Abstract. In this paper the results of studies on three different forms of phosphorus – total, organic and inorganic – in soils of the Chornohora massif (Eastern Carpathians, Ukraine), depending on altitude, have been presented. The studied gleyed acid brown soils are situated in the belt of alpine meadows (1760 and 2057 m a.s.l.) and in the forest layer (1020 and 1120 m a.s.l.).

The distribution of total phosphorus, as well as its inorganic and organic form, in the soil profile depends, among other factors, on: the type of parent rock, climatic conditions, biosphere (especially of higher plants – accumulation of phosphorus in the humus horizon) and upon the manner of cultivation [21].

On the basis of the review of a rich reference material on soil science concerning mountain soils of various geographical regions of the world it can be concluded that there is a direct correlation between altitude and certain soil properties [2, 16]. Similar regularity can also be observed in flysch Carpathians, especially in the Chornohora massif [4, 11, 14, 18]. Only in few studies was attention drawn to the occurrence of phosphorus in mountain soils situated at various altitudes [5, 10, 23].

The aim of this paper was to observe the changes in the content of total phosphorus, as well as its organic and inorganic form, in mountain soils of the Chornohora massif (Eastern Carpathians, Ukraine), depending on altitude.
The Chornohora massif belongs to the mountain group of Polonynian Beskids, which are a part of the Outer Eastern Carpathians [6]. The main ridge of Chornohora is an arch approx. 25 km in length, running between the peaks of Petros (2020 m a.s.l.) in the north west and Pop Ivan (2022 m a.s.l.) in the south east. The highest peak of this massif is Hoverla (2061 m a.s.l., Fig. 1). The main core of Chornohora is built of two groups of flysch rocks, i.e. from szypocki stratum and from schists, sandstones and Chornohora conglomerates [19].

The air temperature and the amount of precipitation occurring in the Chornohora region are mostly contingent upon altitudes and relief. According to Petlin and Matvijiv [7], the mean annual air temperature in valleys surrounding Chornohora is around 5-6°C, whereas at the altitude of 1200 m a.s.l. it reaches 4°C. Above 2000 m a.s.l. the mean annual air temperature drops to below 0°C. The mean decrease in the air temperature that accompanies the increase in altitude in the studied area is 0.47°C/100 m. The amount of precipitation in lower parts of Chornohora amounts to approx. 1200-1500 mm y⁻¹, whereas in the higher mountain parts it exceeds 1500 mm y⁻¹ [1].

Fig. 1. Location of the gleyed acid brown soils in the Czornohora Mts.: 1A - Stagnic Leptic Cambisol (Humic, Dystric); 2A - Stagnic Leptic Cambisol (Dystric); 3A - Endogleyic Cambisol (Dystric); 4A - Endogleyic Cambisol (Humic, Dystric).
The soil cover of Chornohora and its diversity, similar to other mountain areas, correlates with the type of bedrock, relief, climatic conditions and the flora connected with them [4, 12, 14, 17]. Brown acid soils (Dystric Cambisols) predominate in the structure of the soil cover of Chornohora. They occur both under forests and in the area of alpine and subalpine meadows [14, 15]. Currently, the area of Chornohora is legally protected and is included in the Carpathian National Nature Park [12].

The soil profiles analysed in the study are situated at various altitudes (Fig. 1). Profile 1A representing Stagnic Leptic Cambisol (Humic, Dystric) [22] is situated at the height of 2057 m a.s.l. in the part of Hoverla that lies near the peak (Table 1). Approximately 300 m below (1760 m a.s.l.) is the 2A profile classified as Stagnic Leptic Cambisol (Dystric). The surface of soils represented by the 1A and 2A profile is covered with grassland typical of meadows of the alpine belt. Profile 3A – Endogleyic Cambisol (Dystric) and profile 4A – Endogleyic Cambisol (Humic, Dystric) are forest layer soils (Table 1). Profile 3A is situated at the height of 1120 m a.s.l. and is covered in forest plants with a predominance of beech, whereas the lowest profile, 4A (1020 m a.s.l.) is accompanied by a forest predominated by spruce. The parent rock of the studied soil is composed of sandstones, usually fine sandstones with clayey and siliceous binding material. These sandstones may contain schist insertions.

The basic properties of the analysed soils of Chornohora are included in Table 1. The majority of this data has been presented in the study of Melke et al. [13]. Total phosphorus (P-total), inorganic phosphorus (P-inorg.) and organic phosphorus (P-org.) were quantified according to the procedure of Kuo [8].

RESULTS AND DISCUSSION

The greatest thickness of the organic horizon O was noted in Profile 2A situated in the belt of alpine meadows (Table 1). The cooler and more humid climate of the higher parts of Chornohora creates favourable conditions for the accumulation of organic remains. The content of organic matter in O horizons ranges from 25.41 to 70.99% and is higher in the soils of the forest layer (Profiles 3A and 4A, Table 1). The studied soils of Chornohora, their humus horizons A in particular (table 1), are quite rich in organic carbon (C org.). The highest content of organic carbon can be found in the soil that is situated at the greatest altitude, in the part of Hoverla near the peak (Profile 1A), whose humus horizon Ah contains 10.10% of C org. In the lower 2A profile and in the soils of the forest layer (Profiles 3A and 4A) the content of C org. is clearly lower.

The grain-size distribution in soils is usually loamy (light loams low sandy, silty medium loams, silty heavy loams) more rarely clayey (Table 1). The soil reaction is usually strongly acid and the organic horizons O of the soils of alpine
<table>
<thead>
<tr>
<th>Profile No.</th>
<th>Altitude a.s.l.</th>
<th>Position in relief</th>
<th>Vegetation type (occur species)</th>
<th>Horizon</th>
<th>Depth</th>
<th>Texture acc. To SPS</th>
<th>pH</th>
<th>Organic matter (%)</th>
<th>Corg (%)</th>
<th>Soil unit acc. to: SPS 1989; WRB 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>2057</td>
<td>Almost Hoverla top, gently slope</td>
<td>Alpine meadow (Juncus trifidus, Nardus stricta, Carex curvula, Campanula alpina)</td>
<td>O</td>
<td>3-0</td>
<td>n.d.</td>
<td>3.48</td>
<td>36.61</td>
<td>10.10</td>
<td>Gleyed acid brown soil; Stagnic Leptic Cambisol (Humic, Dystric)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ah</td>
<td>0-8</td>
<td>n.d.</td>
<td>3.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ABg</td>
<td>8-12</td>
<td>gspsy</td>
<td>3.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw</td>
<td>12-29</td>
<td>gspsy</td>
<td>3.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BC</td>
<td>29-62</td>
<td>glsdp</td>
<td>4.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>1760</td>
<td>Main ridge of Chornohora</td>
<td>Alpine meadow (Juncus trifidus, Nardus stricta, Vaccinium vitis-idaea, Festuca supina)</td>
<td>O1</td>
<td>15-10</td>
<td>n.d.</td>
<td>3.18</td>
<td>55.31</td>
<td>25.41</td>
<td>Gleyed acid brown soil; Stagnic Leptic Cambisol (Dystric)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O2</td>
<td>10-0</td>
<td>n.d.</td>
<td>3.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AB</td>
<td>0-7</td>
<td>glsdp</td>
<td>3.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw</td>
<td>7-25</td>
<td>glsdp</td>
<td>4.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bwg</td>
<td>25-43</td>
<td>glsdp</td>
<td>4.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BCg</td>
<td>43-60</td>
<td>glsdp</td>
<td>4.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>1120</td>
<td>Medium SW slope</td>
<td>Forest with dominant beech (Fagus sylvatica, Abies alba, Picea abies, Galium odoratum, Dryopteris filix-mas, Dentaria glandulosa, Pheopteris connectillis, Primula eliator)</td>
<td>O</td>
<td>3-0</td>
<td>n.d.</td>
<td>4.39</td>
<td>70.99</td>
<td>4.79</td>
<td>Gleyed acid brown soil; Endogleyic Cambisol (Dystric)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>0-8</td>
<td>gspsy</td>
<td>3.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw1</td>
<td>8-34</td>
<td>gcpsy</td>
<td>3.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw2</td>
<td>34-68</td>
<td>gcpsy</td>
<td>3.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B2Cg</td>
<td>68-100</td>
<td>gcpsy</td>
<td>3.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cg</td>
<td>100-125</td>
<td>gį</td>
<td>3.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4A</td>
<td>1020</td>
<td>Medium SW slope</td>
<td>Forest with dominant spruce (Picea abies, Fagus sylvatica, Vaccinium myrtillus, Luzula luzuloides, Oxalis acetosella, Lycopodium annotinum, Polypodium formosum, Pleuroziun schreberi)</td>
<td>O</td>
<td>3-0</td>
<td>n.d.</td>
<td>3.63</td>
<td>64.82</td>
<td>3.95</td>
<td>Gleyed acid brown soil; Endogleyic Cambisol (Humic, Dystric)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>0-15</td>
<td>ipy</td>
<td>3.57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw1</td>
<td>15-30</td>
<td>ipy</td>
<td>3.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bw2</td>
<td>30-62</td>
<td>ipy</td>
<td>3.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B2Cg</td>
<td>62-100</td>
<td>ipy</td>
<td>3.81</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

meadows (Profiles 1A and 2A) may even be characterised by a very strongly acid reaction (Table 1). According to Skiba [14], the acid reaction of the soils of Chornohora is caused by the bedrock without carbonates and by acidophilic plants (spruce-trees, bilberries) that additionally acidify the surface horizons.

The content of the total phosphorus (P-total) in Chornohora soils increases along with altitude and reaches its maximum point (2176.49 mg kg\(^{-1}\)) at the height of 2057 m a.s.l. (Profile 1A, Fig. 2). Apart from profile 1A, the content of the total phosphorus is highest in organic horizons O and in humus horizons A and decreases in the profile along with depth. On the whole, it can be claimed that the analysed soils of alpine meadows are richer in total phosphorus than the lower soils.

---

**Fig. 2.** Forms of phosphorus in the Czornohora Mts. soils: profile 1A – 2057 m a.s.l.; profile 2A – 1760 m a.s.l.; profile 3A – 1120 m a.s.l.; profile 4A – 1020 m a.s.l. Abbreviations: P-total – total phosphorus, P-inorg. – inorganic phosphorus, P-org. – organic phosphorus.
of the forest layer (Profiles 3A and 4A). The high content of total phosphorus in the soils of alpine belt is not enough to ensure a sufficient amount of phosphate combinations assimilable for plants. Studies carried out by Kocowicz [5] show that the content of available phosphorus in the humus horizons A of brown acid soils in the Sudetes decreases along with the increase in altitude.

The content of organic phosphorus (P-org.) in the soils of Chornohora, similar to the content of total phosphorus (P-total), increases along with altitude (Fig. 2). The maximum content of organic phosphorus has been detected in horizon Bw (2080.37 mg kg\(^{-1}\)) in profile 1A situated at the height of 2057 m a.s.l. In profiles 2A, 3A and 4A the horizons characterised by the highest P-org. content are horizons O and the humus horizons A. In these profiles the amount of P-org. decreases along with depth. The reduction of the P-org content along with depth is arguably connected with the decrease in the content of organic carbon, although this is not always a strict relation (e.g. Profile 1A). The share of organic phosphorus (P-org.) in the total phosphorus (P-total) is considerable and amounts to 43-96% (Fig. 3). This share is biggest (76-96%) in profile 1A, the highest one. The considerable accumulation of organic phosphorus (P-org.) in the soils of alpine meadows (Profile 1A and 2A) ought to be at least partially connected with the decrease in the activity of heterotrophic microorganisms (they are responsible for the mineralization of organic compounds of phosphorus), which results from the not too favourable site conditions (low air temperatures, long period with a snow cap, soil wetness) that prevail above the upper borderline of forest. A considerable amount of the soil organic phosphorus may be additionally stabilised as a result of the sorption of clay minerals or of iron and aluminium hydroxides [9, 21].

The content of inorganic phosphorus (P-inorg.) in Chornohora soils is definitely lower than the organic phosphorus (P-org.) content. The P-inorg. content is not determined by altitude (Fig. 2). The maximum content of P-inorg. was detected in the organic horizon O (244.80 mg kg\(^{-1}\)) in profile 3A, which represents the forest layer soil. Considerable accumulation of this form of phosphorus was also detected in mineral horizons Bwg and BC of alpine meadow soils (Profiles 1A and 2A). The share of inorganic phosphorus (P-inorg.) in the total phosphorus (P-total) ranges from 4 to 57% and is usually highest in mineral horizons BC, BCg and C (Fig. 3). The share of P-inorg in P-total observed in profile 1A (from 4 to 21%) is smaller than in other profiles, which shows that the weathering processes of minerals containing phosphorus are less intensive in the highest parts of the Chornohora massif.

The phosphorus content converted to soil bulk density would be different but it would not eliminate the differences between particular altitude belts. Due to there being no possibility of converting the obtained results to volumetric density of the analysed soils, the results of phosphorus quantification have been presented in mass units (mg kg\(^{-1}\)) recommended by the International System of Units (SI) [3].
CONCLUSIONS

1. Soils of Chornohora are usually (alpine meadows soils) rich and semi-rich (forest layer soils) in total phosphorus (P-total), whose amount increases along with altitude.

2. The content of organic phosphorus (P-org.) in the soils of Chornohora, similar to the total phosphorus (P-total), increases with along altitude and with one exception (Profile 1A) reaches its maximum in surface horizons O and humus horizons A, rich in organic matter. The content of P-org. in the profile usually decreases along with depth, which is connected with the decrease in the content of organic carbon, although it is not always a strict correlation.

Fig. 3. The share of inorganic phosphorus (P-inorg.) and organic phosphorus (P-org.) in total phosphorus (P-total) in the Czornohora Mts. soils.
3. The considerable accumulation of organic phosphorus (P-org.) in soils of alpine meadows ought to be at least partially connected with the decrease in microbiological activity resulting from not very favourable site conditions.

4. The content of inorganic phosphorus (P-inorg.) in Chornohora soils is definitely lower than the organic phosphorus (P-org.) content and is not determined by altitude.

REFERENCES