Magnetic methods application for the physical and chemical properties assessment of Ukraine soil

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SUMMARY

The special attention require the soil studies in Ukraine according to the introduction of the agricultural land market in Ukraine. That is why our aim was to study the content of silicon compounds of different mobility in soils and its correlation with indicators of soil physicochemical properties. Magnetic methods demonstrated high efficiency and low cost when applying to detect soil erosion, indicate the physicochemical properties, and perform fast soil mapping. Soils of the Mokiyivtsi area have an average pH of 4.9-5.4, the acidity of these soils decreases with increasing content of physical clay. The investigated soils of the Khmelnytsky region have mainly low-deficient silicon balance, both of readily-available and hard-soluble forms. However, individual samples of the Mokiyivtsi area have an average deficiency of silicon, in particular if the evaluation is carried out on the content of readily available (actual) silicon compounds in the arable layer of the studied soils. The results of the magnetic studies confirmed the high degree of relationship between MS and salt extract pH ($\rho = -0.80$) for the area Hotkivka.
Introduction
The special attention require the soil studies in Ukraine according to the introduction of the agricultural land market in Ukraine. In recent years, agrarians in Ukraine have noted the direct impact of global warming on crop is increasing and expanding. The study of soil nutrient regimes is of the great importance. However, there is a limited amount of the research of the individual elements, including silicon. That is why our aim was to study the content of silicon compounds of different mobility in soils and its correlation with indicators of soil physicochemical properties. Magnetic methods demonstrated high efficiency and low cost when applying to detect soil erosion, indicate the physicochemical properties, and perform fast soil mapping (Jordanova and Jordanova, 2019). Taghdis and Farpoor, 2018 studied the effect of different land uses and vegetation types on the magnetic susceptibility of topsoil related to soil properties.

State of the art
The large areas of the Earth are affected by accelerated soil erosion (Lal, 2017) with a negative impact on ecosystem services, crop production, drinking water and carbon stocks, silicon content (Panagos et al. 2015). Last year’s Ukraine passes the time of transition to the agrarian economics. Ukraine has a unique raw material base (Mykhailov and Hrinchenko, 2018). Environment friendly land management, assignment of cadastral numbers, precision farming are among the big challenges in Ukraine. The basement for the agricultural studying is clear understanding of the initial (natural) soil properties. Magnetic measurements are sensitive for high-scale identification of the changes in pedogenic properties of soil genetic horizons, geomorphology and landscape position. Silicon (Si) is the second most prevalent crust mineral and occupies 27.6% of the crust mass. Its concentration in soils varies greatly from less than 1% to more than 45%. The main factor influencing this is the parent material, but it is important to study other factors of influence: climate, plants, the land use (Landré et al., 2020). A number of studies (Coskun et al., 2016; Ranjbar et al., 2019) have established the role of silicon in growth and development of plants, their resistance to stress conditions, including salinity and drought. The content of silicon in soils depends of the reaction of the soil environment. The alkalinity of the soil adversely affects the growth and development of agricultural plants, and therefore studies on the effects of exogenous silicon (Si) and salicylic acid (SA) on plants (Khan et al., 2019).

Ayoubi et al., 2018 performed the discriminant analysis that indicated the accuracy of 54.11% to discriminate soil great group for the combination of magnetic measures, different form of Fe, and soil physicochemical properties in the control section. The drainage classes in different landscapes assessment play the significant role in soil magnetism formation. Asgari et al., 2018 concluded that MS is powerful and rapid technique for the determination of the soil drainage classes on an example of Juneqan district, Charmahal and Bakhtiari province, western Iran. Recently, a number of studies considered the modern approaches of soil properties estimation (Tonkha et al., 2018; Khmelovskyi et al., 2019). Among the rapid methods of the investigation of thermal transformations is the temperature programmed desorption mass spectrometry (Palianytsia et al., 2014). According to (Bobos et al., 2019), the density of the plants significantly influenced the economically valuable indicators, because there is always competition for light, moisture and nutrients between plants in the life process.

Magnetic method is the low cost and time saving technology to study soil properties (Menshov et al., 2012, 2014, 2016), to assess soil erosion and degradation (Menshov and Sukhorada, 2010).

Methods
The experiment was performed at the Shepetivka district of Khmelnytsky region close to the settlement of Mokiyivka. The study area is field crop rotation: corn for grain - soybean - winter wheat - corn for grain - pea. The soils of the territory is dark grey forest and chernozems podzolized light- and medium-loamy on loesses. Soils are characterized by good fertility rates. The humus content in the upper horizon reaches 3.0-3.5%.
Soils were sampled from the arable horizon, from a depth of 0-25 cm, the amount is 30 soil samples.
Magnetic methods were applied according to the technology described in (Evans and Heller, 2003) at the area Hotkivka. The main parameter to find the correlation with soil physical parameters was magnetic susceptibility χ (MS).

**Example 1**

The analyzed soil samples were grouped by the content of the fraction of «physical clay», particle size less than 0.01 mm, in the following groups: less than 25.0%, 25.0-29.9%, 30.0-34.9%, 35.0-39.9% of physical clay content. Among the samples tested, the largest amount contained more than 30.0% of the particles of physical clay. The most of studied samples belong to the medium loamy texture. For each group of samples the average values of the studied parameters are deduced. The deviations, which are presented in relative percentages, are calculated. We assume that if the deviation of the individual values from the average is less than 30%, then it is possible to make high reliability conclusions about the regularities and relationships between the indicators.

Soils of the Mokiyivtsi area have an average pH of 4.9-5.4, the acidity of these soils decreases with increasing content of physical clay (see table 1).

| Granulometric composition and physical and chemical properties of the investigated soils of the Khmelnytsky region, Shepetivka district, Mokiyivtsi area, mean values and standard deviations |
|---|---|---|---|---|
| Groups by physical clay particles (<0.01 mm) content in soil | Amount of soil samples analyzed | Content of granulometric particles of different sizes | pH, salt extraction | Humus content, % | Content of sum of exchangeable bases Ca+Mg, mmol/100 g soil |
| | | <0.01 mm % | <0.005 mm % | <0.001 mm % | | average, deviation, % relative | average, deviation, % relative | average, deviation, % relative | average, deviation, % relative | average, deviation, % relative |
| <25.0% | 4 | 20.8 | 10 | 17.7 | 12 | 13.2 | 17 | 4.9 | 16 | 2.1 | 29 | 6.3 | 33 |
| 25.0-29.9% | 4 | 26.8 | 8 | 22.0 | 15 | 15.7 | 18 | 4.9 | 14 | 2.1 | 33 | 8.3 | 19 |
| 30.0-34.9% | 12 | 32.0 | 5 | 26.6 | 5 | 19.5 | 8 | 5.2 | 8 | 2.9 | 21 | 11.6 | 17 |
| 35.0-39.9% | 10 | 36.6 | 4 | 30.6 | 8 | 22.0 | 6 | 5.4 | 7 | 3.3 | 15 | 13.2 | 19 |

The average values of humus content in soils of the Mokiyivtsi area increases from 2.1 to 3.3%, and a positive correlation of this indicator with the content in the soil of physical clay particles is observed. The content of the sum of the exchangeable bases of calcium and magnesium in the soils of the studied area increases with the increasing of content of the physical clay fraction. The average values of readily available silicon content in the studied soils range from 51 to 92 mg/kg SiO₂ (Table 2). But in the soils of this area there is a slight tendency to increase the content of readily available silicon with increasing content of physical clay in soil. The dependence of change in the content of silicon compounds from the particle size distribution and the content of calcium and magnesium bases is better observed for the fraction of hard-soluble silicon in soils of the studied area. Average values of hard-soluble silicon in soils of Mokiyivtsi area increased from 326 to 570 mg/kg SiO₂, and deviations of individual samples from average didn’t exceed 30% (Table 2). The results have shown that the behavior of silicon compounds in soils is influenced by the particle size distribution of the soil, as well as by the composition and content of the exchangeable cations. The content of exchangeable cations in the soil depends largely on the calcium content. We studied the relation between exchangeable calcium and hard-soluble silicon compounds in soil. The average calcium content of the studied soils is 1000-2290 mg/kg of Ca. The average values of the content of...
hard-soluble silicon are 326-570 mg/kg in terms of SiO$_2$. The content of these compounds of silicon in the soil is 3.1-4.0 times lower than the content of calcium. There is a tendency of increasing of the Ca/SiO$_2$ ratio with an increase of physical clay content in the soils of the Makiyivtsi area (Table 2). When evaluating the silicon balance by the specified graduation, we observe that the investigated soils of the Khmelnytsky region have mainly low-deficient silicon balance, both of readily-available and hard-soluble forms. However, individual samples of the Mokiyivtsi area have an average deficiency of silicon, in particular if the evaluation is carried out on the content of readily available (actual) silicon compounds in the arable layer of the studied soils.

**Table 2 Content of exchangeable calcium and magnesium cations, and silicon compounds of different fractions in soils of Khmelnytsky region, Shepetivka district, Mokiyivtsi area**

<table>
<thead>
<tr>
<th>Area</th>
<th>Groups by physical clay particles (&lt;0.01 mm) content in soil</th>
<th>Amount of soil samples analyzed</th>
<th>Exchangeable Calcium content, Ca, mg/kg</th>
<th>Exchangeable Magnesium content, Mg, mg/kg</th>
<th>Readily-available silicon content, SiO$_2$, mg/kg</th>
<th>Hard-soluble silicon content, SiO$_2$, mg/kg</th>
<th>Ratio Ca exchangeable/ SiO$_2$ hard-soluble, based on averages</th>
</tr>
</thead>
<tbody>
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<td>Hard-soluble silicon content, SiO$_2$, mg/kg</td>
<td>Ratio Ca exchangeable/ SiO$_2$ hard-soluble, based on averages</td>
</tr>
<tr>
<td></td>
<td>&lt;25.0%</td>
<td>4</td>
<td>1000</td>
<td>34</td>
<td>157</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>25.0-29.9%</td>
<td>4</td>
<td>1330</td>
<td>24</td>
<td>195</td>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>30.0-34.9%</td>
<td>12</td>
<td>1990</td>
<td>18</td>
<td>205</td>
<td>27</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>35.0-39.9%</td>
<td>10</td>
<td>2290</td>
<td>20</td>
<td>165</td>
<td>28</td>
<td>92</td>
</tr>
</tbody>
</table>

**Example 2**

To find the relation between magnetic susceptibility and soil organic content (humus), we performed the measurements of the MS at KLY and two-frequency magnetometer MS2B. All soil samples from the study area Hotkivka were devoted in two sets: XB 38 (n=4) та XB 39 (n=4). The results are given in Table 3. We used the statistical method of nonparametric statistics and obtained the Spearman correlation ρ.

We registered the high positive correlation between the MS and the humus content on the sample set XB 38. For all collection the correlation was from low to medium.

At the same time the high degree of relationship between MS and salt extract pH (ρ = -0.80) was detected for the sample set XB 38. From the other hand, for the whole samples correlation is quite low (up to ρ = -0.23).

**Table 3 The relation between magnetic susceptibility and soil organic content (humus)**

<table>
<thead>
<tr>
<th>Magnetic measurements</th>
<th>Part</th>
<th>XB 38</th>
<th>XB 39</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS, KLY</td>
<td></td>
<td>0.774597</td>
<td>-0.340637</td>
<td>0.280332</td>
</tr>
<tr>
<td>MS, MS2B, LF</td>
<td></td>
<td>0.774597</td>
<td>-0.545020</td>
<td>0.338179</td>
</tr>
<tr>
<td>MS, MS2B, HF</td>
<td></td>
<td>0.774597</td>
<td>-0.309670</td>
<td>0.436073</td>
</tr>
</tbody>
</table>

**Conclusions**

The average values of the content of readily-soluble silicon compounds in the investigated light loamy and medium loamy soils of agricultural lands of Khmelnytsky region Shepetivka district Mokiyivtsi area range from 51 to 92 mg/kg SiO$_2$, and the content of soluble compounds is 326-570 mg/kg of SiO$_2$. The results have shown that the content of silicon compounds in soils are related to the particle
size distribution of the soil, the value of the exchangeable acidity, the content of humus, and the composition and content of exchangeable cations. The results of the magnetic studies confirmed the high degree of relationship between MS and salt extract pH ($\rho = -0.80$) for the area Hotkivka.

References
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