ECOLOGIA BALKANICA
2024, Vol. 16, Issue 1 June 2024 pp. 140-148

# Study of soils in mountain ecosystems in Yundola, Bulgaria

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**Abstract.** The productivity of forest plantations depends directly on the soil's ability to meet the specific requirements of each tree species. Soil fertility is a determining factor in the existence, development, and normal functioning of forest ecosystems. Natural coniferous forests in mountain ecosystems are a particularly important part of Bulgaria's forest resources. They are of great economic importance, but also have protective functions. The purpose of this study is to examine the characteristics of the main soil types in natural mountain ecosystems in Yundola, Bulgaria. The object of this study is the most widely distributed soils in Bulgaria's natural mountain ecosystems. These are Dystric-Eutric Cambisols, Umbric Cambisols and Modic Cambisols, which belong to the class of metamorphic soils (Cambisols). Statistical analysis of the results revealed statistically significant differences in soil organic matter content, C:N ratio, and pH among the three studies soil types, which were consistent with changes in altitude.

**Key words:** soil organic matter, C:N ratio, pH, Cambisols.

## Introduction

Soil is among the most significant natural resources that performs essential functions for the environment, including supporting plant and animal life, regulating water flow, storing water, filtering pollutants, and cycling nutrients. The quality of soil largely determines food quality, which is directly related to a country's economy and the health of its population (Naydenov & Aleksandrov, 2020; Bogdanov, 2022a).

The productivity of forest plantations depends directly on the ability of the soil to meet the specific requirements of each tree species. Soil fertility is a critical determinant of the existence, development, and normal functioning of forest ecosystems. This highlights the need for research on soil composition and properties in order to generate the required information for sound planning and sustainable management of forest resources (Bogdanov, 2022b).

Natural, primarily coniferous forests in mountain ecosystems are a particularly important part of a country's forest resources. Their economic importance is determined primarily by their protective functions, rather than by the production of wood and non-timber products. These forests also play a significant role in shaping and stabilizing the environment, which exceeds their resource potential (Naydenov & Alexandrov, 2020; Glogov, 2022; Velizarova, 2008).

Natural forests of mountain ecosystems in Bulgaria are dominated by pure and mixed stands of *Quercus petraea* (Mattuschka) Liebl., *Fagus sylvatica* L., *Pinus nigra* Arn., *Pinus sylvestris* L., *Abies alba* Mill., *Picea abies* (L.) H. Karst., *Pinus peuce* Gris., *Pinus heldreichii* Christ. and *Pinus mugo* Turra) (Alexandrov et al., 1988).

Metamorphic soils (Cambisols class) are typical mountain soils of the country. Their typical diagnostic feature is a well-developed and thick metamorphic cambic B horizon, which may be absent if the A horizon is thicker than 25 cm. Other characteristics of this soil class include the absence of textural differentiation along the profile, dark colours in the surface horizon, medium to light soil texture, pronounced stoniness and water permeability, and the presence of rocks throughout the profile (Penkov et al., 1992).

Dystric-Eutric Cambisols are the most widespread soil type in the mountainous regions of Bulgaria, occupying the zone between 500 and 1800 m above sea level (Malinova et al., 2022; Pavlov, 2018). Their characteristics are similar to those of Cambisols in the World Reference Soil Resources (IUSS, 2022). Dystric and Eutric are the main qualifiers for this soil type at the next lower taxonomic level under the same classification.

Umbric Cambisols are placed in the high mountain zone between 1500 and 2500 m above sea level and have the following main diagnostic characteristics: a humus-accumulative A horizon with a thickness of more than 30 cm, which is diagnostic for Umbric; another powerful transitional metamorphic B horizon; a ratio of the thickness of the B horizon to the A horizon of 0.5 to 1; absence of hydromorphic features to a depth of 50 cm (Bogdanov, 2022a). These characteristics correspond to the Umbrisols soil group in the International Reference Base for Soil Resources, as cambic is the main qualifier for these soils at the next, lower taxonomic level (IUSS, 2022).

Modic Cambisols are widespread above the upper forest boundary in most of the high-mountain forest zone (Penkov et al., 1992). Their characteristics are similar to those of the soil group Umbrisols and the main qualifier Haplic in the International Reference Base for Soil Resources (Bogdanov, 2022a).

The aim of this study is to examine the characteristics of the main soil types in natural mountain ecosystems in Yundola, Bulgaria.

**Materials and Methods**

The object of this study are the most widely distributed soils in Bulgaria's natural mountain ecosystems considering Yundola area. The classification of Penkov et al. (1992) was used to determine the soil types. In this classification the names of the soil types are given in Bulgarian and in English according to the compiled classification. These are Dystric-Eutric Cambisols, Umbric Cambisols and Modic Cambisols, which belong to the class of metamorphic soils (Cambisols) (Penkov et al., 1992). They were studied on the territory of the Yundola Training and Experimental Forestry. According to the forest-vegetation zoning of Bulgaria (Zahariev, 1979), the study area falls within the middle forest belt (700-2000 m a.s.l.) of the Thracian Forest vegetation zone.

The classification of plant communities in the sample plots is based on the works of Dimitrov (2022) and Roussakova (2000).

Twenty-five soil samples have been taken from a total of three soil profiles in five-year dynamics. The following methods were used to analyse the soil samples:

- Soil organic matter (SOM, %) by the modified method of Turin (Filcheva & Tsadilas, 2002);
- Total N (%) content, with a modified version of the classic Kjeldahl method (ISO 11261:2002);
- $P_2O_5$ (mg.100g$^{-1}$) – extraction with Ammonium Acetate and Calcium Lactate-pH 4.2 (UV-VIS spectrophotometer Perkin Elmer Lambda 5) (Ivanov, 1984);
- $K_2O$ (mg.100g$^{-1}$) – extraction with Ammonium Acetate and Calcium Lactate-pH 4.2 (Flame photometer Jenway php 7), (Ivanov, 1984);
- C:N ratio – calculation method;
- Soil acidity (pH in water extraction) – measured potentiometric;
- Plant available water capacity (PAWC, mm), by a laboratory method, with the calculation of field capacity and permanent wilting point (Bogdanov, 2023).

The results of the soil properties study were statistically analysed using StatSoft Statistica 12 and SPSS programs at significance thresholds 95%. Mean, minimum (Min) and maximum (Max) values, standard deviation (SD) and coefficient of variation (CV) were determined. LSD Post-Hoc analysis (IBM SPSS 26.0 for Mac) was applied to prove statistically significant differences between indicators in individual sample areas. A significance level of $p < 0.05$ was chosen.

**Results and Discussion**

In order to investigate the soil properties, three representative sample plots (SP) were defined: SP-1 is Dystric-Eutric Cambisols, according Penkov's classification (Penkov et al., 1992); SP-2 is Umbric Cambisols, according Penkov's classification (Penkov et al., 1992); SP-3 is Modic Cambisols according Penkov's classification (Penkov et al., 1992) (Table 1).

The results of the studied soil parameters of each sample plot are presented in Table 2.

**Table 1.** Sample plots data.

| Sample plot | Geographic coordinates | Altitude, m | Soil type by Penkov et al. (1992) | Plant communities |
|---|---|---|---|---|
| SP-1 | 42°07'01.528'' N 23°83'13.027'' E | 1600 | Dystric-Eutric Cambisols | Community *Pinus sylvestris* + *Abies alba*, SubAl. *Abieti-Piceenion* Br.-Bl. in Br.-Bl., Sissingh et Vlieger 1939, Al. *Piceion abietis* Pawlowski in Pawlowski, Sokolowski et Walisch 1928, Ord. *Piceetalia excelsae* Pawlowski in Pawlowski, Sokolowski et Walisch 1928, Cl. *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl., Sissingh et Vlieger 1939 |
| SP-2 | 42°08'84.926'' N 23°80'22.933'' E | 1750 | Umbric Cambisols | *Picea abies* community, Al. *Piceion abietis* Pawlowski in Pawlowski, Sokolowski et Walisch 1928, Ord. *Piceetalia excelsae* Pawlowski in Pawlowski, Sokolowski et Walisch 1928, Cl. *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl., Sissingh et Vlieger 1939 |
| SP-3 | 42°12'24.436'' N 23°78'70.466'' E | 1900 | Modic Cambisols | Ass. *Lerchenfeldio flexuosae-Pinetum mugo cetrarietosum islandicae* Roussakova 2000, Al. *Pinion mugo* Pawłowski in Pawłowski et al. 1928, *Junipero-Pinetalia mugo Boşcaiu* 1971, Cl. *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl., Sissingh et Vlieger 1939 |

***SP-1. Dystric-Eutric Cambisols***

The climate in which these soils have been formed is characterized as moderately cool and humid, with high air humidity and moderate temperature fluctuations. Winters are relatively long and have a thick snow cover. The average annual temperature ranges from 4°C to 10°C, and the average annual precipitation exceeds 600-700 mm, with a distribution that is mostly characteristic of a continental climate (Sabev & Stanev, 1963; Topliyski, 2006).

Dystric-Eutric Cambisols form entirely under the influence of woody vegetation, with pure and mixed coniferous forests of *Pinus sylvestris* L, *Abies alba* Mill., and *Picea abies* (L.) H. Karst., playing an important role in the pedogenesis of the studied soils.

Relief significantly influences the formation and distribution of various varieties of these soils in this mountainous area with gentle and steep slopes of varying exposure. Assuming relatively similar characteristics of the other main factors of soil formation (climate, vegetation, and basic rock), as well as the similarity of two other relief elements (elevation and slope), exposure is the factor that determines hydrothermal conditions. Hydrothermal conditions determine the specificity of organic matter transformation, the direction and speed of biochemical reactions, the amount and composition of soil microflora, which directly or indirectly affect the forest-growing properties of the soil and the productivity of forest plantations (Bogdanov, 2022b). In this case, the studied brown forest soils are formed in shaded areas, a prerequisite for their high fertility.

The soil-forming rocks are mainly light, eluvial and deluvial weathered acidic rocks - granite, syenite and gneisses. Carbonate rocks are thought to play a minor role in the pedogenesis of these soils (Penkov et al., 1992).

The main elementary soil-forming processes are humification, acidification, and weak translocation of newly formed products along the profile. Hydrolytic decomposition of primary minerals leads to slow clay formation of the profile without translocation of products into depth. Due to the acidic reaction and relatively low temperatures, clay formation is weak, and the synthesized clay minerals are mainly kaolinite. Some of the sesquioxides formed during the hydrolytic decomposition of primary minerals remain free and coat soil particles, giving the soil a characteristic brown colour (Penkov et al., 1992).

The soil profile is poorly differentiated in terms of soil texture. Its morphological structure is expressed by the formula OABCD. Plant litter (O-horizon) is of transitional type (Moder), with a thickness of 7 to 10 cm and two subhorizons are distinguished in it. The first consists of undecomposed and semi-decomposed plant residues, the second consists of amorphous humic substances in the process of mineralization. The formation of this type of plant litter contributes to the fertility of brown forest soils (Bogdanov, 2022a).

The humus-accumulative A horizon is 24-30 cm thick and has a darker brown colour and a crumbly-granular structure, corresponding to its higher soil organic matter content. The transitional metamorphic B horizon is lighter in colour, has a nutty structure, and is significantly thicker, at 85-100 cm. The C horizon consists of bedrock that has weathered into smaller particles, between which tree roots can grow. The D horizon is the underlying solid bedrock, which has not been affected by weathering or soil formation processes. The transition between horizons is generally gradual.

The B-to-A horizon thickness ratio is a characteristic diagnostic feature of brown forest soils, with a typical value of 3 or greater. Penkov et al. (1992) observed a tendency for the B horizon to become thinner and the A horizon to become thicker with increasing altitude.

The average soil organic matter content in the A horizon of the studied soils is 8.30%, which decreases sharply to approximately 1.49% in the transitional metamorphic B horizon (Table 2). This, combined with the significantly lower thickness of the A horizon, results in relatively low humus reserves, not exceeding 330 t/ha.

A higher soil organic matter content in the A horizon favors the formation of a more stable dry granular structure, with better water resistance of structural aggregates. The low content of soil organic matter in the transitional metamorphic B horizon corresponds to a less stable nut-like structure.

The studied Dystric-Eutric Cambisols are phosphorus-poor and potassium-rich. The total nitrogen content corresponds to the soil organic matter content, averaging 0.417% in the A horizon and significantly less (0.077%) in the B horizon (Table 2). The C:N ratio is relatively low, ranging from 9.1 to 13.3. It is thought to increase to 15-16 at high altitudes (Bogdanov, 2022b). The insufficient amount of available nitrogen in mountain soils is generally due to unfavorable nitrification conditions, resulting from the acidic reaction and leaching of the soil profile, which removes mobile nitrogen (Penkov et al., 1992).

The low base cation content of organic residues and parent rock, as well as the formation of humate-fulvate type of humus, are factors that determine the acidic reaction of the entire soil profile. This is confirmed by the pH values, which range between 4.0 and 5.0 (Table 2).

The climate and structure of the soil profile determine the leaching type of water regime in Dystric-Eutric Cambisols, which played a signifycant role in their formation. Penkov et al. (1992) do not accept the concept of complete leaching of the soil profile. In their opinion, only 5-6% of the water that penetrates the soil passes through the metamorphic B horizon.

The results show that Dystric-Eutric Cambisols have relatively good plant available water capacity (PAWC). The average value of this indicator is 355 mm (Table 2). This is facilitated by the significant thickness of the soil profile, despite the relatively low content of clay and soil organic matter.

The studied Dystric-Eutric Cambisols are characterized by favorable physical and mechanical properties. They are loose, without vertical signs, do not have strong stickiness and plasticity, are easily tilled in a wide range of optimal moisture. They are characterized by good aeration and large effective depth, which allows for the development of a deep root system.

Despite the relatively low content of available nutrients, Dystric-Eutric Cambisols are considered to be fertile from the point of view of forestry, with favorable water and air properties for forest vegetation. They support highly productive forests of *Pinus sylvestris* L. and *Abies alba* Mill.

**Table 2.** Soil properties.

| Soil type/ Sample plot | Soil hor. | Depth, cm | Ind. | SOM, % | Total N, % | $P_2O_5$, mg.100g$^{-1}$ | $K_2O$, mg.100g$^{-1}$ | C:N | pH | Depth, cm | PAWC, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dystric-Eutric Cambisols (SP-1) | A | 0–27 | Min | 8.02 | 0.390 | 6.3 | 15.9 | 10.8 | 4.4 | 0-92 | 304 |
| | | | Max | 8.77 | 0.444 | 14.5 | 24.2 | 12.2 | 4.9 | | 416 |
| | | | Mean | 8.30 | 0.417 | 10.5 | 19.3 | 11.6 | 4.6 | | 355 |
| | | | SD | 0.27 | 0.021 | 3.5 | 3.1 | 0.5 | 0.2 | | 45 |
| | | | CV | 0.03 | 0.052 | 0.3 | 0.2 | 0.1 | 0.1 | | 0.13 |
| | B | 27–92 | Min | 1.42 | 0.063 | 7.5 | 19.7 | 9.1 | 4.8 | | |
| | | | Max | 1.51 | 0.098 | 12.8 | 27.3 | 13.3 | 5.0 | | |
| | | | Mean | 1.49 | 0.077 | 10.2 | 22.8 | 11.4 | 4.9 | | |
| | | | SD | 0.05 | 0.010 | 2.4 | 3.1 | 1.6 | 0.1 | | |
| | | | CV | 0.03 | 0.131 | 0.2 | 0.1 | 0.1 | 0.01 | | |
| Umbric Cambisols (SP-2) | A | 0–50 | Min | 18.28 | 0.492 | 8.1 | 17.4 | 18.6 | 4.0 | 0-93 | 337 |
| | | | Max | 22.00 | 0.638 | 13.1 | 23.3 | 22.6 | 4.2 | | 464 |
| | | | Mean | 20.08 | 0.569 | 10.9 | 19.7 | 20.6 | 4.1 | | 389 |
| | | | SD | 1.43 | 0.060 | 1.9 | 2.3 | 1.9 | 0.1 | | 53 |
| | | | CV | 0.07 | 0.110 | 0.8 | 0.1 | 0.02 | 0.02 | | 0.14 |
| | B | 50–93 | Min | 1.77 | 0.045 | 7.5 | 19.0 | 19.3 | 4.1 | | |
| | | | Max | 2.05 | 0.057 | 11.4 | 24.1 | 23.8 | 4.2 | | |
| | | | Mean | 1.92 | 0.052 | 9.7 | 22.1 | 21.6 | 4.2 | | |
| | | | SD | 0.11 | 0.005 | 1.5 | 2.3 | 1.8 | 0.1 | | |
| | | | CV | 0.06 | 0.101 | 0.2 | 0.1 | 0.1 | 0.01 | | |
| Modic Cambisols (SP-3) | A | 0–60 | Min | 22.25 | 0.565 | 7.9 | 16.8 | 21.9 | 3.5 | 0-60 | 207 |
| | | | Max | 26.80 | 0.710 | 12.4 | 21.0 | 25.8 | 3.9 | | 288 |
| | | | Mean | 24.90 | 0.608 | 10.5 | 18.5 | 23.9 | 3.7 | | 246 |
| | | | SD | 1.65 | 0.062 | 1.7 | 1.7 | 1.3 | 0.1 | | 30 |
| | | | CV | 0.07 | 0.104 | 0.2 | 0.1 | 0.1 | 0.04 | | 0.12 |

Note: Soil hor. – soil horizon, Ind. – indicator, SOM – soil organic matter, PAWC – plant available water capacity.

***SP-2. Umbric Cambisols***

The soil-forming climate in the study area is mountainous, cold, and humid. The average annual temperature ranges from 2.8 to 4.0°C, and precipitation exceeds 900-1000 mm, with a maximum in May and June (Sabev & Stanev, 1963; Topliyski, 2006).

The relief is mountainous, with steep slopes ranging from 15 to 35 degrees. The vegetation in the study area is represented mainly by pure stands of *Picea abies* (L.) Karst.), with a smaller proportion of mixed stands with *Pinus peuce* Gris. and *Pinus sylvestris* L.

Soil-forming rocks in the study area are mainly acidic, non-carbonate igneous or metamorphic rocks, such as granite, rhyolite, and gneisses.

The soil formation processes are similar to those of Dystric-Eutric Cambisols. Herbaceous vegetation plays a significant role in the formation of Umbric Cambisols, contributing to the development of a thicker hummus horizon.

The soil profile structure of this soils is expressed by the OABC formula. The O horizon is a transitional type (Moder) of plant litter that is 10 cm or thicker. In some cases, a coarse type (Rohhumus) of plant litter may form, with a thickness of more than 10 cm. This type of litter is clearly divided into three horizons: fresh litter, semi-decomposed organic matter, and completely decomposed organic matter. When combined with other environmental factors, even a thin layer of this type of litter can create the conditions for podzolization and the formation of podzolic soils (Podzols), which are extremely unfavorable for the development and productivity of forest plantations (Bogdanov, 2022a).

Compared to Dystric-Eutric Cambisols, Umbric Cambisols have a thicker A horizon (typical Umbric horizon), which can reach 45-55 cm. The metamorphic B horizon is less thick, and the B-to-A horizon thickness ratio is 1-0.5.

The soil organic matter content in the A horizon is 18.28-22.00%, while in the B horizon it decreases to an average of 1.92%. The humus type is humate-fulvate, and the relative proportion of fulvic acids increases with the altitude (Bogdanov, 2022b). The amount of total nitrogen is around 0.569% in the A horizon and 0.052% in the B horizon. The C:N ratio is about 20.6 for A horizon and 21.6 for B horizon. Like brown forest soils Dystric-Eutric Cambisols, Umbric Cambisols are poor in phosphorus and well-supplied with potassium. The reaction of the soil solution is 4.0-4.2, with acidity remaining constant throughout the profile (Table 2).

The climatic conditions, the high content of soil organic matter, and the relatively large thickness of the soil profile contribute to high values of the plant available water capacity, on average 389 mm. This contributes to the fertility of the studied soils, creating favorable conditions for the development of forest vegetation. From the point of view of forestry, Umbric Cambisols have high fertility, which is reflected in the formation of highly productive, pure and mixed spruce stands.

***SP-3. Modic Cambisols***

They are formed in a cold and humid mountain climate. The mean annual temperature ranges from 2 to 3°C, and snow cover persists for more than 200 days. Precipitation exceeds 900-1000 mm, with a spring-autumn maximum (Sabev & Stanev, 1963; Topliyski, 2006).

The relief is strongly dissected, and the bedrock is composed of acidic igneous rocks: pegmatite, aplite, and granite.

Soil formation occurred under the influence of meadow vegetation and *Pinus mugo* Turra formations. The main elementary soil-forming process in Modic Cambisols is humus accumulation (Bogdanov, 2022a).

The profile structure is described by the formula AC, i.e., it is incomplete, as there is no B horizon. The humus-accumulative A horizon is diagnosed as Umbric and has a large thickness of more than 60 cm.

These soils are very rich in soil organic matter, with an average content of 24.90%. It is coarse-grained and acidic, of humate-fulvic or fulvic type (Bogdanov, 2022a). The nitrogen content is relatively low in relation to the amount of soil organic matter, at 0.608%, which is a result of the weak intensity of organic residue mineralization processes. This leads to high C:N ratios, with an average of 23.9. The soil reaction is acidic, with pH values ranging from 3.5 to 4.5 (Table 2).

Modic Cambisols, like Umbric Cambisols, have high values of plant available water capacity in the A horizon, averaging 246 mm. This is due to the climatic conditions, the high soil organic matter content, and the relatively large thickness of the soil profile.

Modic Cambisols have high potential fertility, owing to their thick soil profile and high soil organic matter content. The main limiting factor for forest vegetation development is the climatic conditions.

The statistical analysis of the results showed statistically significant differences between the three studied soil types in terms of soil organic matter (Fig. 1), C:N ratio (Fig. 2) and pH (Fig. 3), which is in conformity with the change in altitude.

With increasing altitude, the soil organic matter content increases (Fig. 1), as does the relative proportion of fulvic acids in its composition. This can be attributed to changes in climatic conditions, which, at lower temperatures and higher humidity, favor a lower intensity of mineralization processes of soil organic matter, with the dominant participation of fungal microorganisms in the soil microflora (Bogdanov, 2022b; Malcheva, 2020).

The ratio of total carbon to total nitrogen (C:N) is an indicator of the rate of decomposition of organic matter and its incorporation into the nutrient cycle. The amount of carbon in the soil reflects the content of organic matter, and the C:N ratio provides an indication of the nitrogen content of humus. The higher the nitrogen content, the faster the mineralization. Higher C:N ratios at higher altitudes indicate that the intensity of mineralization decreases, and at the same time, that the nitrogen content of soil organic matter is lower in more severe climatic conditions (Fig. 2).

The decrease in average annual temperature and the increase in precipitation at higher altitudes affects not only the overall soil biogenicity, but also the composition of the soil microflora (Malcheva, 2020). In a more humid and cooler climate, the participation of fungal microorganisms increases, whose chemical activity is associated with the formation of a greater amount of organic acids, including fulvic acids. This also leads to a more pronounced soil acidity with increasing altitude (Fig. 3).

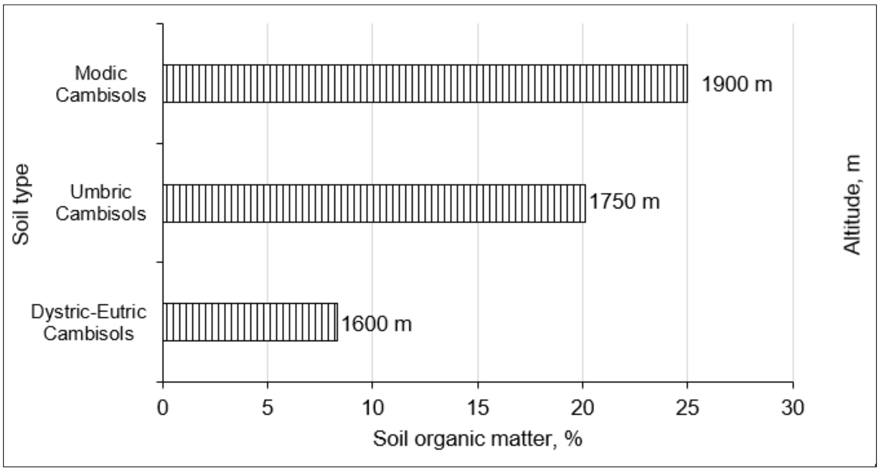


**Fig. 1.** Statistically significant differences ($p = 0.034 < 0.05$) in content of soil organic matter depending on altitude.

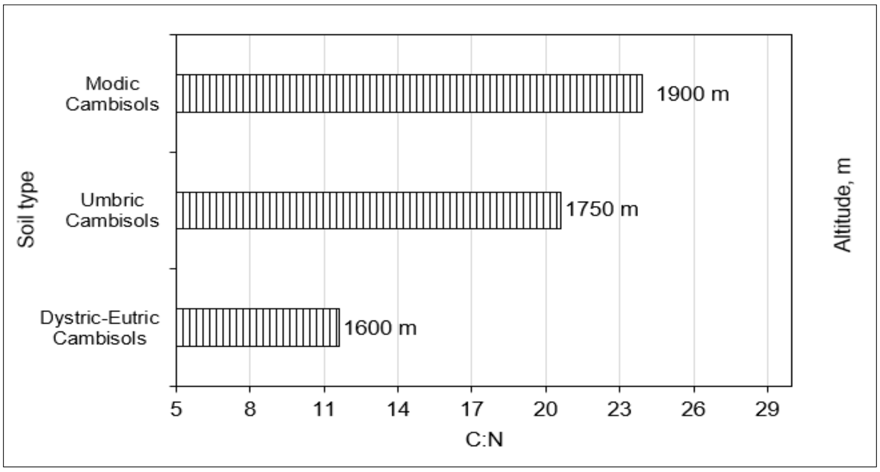


**Fig. 2.** Statistically significant differences ($p = 0.04 < 0.05$) in values of C:N ratio depending on altitude.

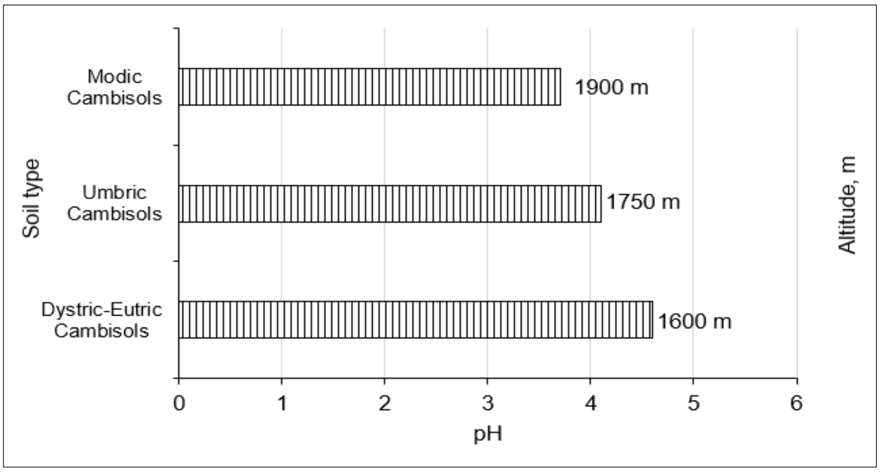


**Fig. 3.** Statistically significant differences ($p = 0.003 < 0.05$) in pH values depending on altitude.

**Conclusions**

Sustainable management of natural coniferous forests depends on proper planning of forestry activities, which requires a careful analysis of soil conditions. Their specificity in individual soil types of the class of metamorphic soils (Cambisols) reflects the importance of vertical zonality in the distribution of soils. The composition and properties of Dystric-Eutric Cambisols, Umbric Cambisols and Modic Cambisols change in accordance with the change in altitude and the associated change in climatic conditions.

With increasing altitude, the intensity of organic matter mineralization and chemical weathering processes decreases, and the participation of soil fungi in the soil microflora increases. All this leads to an increase in the thickness of the humus-accumulative A horizon at the expense of the transitional, metamorphic B horizon, an increase in soil acidity, soil organic matter content, and the relative proportion of fulvic acids.

The continuous interaction between forest vegetation and forest soils manifests itself in two main aspects: the influence of soil on the composition, growth, and productivity of forests and the influence of forests, with their characteristics, on the soil type and soil properties. The analysis of these dependencies determines the directions for the restoration, preservation, and improvement of soil fertility as a condition for increasing the productivity of plantations and the rational use of forest resources.

**Acknowledgements:** This study was supported by the Agreement on international scientific and academic cooperation № Д-33/20.02.2023.

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Received: 27.11.2023
Accepted: 09.05.2024