizosphere. The calculation results do not contradict the published data, which suggests the successful application of discriminant analysis for this area.

Further similar investigations require purposeful database creation with a large number of records. The parameters and their number in each record should be carefully chosen, that is determined by the purpose of database creation. Each record should be carried out with a thorough inspection of each parameter on the possible error, since an increase in the database leads to greater probability of errors. Uniformity of database content is, undoubtly, an essential condition for the subsequent work with it.

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