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The quality and health of soil in terms of sustainable land use

Jakość i zdrowotność gleby w kategoriach zrównoważonego użytkowania ziemi

Summary. Soil quality represents the ability of the soil to secure environmental functions in a particular way of using it. Health of soil expresses protection and increasing biological productivity, environmental quality and health promotion of all living forms, including humans. This study presents the results of long-term monitoring and evaluation of selected parameters of soil in terms of sustainable land use in the marginal areas of the northeastern Slovakia During 1997–2013 (48º57'N, 20°05'E). Physical (bulk density, porosity), chemical (pH, anorganic nitrogen, available phosphorus, potassium, magnesium and organic carbon content) and biological (soil enzyme activity – urease, alkaline and acid phosphatase) soil properties and available heavy metal content (Cd, Pb and Ni) were monitored and statistically evaluated. The results show that in assessing the quality of soil and environmental pollution of soil the microbial parameters (activity of soil enzymes) appear to be useful. These parameters rapidly respond to environmental stress and can lead to changes in physical and chemical properties leading to early detection of soil degradation.

Key words: ecological farming system, chemical properties, physical properties, soil enzymes, heavy metals

INTRODUCTION

The soil is in its scope and function key component of nature, so it is inevitable to ensure its sustainable development. Without sustainable land use the sustainable development of nature as well as sustainable development of economic and social parameters of the society is not thinkable. The basic principle of the philosophy of sustainable use of soil is its protection against any of natural or human-induced degradation. Sustainable land use in Slovakia is conducted according to the principles of ecological management of the soil. Its aim is to change elements for intensification for technology with significant economic and environmental characteristics [Fazekašová 2003]. An essential prerequisite for sustainable use of land and the landscape is to understand their properties, functions and production potential. Soil quality represents the ability of the soil to secure environmental functions in a particular way of using it. In the literature is the term quality of the soil replaced by the term health of the soil in the broad sense of the word expressing the biological protection, and increasing the productivity, quality and environmental health support of all living forms, including humans. In this sense the soil health can be synonymous with sustainability [Doran and Zeiss 2000]. The quality of soil is in significant extent affected by the physical, chemical, biological and biochemical properties [Fazekašová 2012, Wick *et al*. 2002]. Enzymatic activity can be used as soil microbial quality indicator, because the activity of soil enzyme is closely related to the important characteristics of soil. It may show changes sooner than other soil properties [Dick et al. 1996]. Reducing the quality of the soil may be derived from the level of critical burden by hazardous substances [Hronec *et al*. 2010].

The aim of this work is synthetic and comparative analysis of the biological properties of the physical, chemical characteristics of the soil and heavy metals in the soil in the space and time horizon in terms of sustainable land use.

MATERIAL AND METHODS

The research project was carried out during the years 1997–2013 under production conditions in the investigated area Liptovská Teplička (48°57´N, 20°05´E), situated in the marginal region of north-eastern Slovakia. The ecological farming system has been applied here since 1996. The area of Liptovská Teplička is situated in the Low Tatras National Park at an altitude ranging from 846 to 1492 m a.s.l. In terms of geomorphological division, it is a part of the sub-assemblies of the Kraľovohoľske Mountains [Michaeli and Ivanova 2005]. The whole area is situated in the mild zone with sum of average daily temperatures above 10°C ranging from 1600 to 2000 mm and average precipitation of 700–1200 mm.

Soil samples for physical, chemical and biological properties and heavy metals content determination were sampled in spring time in connected stand on 11 permanent research sites (Fig. 1). Soil bulk density and soil porosity were studied and evaluated as the general physical properties in Kopecky physical cylinder with a capacity of 100 cm^3 [Fiala *et al*. 1999]. From the chemical soil characteristics, we monitored and evaluated soil pH in 1 M $CaCl_2$ solution anorganic nitrogen, available phosphorus, potassium and magnesium with Mehlich III and organic carbon content [Fiala *et al*. 1999]. Available heavy metal content (Cd, Pb and Ni) in the soil samples were determinated in 2 M HNO_3 solution using atomic absorption spectrophotometer [Matuškova and Vojtaš 2005]. Monitored biological soil characteristics were as follows: activity of acid and alkaline phosphatase [Grejtovsky 1991] and urease [Chaziev 1976].

The results were evaluated by mathematical – statistical methods by using the statistical program STATISTICA 10.

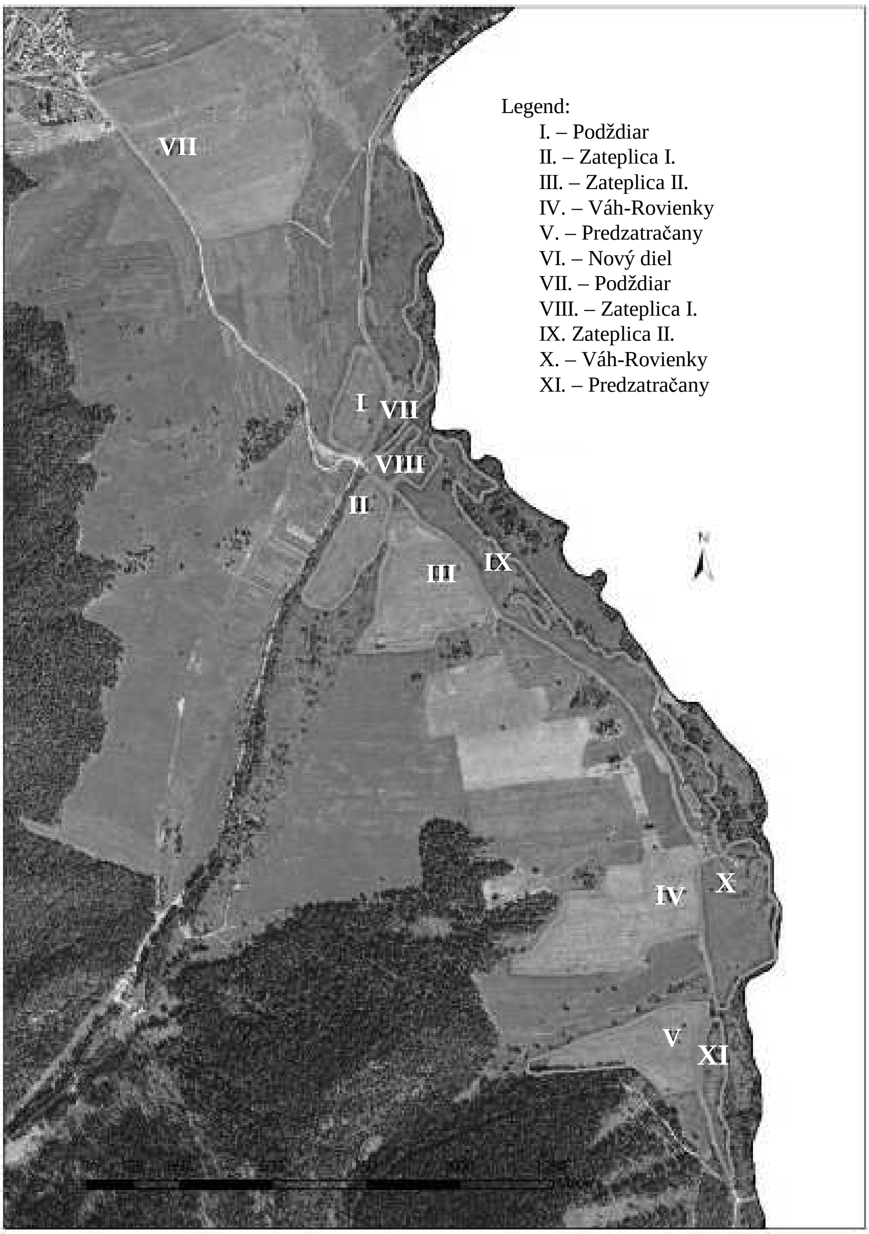

Fig. 1. The map of localization of sampling sites in Liptovská Teplička (Slovakia)
Ryc. 1. Mapa lokalizacji stanowisk w miejscowości Liptovská Teplička (Slowacja)

RESULTS AND DISCUSION

To assess soil quality, we quantified spatial and temporal variability of physical, chemical, biological soil properties and heavy metals in soil and their mutual correlations in terms of ecological management systems in marginal areas of northeastern Slovakia – Liptovská Teplička – the territory which is part of the National Park Low Tatras.

The soil conditions are relatively homogeneous, the largest area being represented by Cambisols, mostly moderate (Fig. 2) and strongly skeletal (Fig. 3), mainly in the subsoil, medium-weight and heavy in granularity (loamy sand, loam, clayey loam) (Fig. 4). From the relief viewpoint, the majority of the land is situated on slopes (Fig. 5).

Long-term studies have shown that organic soil management positively influences the observed physical, chemical and biological soil properties. The measured values of bulk density ranged from 1.04 to 1.35 t m^{-3} (Tab. 1) and reached values comparable with the average values for a given soil type and class [Líška *et al*. 2008]. General porosity is closely related to bulk density. From the total pore volume, this should not fall below 38% for sandy soil and below 48% for clayey-loamy soil [Líška *et al.* 2008]. As seen from Table 1, the values show that, in the observed time frame, porosity levels ranged between 49.15 and 60.56%. Considering this parameter, optimum conditions were created for the growth of most arable crops, which are given by general porosity between 55 and 65% and 20 and 25% soil air content [Rode 1969]. Chemical parameters of soils are considered relatively dynamic (pH, nutrient content); in terms of growth and development are necessary and their lack is reflected in crop production. Sustainable systems exclude or limit the use of commercial fertilizers; for that reason, it is necessary to pay attention to the dynamics of chemical parameters of soil to avoid one-sided exhausting of nutrients from the soil, especially phosphorus and potassium [Fazekašová 2003].

Within the monitoring of soil chemical parameters, we have focused on soil reaction (pH/$CaCl_2$), Nanorg, Pavail, Kavail and Mgavail as well as Cox. Soil reaction during the research period fluctuated minimally and ranged in categories weakly acidic (5.77) to neutral (7.13). This fact can be attributed to organic farming, where physiologically acidic mineral fertilizers are not applied; on the contrary – high doses of organic fertilizers (manure at a dose of 60 t ha^{-1}) were applied. Humus content and quality are among the factors that affect soil fertility and also serve as one of the main indicators of soil quality and health. The values of Cox ranged from 2.25 to 3.61%, which on conversion to humus (conversion coefficient 1.724) are medium and good humic soils [Vilček *et al*. 2005].

Most of the nitrogen in the soil is bound in organic compounds (95 to 98%) and just a small part falls on inorganic nitrogen [Kotorová and Šoltysová 2011]. In our long-term research has been reported moderate to high levels of N_{anorg}.

Phosphorus is firmly fixed in soil and its proportion is relatively stable and dependent on soil reaction values. The value of soil pH did not change significantly in the investigated area and the proportion of available phosphorus changed only minimally. The proportion of potassium and magnesium was relatively stable during the research period (Tab. 1).

The urease values ranged from 0.454 to 0.674 mg $NH4^{+}$-N g^{-1} 24 h^{-1}, and the values of acidic and alkaline phosphatise between 264.35 and 329.33 µg P g^{-1} 3 h^{-1} (Tab. 1). These are values typical for sparse-vegetation soils [Burns 1978].

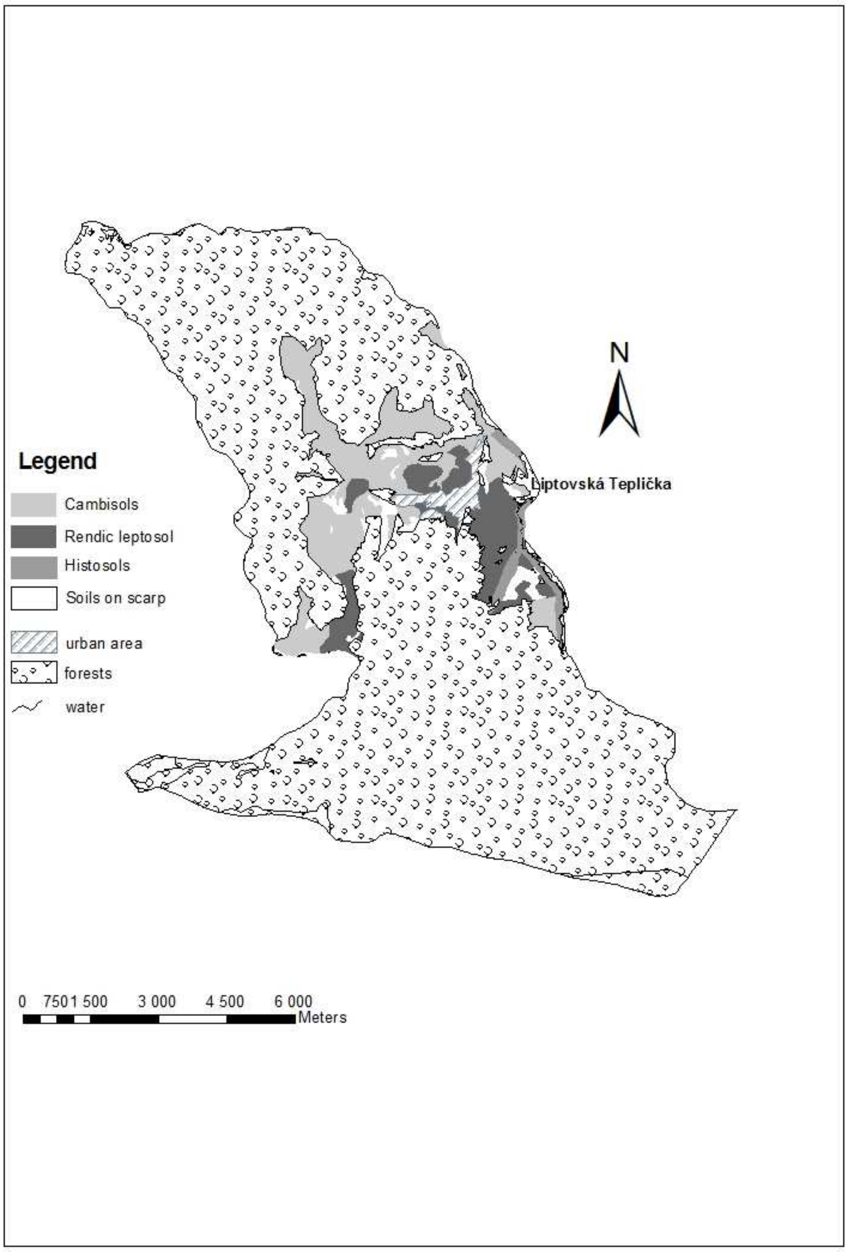

Fig. 2. Map of soil types studied area (Liptovská Teplička, Slovakia)
Ryc. 2. Mapa typów gleby na badanym obszarze (Liptovská Teplička, Slowacja)

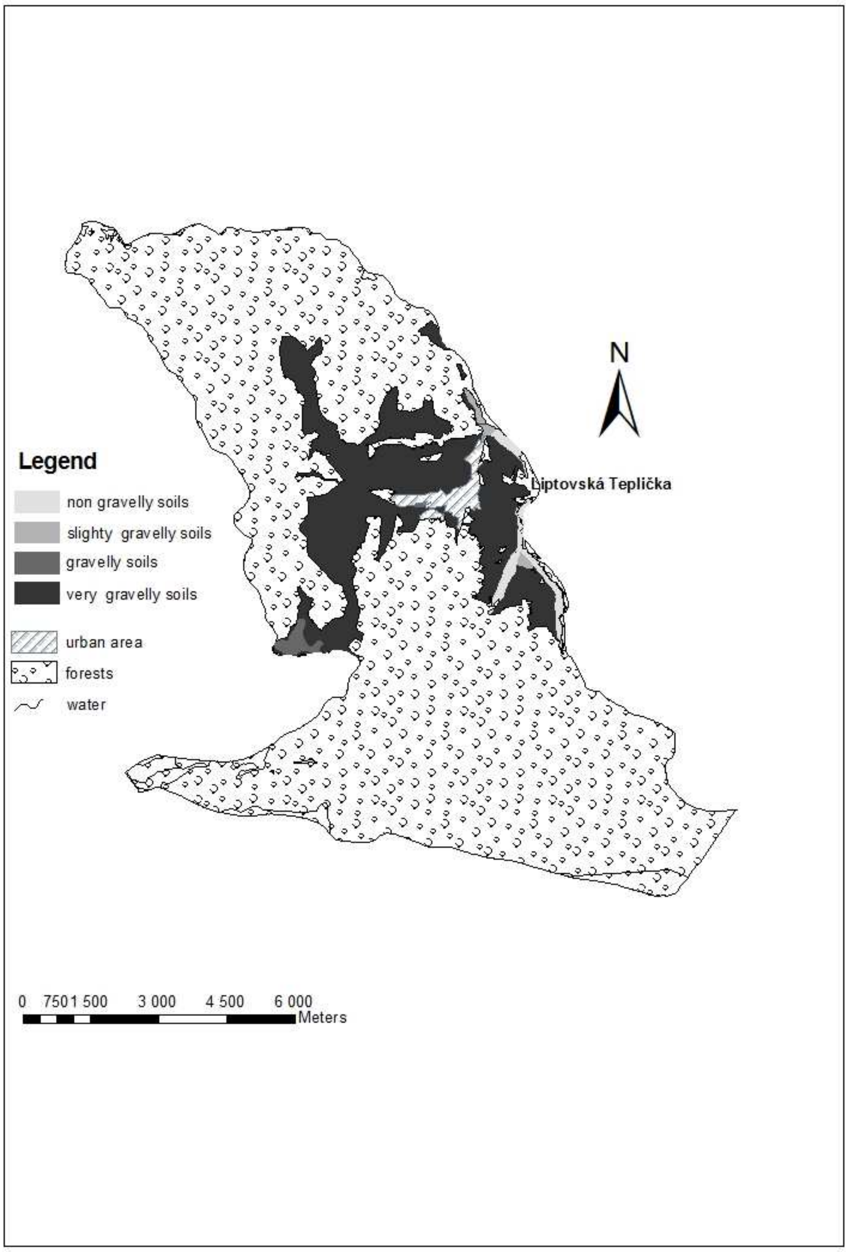

Fig. 3. Map of skeletal studied area (Liptovská Teplička, Slovakia)
Ryc. 3. Mapa szkieletowa badanego obszaru (Liptovská Teplička, Slowacja)

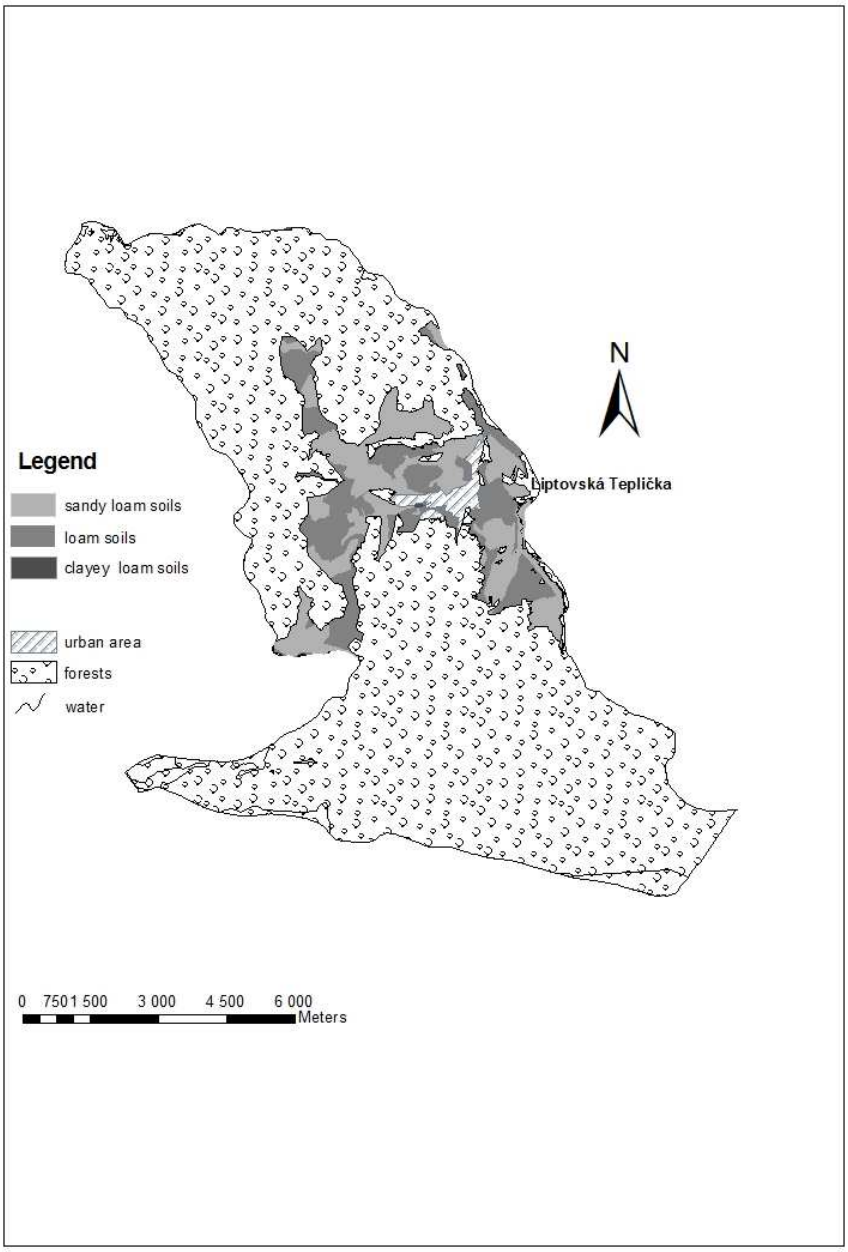

Fig. 4. Map kinds of soil studied area (Liptovská Teplička, Slovakia)
Ryc. 4. Mapa rodzajów gleby na badanym obszarze (Liptovská Teplička, Slowacja)

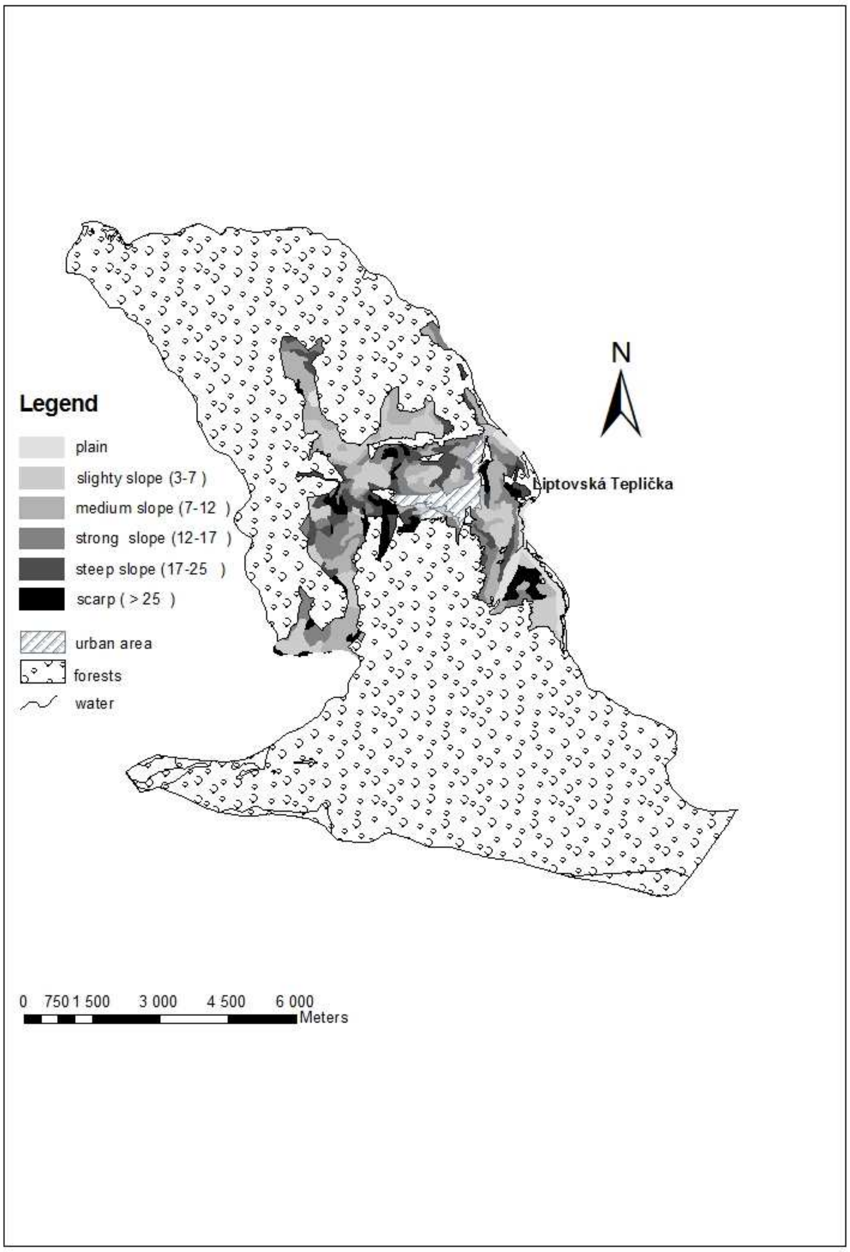

Fig. 5. Map sloping studied area (Liptovská Teplička, Slovakia)
Ryc. 5. Mapa nachylenia badanego obszaru (Liptovská Teplička, Slowacja)

In terms of sustainable land use and following the above findings, we monitored hazardous elements as lead, cadmium and nickel (in extract of 2M HNO_3) (Tab. 1). The evaluation found that the content of hazardous elements in the soil reached maximum admissible values for the Slovakia Republic (act. no. 220/2004 Coll.) and the measured values responded to the natural content of elements in soil and parent rock. At the same time in the ecological systems there is no anthropogenic pollution caused by application of chemicals and sludge into the soil [Makovníková *et al*. 2006].

Table 1. Analysis of variance of the physical and chemical parameters of the soil, soil enzymes and heavy metals in studied area (Liptovská Teplička, Slovakia)
Tabela 1. Analiza wariancji dotycząca fizycznych i chemicznych właściwości gleby, enzymów glebowych oraz metali ciężkich na badanym obszarze (Liptovská Teplička, Slowacja)

Parameter/Parametr	Min.	Max.	Mean Średnia	Standard error Błąd standardowy	P	Source of variability Źródło zmienności
Bulk density Gęstość objętościowa ($t\ m^{-3}$)	1.04	1.35	1.18	0.016347	++	year/rok locality/miejscowość
Porosity Porowatość (%)	49.15	60.56	55.52	0.617864	++	year/rok locality/miejscowość
pH/$CaCl_2$	5.77	7.13	6.41	0.083124	-	year/rok locality/miejscowość
C_{ox} (%)	2.25	3.61	3.03	0.084802	-	year/rok locality/miejscowość
$N_{anorg}/N_{nieorg.}$ ($mg\ kg^{-1}$)	16.76	40.50	27.52	1.698623	++	year/rok locality/miejscowość
$P_{avail}/P_{dost.}$ ($mg\ kg^{-1}$)	19.97	127.88	64.63	3.494827	++	year/rok locality/miejscowość
$K_{avail}/K_{dost.}$ ($mg\ kg^{-1}$)	168.59	427.98	290.91	12.5772	++	year/rok locality/miejscowość
$Mg_{avail}/Mg_{dost.}$ ($mg\ kg^{-1}$)	215.98	301.43	265.0	4.918103	++	year/rok locality/miejscowość
Pb 2M HNO_3 ($mg\ kg^{-1}$)	7.77	22.18	14.11	0.823555	++	year/rok locality/miejscowość
Cd 2M HNO_3 ($mg\ kg^{-1}$)	0.129	0.697	0.343	0.037233	++	year/rok locality/miejscowość
Ni 2M HNO_3 ($mg\ kg^{-1}$)	0.934	3.436	2.392	0.140375	++	year/rok locality/miejscowość
Urease/Ureaza ($mg\ NH_4^+ - N\ g^{-1}\ 24\ h^{-1}$)	0.454	0.674	0.551	0.007954	++	year/rok locality/miejscowość
Acid phosphatase Fosfataza kwaśna ($\mu g\ P\ g^{-1}\ 3\ h^{-1}$)	271.23	306.77	294.91	2.65001	++	year/rok locality/miejscowość
Alcaline phosphatase Fosfataza zasadowa ($\mu g\ P\ g^{-1}\ 3\ h^{-1}$)	264.35	329.33	291.97	1.96567	++	year/rok locality/miejscowość

$^{++}P < 0.01$, $^{+}P < 0.05$

Table 2. Correlation dependence between the physical, chemical soil parameters, heavy metals and soil enzymes in studied area (Liptovská Teplička, Slovakia)
Tabela 2. Korelacja między fizycznymi i chemicznymi parametrami gleby, metalami ciężkimi oraz enzymami glebowymi na badanym obszarze (Liptovská Teplička, Slowacja)

Parameter/Parametr	Urease/Ureaza	Acid phosphatase Fosfataza kwaśna	Alcaline phosphatase Fosfataza zasadowa
Bulk density Gęstość objętościowa	-0.088	-0.036	-0.032
Porosity/Porowatość	0.089	0.036	0.033
pH/$CaCl_2$	0.255	-0.207	-0.164
C_{ox}	0.176	0.086	0.022
$N_{anorg}/N_{nieorg.}$	0.012	0.119	0.066
$P_{avail}/P_{dost.}$	0.297	-0.173	-0.125
$K_{avail}/K_{dost.}$	**0.378**$^{+}$	**-0.322**$^{+}$	-0.099
$Mg_{avail}/Mg_{dost.}$	-0.285	-0.281	-0.280
Pb	-0.057	**0.441**$^{+}$	**0.378**$^{+}$
Cd	-0.039	0.220	0.258
Ni	-0.293	**0.492**$^{+}$	**0.354**$^{+}$

$^{++}P < 0.01$, $^{+}P < 0.05$

Analysis of variance confirmed statistically significant effect of year and location on all monitored soil parameters except pH/$CaCl_2$ and C_{ox} (Tab. 1). Statistical testing confirmed the correlation dependence between K_{avail} and urease, acid phosphatase and K_{avail}, Pb and Ni and between alcaline phosphatase and Pb and Ni (Tab. 2). Based on the above, we can conclude, in accordance with the opinion of Zhang *et al.* [2008] that the activity of soil enzymes is a useful indicator of soil quality and health.

CONCLUSION

Research has shown that physical, chemical and biological soil properties were stable and achieved comparable values for a given soil type and species. High doses of organic fertilizers had a positive impact on soil fertility, and thus indirectly to maintain the pH of the soil, the content of available nutrients and accumulation of humus in the soil. This study underlines the importance of long-term monitoring of soil in determining changes in soil ecosystem and evaluating soil quality.

Based on synthetic and comparative analysis of biological properties of the physical and chemical characteristics of the soil as well as heavy metals in the spatial and time horizon in terms of sustainable land use, we can conclude that in assessing the quality of soil and environmental pollution of soil, the microbial parameters (activity of soil enzymes) appear to be useful. These parameters rapidly respond to environmental stress and can lead to changes in physical and chemical properties resulting in early detection of soil degradation.

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Streszczenie. Jakość gleby jest zdolnością gleby do zachowania funkcji środowiskowych w danym sposobie jej użytkowania. Zdrowotność gleby wyraża ochronę oraz rosnącą wydajność biologiczną, jakość środowiskową oraz wspieranie zdrowia wszystkich form żywych, łącznie z ludźmi.

Niniejsze badanie przedstawia wyniki długoterminowego monitorowania oraz oceny wybranych parametrów gleby w kategoriach zrównoważonego użytkowania ziemi na północno-wschodnich krańcach Słowacji w latach 1997–2013 (48º57'N, 20°05'E). Monitorowano i statystycznie oceniono fizyczne właściwości gleby (gęstość objętościowa, porowatość), chemiczne (pH, azot nieorganiczny, zasobność w fosfor, potas, magnez oraz zawartość organicznego węgla), a także biologiczne (enzymatyczna aktywność gleby – ureaza, zasadowa i fosfataza kwaśna) oraz zasobność w dostępne metale ciężkie (Cd, Pb i Ni). Rezultaty wskazują, że parametry mikrobiologiczne (aktywność enzymów glebowych) wydają się przydatne do oceny jakości gleby i jej środowiskowego zanieczyszczenia. Te parametry gwałtownie reagują na stres środowiskowy i mogą powodować zmiany fizycznych i chemicznych właściwości gleby, co umożliwia wczesne wykrycie jej degradacji.

Słowa kluczowe: system ekologicznej uprawy, właściwości chemiczne, właściwości fizyczne, enzymy glebowe, metale ciężkie