EVALUATION OF BUFFERING CAPABILITY OF EXTREME ACID SOILS IN RELATION TO LIMING DOSES

HODNOTENIE TLMIVEJ FUNKCIE EXTRÉMNE KYSLÝCH PÔD VO VÄZBE NA POTREBU VÁPNENIA

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The paper is aimed to the effect of the soil organic matter and the time on buffering capability of acid soils. For this purpose the buffering capability was measured in extremely acid soil samples with variable textures and humus contents in humic (ochric, light) and umbric horizons.

Laboratory tests were performed for the buffering capability measurement in studied soils. The tests were based on the application of increasing doses of calcium carbonate (0.01 g, 0.05 g, 0.1 g, 0.5 g, and 1.0 g) to soil samples (20 g) and subsequent determination of soil pH in distilled water. Two different approaches were used for evaluation of soil buffering capability. The first approach is based on the measurement of soil pH immediately after calcium carbonate application and the second approach evaluates soil pH values measured 10 days after calcium carbonate application.

The results of buffering capability measurement demonstrate importance of time effect for calcium carbonate interaction with soils. The buffering capability was very high in soil samples from umbric horizons with higher humus content. The effect of time on buffering capability of umbric horizons was insignificant. The buffering capability was lower in the soil samples from humic (ochric, light) horizons with medium and low humus content. In this case the time has significant effect.

Based on the obtained results on the buffering capability of acid soils, we recommend increasing lime doses in relation to humus content.

Key words: acid soils, buffering capability, liming, umbric horizon, humic (ochric, light), horizon, pH, organic matter

INTRODUCTION

Majority of agricultural crops react negatively on acid conditions. Even those crops considered acidophilous such as potatoes, strawberries, blackberries, wild cranberry, lingonberry and among the decorative plants first of all rhodorendrons, Scotch heathers, heathers, magnolias and grasses do not sustain extremely acid conditions (pH below 4.5). The reason is the toxic effect of active alluminium which attacks the surface of roots and prevents the phosphorus uptake transforming it from available forms to non-available. Therefore the liming is unavoidable measure of effective agricultural exploitation of acid soils. This phenomenon was explained in many studies (Masaryk et al. 1980; Čurlík et al. 2003; Adams 1984, Lal and Stewart 1990, etc.).

Liming of acid soils was usually recommended as one-event measure and the criterium for liming was the value of exchangeable soil acidity, eventually the neutralization of acidity measured in laboratory using the Goy-Ross method (Hraško et al. 1962). Later the doses of lime fertilizer according to target pH value requested by the set of grown crops and also according to buffering capability of soil determined by soil texture. Higher doses were recommended for clayey soils and for calciphilous plants, lower doses for loamy soils and majority of agricultural crops, and the lowest doses for sandy soils and for acidophilous plants. Partially there

was accepted also the need of repeated liming of reac-
didifield limed acid soils (Bedrna 1986). However the
buffering capability of soil organic matter was still not
taken into the account.
Although the principles of acid soil classification
applied for liming (Bedrna 1989) the differences of
liming doses for organic and mineral soils, the impor-
tance of organic matter buffering capability was not
fully understood.
The extreme acidity is in Slovak conditions typical
for soils classified as podzols and cambisols. The Slo-
vak soil classification (Collective, 2000) distinguish
in these soils also humiferous horizon characterised
by dark color and pH (H₂O) < 5.5 base saturation of
< 50% and thus also by extreme acidity and high or-
ganic matter content. It is called “umbric horizon”. Re-
cently running investigations of soils with this horizon
showed that this horizon occur not only in podzols and
cambisols, but also in rankers and eve in soils known
as “acid alluvial soils” which are classified by WRB
(IUSS 2006) as Umbrisols (the Slovak equivalent um-
brizem is under the discussion). Soils with umbric ho-
rizons occur not only in podzols and cambisols, but also
in rankers and even in soils known as “acid alluvial soils”
which are classified by WRB (IUSS 2006) as Umbrisols
(the Slovak equivalent umbrizem is under the discus-
sion). Soils with umbric horizon occur in Slovakia not
only in mountainous areas, but rarely also as Umbrisols in area of Záhorská nižina
lowland. Majority of them are forest soils, but great
part of them is exploited also as grassland and even as
arable land. These soils were studied especially from
the point of view of heavy metals adsorption (Covelo
et al. 2004), but the buffering capability of umbric ho-
rizons with high organic matter content in comparison
with humic (ochric, light) horizons having lower or-
ganic matter content was not investigated.
The goal of this paper is to evaluate the importance
of buffering effect of organic matter in humic (ochric,
light) and umbric horizons on the change of soil reac-
tion resulting from liming and based on that to identify
the further need for liming and recommend the doses
of lime fertilizer.

MATERIAL AND METHODS

For the purposes of this study the soil samples of
variable physical and chemical characteristics were
used. The surface soil horizons at 8 sites with extreme-
ly acid soils (pH in H₂O ≤ 4.5) under variable ecosys-
tems and land uses were sampled. In Zahorie region
4 sites representing soils of lowland conditions were
sampled: the sandy humic (ochric, light) humiferous

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**Table 1**

Selected physical properties of investigated soil samples

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Depth [cm]</th>
<th>Soil groups Prefix (Suffix)</th>
<th>Horizon</th>
<th>Color</th>
<th>Particle size distribution [%]</th>
<th>Soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dry</td>
<td>Moist</td>
<td>&lt;0.002 mm</td>
</tr>
<tr>
<td>1</td>
<td>7–12</td>
<td>etPZ(ar)</td>
<td>hu</td>
<td>10 YR 4/3</td>
<td>10 YR 2/3</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>5–15</td>
<td>cmUm</td>
<td>um</td>
<td>10 YR 4/2</td>
<td>10 YR 2/2</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>0–10</td>
<td>umLP</td>
<td>um</td>
<td>10 YR 3/2</td>
<td>10 YR 2/3</td>
<td>10.7</td>
</tr>
<tr>
<td>4</td>
<td>0–20</td>
<td>haUM</td>
<td>um</td>
<td>10 YR 2/2</td>
<td>10 YR 2/1</td>
<td>10.5</td>
</tr>
<tr>
<td>5</td>
<td>0–20</td>
<td>cmumLP</td>
<td>um</td>
<td>10 YR 5/2</td>
<td>10 YR 2/2</td>
<td>11.0</td>
</tr>
<tr>
<td>6</td>
<td>5–15</td>
<td>haCM(dy)</td>
<td>hu</td>
<td>10 YR 6.5/2</td>
<td>10 YR 4/2</td>
<td>11.8</td>
</tr>
<tr>
<td>7</td>
<td>0–17</td>
<td>haCM(dyar)</td>
<td>hu</td>
<td>10 YR 5/2</td>
<td>10 YR 4.5/2</td>
<td>14.3</td>
</tr>
<tr>
<td>8</td>
<td>0–8</td>
<td>haAR(dy)</td>
<td>hu</td>
<td>10 YR 6/2</td>
<td>10 YR 4.5/2</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Explanation of abbreviations:

- Soil Groups, Prefix (Suffix): etPZ(ar) = Entic Podzol(Arenic), cmUm = Cambic Umbrisol, umLP = Umbric Leptosol, haUM = Haplic Umbrisol, cmumLP = Cambic-Umbric Leptosol, haCM(dy) = Haplic Cambisol(Dystric), haCM(dyar) = Haplic Cambisol(Dystric, Arenic), haAR(dyar) = Haplic Arenosol (Dystric)
- Horizons: hu = humic (ochric, light) um = umbric
- Soil Texture: s = Sand, ls = Loamy Sand, sl = Sandy Loam, stl = Silty Loam, l = Loam
horizon (hu) of Entic Podzol (Arenic) – etPZ(ar) on eolian sand under the forest near Rohožník village (sample 1), the sandy-loam umbric humiferous horizon (um) of Haplic Umbrisol (haUM) on alluvial terrace material under the meadow near Borský Mikuláš village (sample 4), the loamy-sand humic (ochric, light) humiferous horizon (hu) of Haplic Cambisol (Dystric, Arenic) – haCM(dyar) on eolian sand under the forest near Šajdíkové Humence village (sample 7) and the loamy-sand (ochric, light) humiferous horizon (hu) of Haplic Arenosol (Dystric) – haAR(dy) on eolian sand under the meadow near Šajdíkové Humence village (sample 8).

Another two samples represent the mountainous areas with elevation 600–800 m a.s.l.: the sandy-loam umbric humiferous horizon (um) of Cambic Umbrisol – cmUM on weathering products of granite under the forest in Západné Tatry mountains nearby Podbanské village (sample 2) and the sandy-loam umbric humiferous horizon (um) of Umbric Leptosol – umLP, on weathering products of granite under the forest in Nízke Tatry mountains at Kozí chrbát site (sample 3).

The last two samples represent the mountainous areas with lower elevation (300–500 m a.s.l.): the silty-loam umbric humiferous horizon (um) of Cambic-Umbric Leptosol (cmumLP) on weathering product of sandstones under forest in Biele Karpaty mountains near the village Chocholná-Velčice (sample 5), and the loamy humic (ochric, light) humiferous horizon (hu) of Haplic Cambisol(Dystric) – haCM(dy) on weathering products of granite under the forest in the Malé Karpaty mountains, Rača district of Bratislava city (sample 6).

The soil classification was done for this characterization of the study sites according to WRB (IUSS, 2006). Detailed characterization of soil physical and chemical properties of samples soils provide Tables 1 and 2.

The assessment of buffering capability was done using the laboratory test based on treatment by incremental doses of calcium carbonate and successive measurements of active soil reaction. The following doses of calcium carbonate were used: 0.01, 0.05, 0.1, 0.5 and 1.0 g for 20 g of soil sample. Active soil reaction was determined in the water extract using the potentiometric method described by Hrasko et al. (1962) using the pH-meter INOLAB pH 730 produced by WTW. For assessment of buffering capability the two approaches of neutralizing effect of liming were used. The first was based on immediate determination of pH and the second approach determined pH after 10 days of sample moistening. The soil texture was determined by pipette method, the organic carbon by Walkey-Black method and sorption capacity according to Godlin (Fiala et al. 1999; Hrasko et al. 1962).

The doses of calcareous fertilizer were determined

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### Table 2

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Depth [cm]</th>
<th>Soil groups</th>
<th>Horizon</th>
<th>pH H₂O</th>
<th>pH KCl</th>
<th>C₉₀⁺</th>
<th>CEC cmol kg⁻¹</th>
<th>EA cmol kg⁻¹</th>
<th>EBCC cmol kg⁻¹</th>
<th>BS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7–12</td>
<td>etPZ(ar)</td>
<td>hu</td>
<td>5.5</td>
<td>4.7</td>
<td>2.8</td>
<td>9.9</td>
<td>5.3</td>
<td>4.6</td>
<td>46</td>
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<tr>
<td>2</td>
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<td>cmUM</td>
<td>um</td>
<td>4.6</td>
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<td>21.6</td>
<td>12.4</td>
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<tr>
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<td>3.8</td>
<td>3.6</td>
<td>3.6</td>
<td>17.4</td>
<td>16.2</td>
<td>1.2</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>0–20</td>
<td>haUM</td>
<td>um</td>
<td>4.0</td>
<td>3.1</td>
<td>2.6</td>
<td>20.2</td>
<td>19.0</td>
<td>1.2</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
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<td>cmumLP</td>
<td>um</td>
<td>3.5</td>
<td>3.1</td>
<td>4.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>5–15</td>
<td>haCM(dy)</td>
<td>hu</td>
<td>3.6</td>
<td>3.2</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0–17</td>
<td>haCM(dyar)</td>
<td>hu</td>
<td>4.3</td>
<td>3.5</td>
<td>1.0</td>
<td>6.1</td>
<td>4.8</td>
<td>1.3</td>
<td>21</td>
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<tr>
<td>8</td>
<td>0–8</td>
<td>haAR(dy)</td>
<td>hu</td>
<td>4.2</td>
<td>3.4</td>
<td>0.4</td>
<td>4.2</td>
<td>3.1</td>
<td>1.1</td>
<td>26</td>
</tr>
</tbody>
</table>

For explanation of soil groups and horizons abbreviations see Table 1

Cox = Organic Carbon, CEC = Cation Exchange Capacity, EA = Exchangeable Acidity, EBCC = Exchangeable Base Cation Content, BS = Base Saturation
on the base of buffering capability caused by organic matter, thus it was not based only on the soil texture as it is usually recommended by guidelines for liming of acid agricultural soils. A special attention was paid to liming of acid soils before the establishment or after the recultivation of perennial grassland and to liming of acid arable land.

RESULT AND DISCUSSION

The investigation results showed that the time of soil exposure to liming has an important effect on buffering capability of extremely acid soils (Table 3, 4). The samples 2, 3, 4 and 5 with higher organic matter content have momental buffering capability only slightly lower (pH higher in maximum of 0.4) in comparison with longer effect of calcium carbonate. In samples with medium (sample 1) and low (samples 6, 7 and 8) organic matter content in humic (ochric, light), eventually umbric horizons it is considerably lower not only in relative, but in absolute values as well (pH higher of 0.5–1.0).

Table 3

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Doses of CaCO$_3$ [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>1</td>
<td>5.49</td>
</tr>
<tr>
<td>2</td>
<td>4.56</td>
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<tr>
<td>3</td>
<td>3.73</td>
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<td>4.02</td>
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<td>3.48</td>
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<td>6</td>
<td>3.62</td>
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<td>7</td>
<td>4.30</td>
</tr>
<tr>
<td>8</td>
<td>4.20</td>
</tr>
</tbody>
</table>

The buffering of the soil reaction change caused by liming was observed also in samples with different soil texture. The absolute values of buffering are greater especially for long lasting effect of liming. The final pH values were 6.2 a 7.0 for loamy soils, 6.6–6.9 for sandy-loam soils, 7.7–7.9 for loamy-sand soils and 8.1 for sandy soils.

Table 4

The pH values in H$_2$O after addition of calcium carbonate measured in 10 days moistering

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Doses of CaCO$_3$ [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
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<td>7</td>
<td>4.30</td>
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<tr>
<td>8</td>
<td>4.20</td>
</tr>
</tbody>
</table>

The soils with higher organic matter content have higher not only immediate but mainly long lasting buffering capability. This feature should be considered when the doses of lime fertilizer are determined. The lower lime fertilizer doses are able to increase the pH to required optimum value of soils poor in organic matter in longer time horizon as well as higher doses applies to soils rich in organic matter.

In literature most often the maintenance and amelioration liming of acid soils are presented (Masaryk et al. 1980; Čurlík et al. 2003, etc.), which are the most commonly used categories of acid soil liming. The purpose of maintenance liming is to compensate the annual loses of calcium, while the amelioration liming has to improve the soil reaction to level defined as required pH. The results of this investigation indicate that it would be more appropriate to distinguish nutrition, neutralization and amelioration approach of soil liming (Bedrna 1989). The characterization of these three categories is following:

1. Nutrition liming provides the lacking lime for acidophilous plants in case of extremely acid soil reaction. It is applied in agriculture only at grassland or for acidophilous perennial crops cultivated on sandy soils with extremely acid soil reaction low 4.5 and at loamy textured and clayey soils with pH below 5.0.

2. Neutralisation liming improves pH of arable land and land under the grassland before its restoration or establishment to required pH which has most usually the value of 5.5 for sandy soils, 6.0 for loamy textured soils and 6.5 for clayey soils.
3. Amelioration liming is applied for land used for cultivation of calciphilous mostly perennial crops and vegetables. It should reach the level of 0.1–0.3% of free carbonates in soil as recalculated to CaCO₃. However, this approach is not suitable for extremely acid soils.

The impact of soil organic matter content for efficiency of lime fertilizers should be considered when nutrition and neutralization liming is applied on extremely acid soils. The doses of lime fertilizers recommended considering the recent knowledge are presented in Tables 5, 6 and 7.

**CONCLUSION**

The investigation of buffering capability of extremely acid soils having humic (ochric, light) and umbric horizons of variable texture showed that apart of soil texture the soil organic matter content plays an important role. Moreover, the time of the soil expo-
sure to lime fertilizer has considerable impact as well. The higher buffering capability against alkalinization showed not only the soils with higher clay content, but also the soils with higher organic matter content. This fact should be considered when determining the doses lime fertilizers for liming extremely acid soils. The increased doses for soils with high organic matter content were proposed proportionally corresponding to the doses recommended in literature. This way the liming was adjusted in order to improve the nutrition of acidophilous grasslands by calcium and to neutralize the extreme soil acidity at cultivated land and reconstructed grassland in order to achieve the required pH of soil.

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REFERENCES


SÚHRN

Cieľom príspevku je zhodnotiť význam tlmivosti organických látok v ochrických (humóznych svetlých) a umbrických horizontoch pôd voči zmene pôdnej reakcie pri použití vápnenia a na tomto základe prehodnotiť s kategorizovať novú potrebu vápnenia príslušným dávkami vápenatých hnojív. K zisteniu tlmivosti skúmaných vzoriek zemín sme použili laboratórne testy, ktorý svoj výsledok čítali ako účinnosť uhlíčitanu vápenatého v tiahajúcich dávkach a následného stanovenia aktívnej pôdnej reakcie. Použili sa dávky 0,01, 0,05, 0,1, 0,5 a 1,0 g CaCO₃ do 20 g navážky zeminy. Aktívna pôdna reakcia sa stanovila potenciometricky vo vodnom výluhu. Pre hodnotenie tlmivosti sme použili dva prístupy neutralizačného činiteľa vápnenia, prvý spočíval v okamžitému vzniku vápnenia a druhý predstavoval zistenie pH až po 10 dňovom vlhčení zemín.

Výsledky skúmania tlmivosti extrémne kyslých pôd ukázali na značný význam doby pôsobenia uhlíčitanu vápenatého na pôdu. Vzorky s výšším obsahom humusu z umbrických horizontov pôd mali okamžité tlmivosť len napätne vyššiu (nižšie pH o 0,0–0,4) v porovnaní s dlhším pôsobením uhlíčitanu vápenatého na pôdu. Tlmivosť v prípade vzorkov sa podľa stredných a nižších obsahom humusu poľováujúcich horizontov pôd, bola výrazne nižšia (vyššie konečné pH o 0,5 až 1,0) nielen v relatívnych, ale aj absolútnych hodnotách. Zrnotiať sa na tlmivuť voči alkalizácii prejavila známy zvyšovaním hodnot od písčitých cez hlinitos-písečitý až k hlinitos-hlinitej v tlmivosti a pH závislosti pôdnej textúry.

Na základe získaných výsledkov o tlmivosti extrémne kyslých pôd odporúčame zvýšenie dávok vápenatých hnojív nielen podľa zrnotiať, ale aj podľa obsahu humusu v pôde. Takto sme navrhli postupovať nielen pri živinovom vápnení kyslomilných trávnych porastov k odstráneniu nedostatku vápnika vo výžive rastlín, ale aj neutralizačnom vápnení ornej pôdy a obnovovaných trávnych porastov na dosiahnutie cieľového pH.