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DEVELOPMENT OF BIOCHEMICAL PARAMETERS OF SOIL IN CONDITIONS OF SUSTAINABLE USE OF SOIL

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Abstract

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The investigation was carried out during the years 1997-2000 and 2008-2009 under the production conditions of the marginal region of north-eastern Slovakia. The aim of the research was the monitoring of the basic chemical soil properties (pH, N_{total}, N_{inorg}, P_{avail}, K_{avail}, Mg_{avail}, Co_x) in relation to soil enzymes (acid phosphatase, alkaline phosphatase, urease), in the conditions of sustainable use of soil in the temporal and spatial dimension. From the point of view of application of ecological approaches in plant production, the biologically balanced rotation of crops was applied with adequate proportion of plants that regenerate soil fertility and protect the environment. Monitored biochemical soil properties did not changed significantly during the research period. High doses of organic fertilizers had positive effect on soil productivity, and thus indirectly on maintaining soil pH, available nutrients content, retention of humus in soil and promotion of natural protection of soil enzymes. Linear regression showed significant dependence between content of C_{ox} and alkaline phosphatase, between available potassium and urease and between available magnesium and urease, acid phosphatase and alkaline phosphatase.

Key words: ecological agriculture, agrochemical properties of soil, enzymatic activity

Introduction

For evaluation of soil development, standard characteristics of soil environment – physical, chemical and biological are used. The physical ones are bulk capacity, porosity, water retention capacity, soil temperature etc. To chemical characteristics belong total carbon and nitrogen content and available nutrients content. Evaluation of biological parameters focuses on microbial mass and its activity, soil respiration, potentially mineralised nitrogen, soil enzymes activity etc. The enzymatic activity can be used as a microbial indicator of soil quality. Soil enzyme activity is in a close relationship to important soil characteristics, it indicates the changes earlier than other soil characteristics and can be a integrating soil-biological index reflecting soil utilization (Javoreková et al., 2008; Šarapatka, 2002; Ďugová, Šimonovičová, 2008). Selected enzymatic activities are considered as an applicable indicator for a long-term soil monitoring and quality assessment (Wick et al., 2002; Miralles et al., 2007; Geisseler, Horwath, 2009).

At the present time, there is little knowledge about soil development in the conditions of sustainable farming systems, principles of which consist of soil maintenance in an effort to increase its natural productivity, following as closed a cycle as possible with highest possible reduction of external, mainly energetic and chemical inputs (Lacko-Bartošová et al., 2005; Fazekašová, 2003; Duguma et al., 2010). Present findings are difficult to compare due to the different soil-ecological conditions in which they were obtained.

A general issue in research of the soil environment is using a universal method for every type of soil. Without integration in this area, objective comparison will remain on the level of region or country. Delimitation of soil parameters is usually related specifically to topsoil. Certain physical and chemical parameters in subsoil cannot be neglected regarding guaranteed soil functions (Bujnovský, Juráni, 1995; Fazekašová et al., 2011).

The goal of our research was monitoring of basic chemical soil characteristics in relation to soil enzymes in the conditions of sustainable soil utilization, both in a temporal and spatial dimension.

Material and methods

The research project was carried out during the years 1997–2000 and 2008–2009 under production conditions in the investigated area Liptovská Teplička (48°57' N; 20°05' E), situated in the marginal region of north-eastern Slovakia (Špulerová et al., 2011). The ecological farming system has been applied here since 1996.

The area of Liptovská Teplička is situated in the Nízke Tatry 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 Kráľovohoľské Mts. The whole area is situated in the mild zone with sum of average daily temperatures above 10 °C ranging from 1600 to 2000 and average precipitation of 700–1200 mm (Boltižiar et al., 2008).

T a b l e 1. Particle grain-size composition of soil (%) of the studied area Liptovská Teplička in depth 0.05–0.15 m.

Diameter of the particles (mm)	Studied locality					
	I.	II.	III.	IV.	V.	VI.
	Cambisols	Histosols	Cambisols	Cambisols	Cambisols	Cambisols
> 0.25	31.3	24.9	14.5	11.5	32.5	16.0
0.25–0.05	21.6	13.9	15.5	18.9	13.9	14.9
0.05–0.01	27.8	27.7	32.4	24.3	22.2	31.3
0.01–0.001	15.5	27.4	29.3	34.3	24.0	29.6
< 0.001	3.8	6.1	8.3	11.0	7.4	8.2
I. Category	19.3	33.5	37.6	45.3	31.4	37.8
Soil	loamy sand	loam	loam	clayey loam	loam	loam

The soil conditions are relatively homogeneous, the largest area being represented by Cambisols mostly moderate and strongly skeletal, mainly in the subsoil. The second most common type of soil is Rendzic, moderate, shallow and skeletal. In addition, Histosols occur in this territory (Table 1). From the point of view of relief, the majority of the land is situated on the slopes.

In the current crop structure cereal acreage represents 33.3%, potatoes 16 to 18% and fodder crops 49.8%. Crop rotation is as follows: perennial fodder (clover mixture), perennial fodder (clover mixture), winter crops (winter wheat, winter rye, triticale and winter barley), root crops (potatoes), spring crops (spring barley, oats), annual mixture (oats pea, peas, ryegrass). Arable land is fertilized with manure dosage of about 30 t ha^{-1} once in two years. The permitted phosphorous and potassium mineral fertilizers were not added in the last five years). The permanent grassland and arable land were fertilized with the Natural Harmony fertilizer in the spring season, 3 000 l ha^{-1} (minimum nutrients content: total nitrogen expressed as N in dry mass at least 15%, total phosphorus as P_2O_5 in dry mass less than 0.2%, total potassium as K_2O in dry mass less than 0.4%, total sulphur as S in dry mass at least 16.5%).

The soil samples for chemical and biological soil properties determination were sampled in spring time in connected stand and in summer before harvesting, on six permanent research sites (I.–VI.), from the depth of 0.05 to 0.15 m.

From the chemical soil characteristics, we monitored and evaluated soil pH in 1N solution KCl and $CaCl_{2,}$ total nitrogen (Joldbauer), inorganic nitrogen, available phosphorus, potassium, and magnesium with Mehlich III, organic carbon (Fiala et al., 1999). Monitored biological soil characteristics were as follows: activity of acid and alkaline phosphatase (Grejtovský, 1991) and urease (Chazijev, 1976). Obtained data were statistically processed using analysis of variance from StatGraphic package, and evaluated according to Grofík and Fľak (1990).

Results and discussion

The chemical parameters are considered relatively dynamic (pH, nutrient content), in terms of plant growth and development. Their deficiency is reflected on the crop production. At the same time they serve as indicators of additional inputs in the form of fertilizers. Sustainable farming systems exclude, or reduce artificial fertilizers use, therefore, it is necessary to pay attention to the dynamics of chemical soil parameters changes in order to prevent one-way draining of nutrients, particularly phosphorus and potassium.

Soil pH is one of important factors of soil fertility despite the fact, that its values changes dynamically depending on so called internal and external factors. During the monitoring period the value varied minimally, and the average value of soil reaction, expressed in pH/KCl and pH/$CaCl_2$, ranged between 6.3 and 6.6 (Table 2). This can be assigned to the ecological farming system, because the physiologically acid mineral fertilizers were not applied, and the organic fertilizers (manure at the dosage 30 t ha^{-1} and Natural Harmony at the dosage 3000 l ha^{-1}) were applied. Organic matter positively influences the buffering capacity of soil and thus the soil reaction was not reduced. However, it is necessary to continuously pay attention to soil reaction, because soil is naturally acidified through acid atmospheric fallout as well as calcium uptake off by plants.

There is a little probability that increasing of the total nitrogen content has a positive effect on the soil fertility (Bielek, 1998). This applies only for productive and highly productive soils. For the soils with low production capacity, the investigated area belongs, a reciprocal relationship between total nitrogen content and soil fertility is typical. Total nitrogen in soil, 95 to 98% is bound in organic forms; fertility functions are conditioned to mechanisms of its accessibility to plants. It is mainly organic nitrogen mineralization, more specifically the part of mineralization, which prevails over carbon immobilization that relates to fertility. In the soil-ecological conditions of the investigated area (mild zone with sum of average daily temperatures above 10 °C ranging from 1600 to 2000 °C and average precipitation of 800–1100 mm), the nitrogen mineralization is less intensive (optimal temperature for intensive process is 28–30 °C), therefore, the content of mineral, i.e. immediately available nitrogen may not be high even at high levels of total nitrogen (Table 2). The assumption is that addition of high doses of organic fertilizer will increase the total nitrogen content, but growing legumes included in the crop rotation can increase the content of immediately available nitrogen. These crops leave high amounts of nitrogen in soil, (more than 100 kg ha^{-1} N), which are available for the following crops (Jurčová, Torma, 1998; Kováčik, 2001).

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 changed significantly in the investigated area during 1997–2000 and 2008–2009, and the proportion of available phosphorus changed only minimally (Table 2).

The proportion of potassium and magnesium was relatively stable during the research period (Table 2). Due to the grain structure of the soils (medium and heavy soils) these nutrients are bound to on the soil particles and are not liable to soil washing in spite of high precipitation throughout the year.

Humus content is a parameter that is liable to significant changes during longer periods of time. Application of high amounts of organic fertilizers had an effect on maintaining or slight increasing of humus content. The values of $\%CO_x$ ranged from 2.16 to 4.42, which on conversion to humus (conversion coeficient 1.724) are medium and good humic soils (Vilček et al., 2005). Our research confirmed suitability of the area for ecological farming, at the same time the positive influence of the applied system on humus balance in soil.

We do not have as much information about biological soil parameters as we do about the physical and chemical ones, despite the fact that the effect of edaphon on biochemical processes in soil, nutrients balance, soil structure, etc is proven in general. There are a number of enzymes in soil, depending on diversity of soil organisms and conditions of organic substances turnover. The enzymes are present in the cells of the living organisms in soil (bacteria, fungi, algae, and soil fauna) and plant roots. The major sources of enzymes in soils are microorganisms. The amount and quality of enzymes in soils is dependent on their characteristics, number and forms of organic matter and activity of microflora. Enzymatic soil is activity is higher in fertile soils with plenitudes of organic matter. The highest proportion of various enzymes can be found in the humus soil horizon (Pejve, 1966). Soil enzymes activity can be enhanced by using organic fertilizers (Burns, 1978; Iovieno et al., 2009; Chander et al., 1997).

Soil pH differs from the pH optimal for phosphatase activity. Soil phosphatase can be inactive, if the differences between soil pH and optimal pH of an enzyme are too large. Soil phosphatase activity is higher in soils with higher humidity in comparison to dry soils or the soils with normal humidity. Phosphatase activity declines with increasing depth, which is caused mainly by lower biological activity in lower soil profiles. Inorganic phosphate, T a b l e 2. Basic chemical and biological soil properties on the localities of the studied area Liptovská Teplička (depth of sampling 0.05–0.15 m).

Parameter	Locality	1997	1998	1999	2000	2008	2009
pH	I.	6.5	6.3	6.8	6.3	6.8	6.9
	II.	5.9	5.8	6.2	6.2	6.1	6.6
	III.	6.7	6.8	6.4	5.5	5.9	6.4
	IV.	5.9	5.8	5.3	6.5	6.7	6.8
	V.	6.2	6.6	6.4	6.2	5.4	5.6
	VI.	6.9	6.6	7.0	7.0	7.0	7.2
	average	6.4	6.3	6.4	6.3	6.3	6.6
CO_x (%)	I.	2.62	2.51	2.36	3.45	2.77	2.96
	II.	3.76	3.36	3.23	3.23	5.49	4.42
	III.	3.26	2.73	3.43	3.40	3.86	3.52
	IV.	3.22	3.81	2.81	2.82	3.62	3.82
	V.	2.16	2.64	2.49	2.23	2.47	2.63
	VI.	3.55	3.24	3.24	3.46	3.52	3.07
	average	3.10	3.04	2.93	3.10	3.62	3.40
N_{total} ($mg.kg^{-1}$)	I.	-	2800	2758	-	-	-
	II.	-	3515	3906	-	-	-
	III.	-	2700	2779	-	-	-
	IV.	-	2910	2996	-	-	-
	V.	-	2575	2506	-	-	-
	VI.	-	3080	3206	-	-	-
	average	-	2930	3025	-	-	-
N_{inorg} ($mg.kg^{-1}$)	I.	-	-	-	-	30.0	54.5
	II.	-	-	-	-	35.8	14.8
	III.	-	-	-	-	46.4	15.2
	IV.	-	-	-	-	31.7	18.0
	V.	-	-	-	-	43.4	17.1
	VI.	-	-	-	-	33.5	13.8
	average	-	-	-	-	36.8	22.2
P_{avail} ($mg.kg^{-1}$)	I.	21	30	38	57	33	48
	II.	46	38	51	43	34	28
	III.	69	82	57	75	66	87
	IV.	53	29	25	50	76	66
	V.	10	40	47	30	20	20
	VI.	142	123	106	129	154	104
	average	57	57	54	64	64	57
K_{avail} ($mg.kg^{-1}$)	I.	222	258	190	138	185	332
	II.	210	203	188	168	166	155
	III.	307	397	245	309	255	145
	IV.	435	469	340	374	243	226
	V.	231	220	200	207	175	167
	VI.	430	412	400	361	502	371
	average	306	327	261	260	254	233

T a b l e 2. (Continued)

Parameter	Locality	1997	1998	1999	2000	2008	2009
Mg_{avail} (mg.kg^{-1})	I.	237	226	246	303	268	308
	II.	218	213	226	281	280	282
	III.	271	260	216	289	255	271
	IV.	216	235	214	264	308	296
	V.	254	256	255	257	242	279
	VI.	282	250	205	250	347	266
	average	246	240	227	274	283	284
Urease (mg NH_4^+- N.g^{-1}.24 hour^{-1})	I.	0.57	0.67	0.63	0.58	0.50	0.46
	II.	0.56	0.65	0.56	0.53	0.54	0.53
	III.	0.55	0.67	0.66	0.54	0.57	0.61
	IV.	0.59	0.65	0.55	0.53	0.50	0.42
	V.	0.53	0.62	0.55	0.55	0.43	0.31
	VI.	0.59	0.67	0.58	0.53	0.57	0.56
	average	0.57	0.66	0.59	0.54	0.52	0.48
Acid phosphatase (μg P.g$^{-1.3}$ hour^{-1})	I.	287.9	282.1	326.8	343.8	280.6	284.9
	II.	285.5	284.5	312.2	331.6	250.4	274.5
	III.	295.5	287.0	300.1	317.1	300.5	303.1
	IV.	287.9	291.9	304.9	324.3	290.2	300.1
	V.	293.1	296.9	302.5	331.6	278.7	282.7
	VI.	287.9	287.0	309.8	336.5	236.8	237.9
	average	289.6	288.2	309.4	330.8	272.9	280.5
Alkaline phosphatase (μg P.g$^{-1.3}$ hour^{-1})	I.	290.3	291.9	317.0	329.2	282.3	285.1
	II.	287.9	297.0	307.3	309.8	230.6	250.7
	III.	285.5	296.9	304.9	309.8	280.1	291.0
	IV.	290.3	294.4	321.9	331.6	270.3	287.6
	V.	285.5	289.5	309.8	317.1	260.6	277.9
	VI.	290.3	291.9	300.1	336.5	250.9	241.1
	average	288.3	293.6	310.2	322.3	262.5	272.2

copper, mercury and vanadium have considerable inhibitory effect on the soil phosphatase activity (Burns, 1978; Speir et al., 2003). The values of acid and alkaline phosphatase changed minimally during research period and are typical of values for soils with sparse vegetation (Burns, 1978).

The urease enzyme belongs to the hydrolases group of enzymes. It can be found as a free enzyme in soil solution, but more often in firmly bound with soil organic matter or minerals and also inside the living cells (Klose, Tabatabai, 2000; Alef, Nannipieri, 1995). Its activity depends on soil humidity (Baligar et al., 2005), pH, humus content and quality (Tabatabai, Acosta-Martínez, 2000), and total nitrogen content (Nourbakhsh, Monreal, 2004). High sensitivity to excess levels of heavy metals (Kromka, Bedrna, 2000) and the negative effect of

T a b l e 3. Analysis of variance of soil chemical parameters.

Parameter	Source of variability	Degree of freedom	F-value calculated	P significance
pH	locality	5	19.59	++
	year	5	1.99	+
	repetition	3	0.43	-
	residual	130		
	total	143		
CO_x	locality	5	42.75	++
	year	5	10.76	++
	repetition	3	0.10	-
	residual	130		
	total	143		
N_{total}	locality	5	11.92	++
	year	5	1403.69	++
	repetition	3	0.04	-
	residual	130		
	total	143		
N_{inorg}	locality	5	3.12	++
	year	5	149.54	++
	repetition	3	0.00	-
	residual	130		
	total	143		
P_{avail}	locality	5	165.46	++
	year	5	2.06	+
	repetition	3	0.03	-
	residual	130		
	total	143		
K_{avail}	locality	5	73.71	++
	year	5	11.10	++
	repetition	3	0.04	-
	residual	130		
	total	143		
Mg_{avail}	locality	5	1.74	-
	year	5	27.29	++
	repetition	3	0.19	-
	residual	130		
	total	143		
Urease	locality	5	19.28	++
	year	5	54.14	++
	repetition	3	0.30	-
	residual	130		
	total	143		
Acid phosphatase	locality	5	8.33	++
	year	5	68.08	++
	repetition	3	0.83	-
	residual	130		
	total	143		
Alkaline phosphatase	locality	5	13.40	++
	year	5	114.72	++
	repetition	3	1.21	-
	residual	130		
	total	143		

++$P < 0.01$ +$P < 0.05$

triazine herbicides on the activity of the enzymes (Belińska, Prangal, 2007) has been shown. The results of measurements of soil urease activity in years 1997–2000 and 2008–2009 showed minimal differences, which proved that increasing the amount of organic soil matter promotes the preservation of natural soil urease (Bremner, Mulvaney, 1978).

The data obtained in field conditions were tested using statistical methods. Analyses of variance (Table 3) confirmed the statistically significant effect of experimental locality, with exception of available magnesium, on all other chemical soil parameters. The effect of experimental year was not significant on soil pH and content of available phosphorus. On all further tested soil parameter it was statistically significant.

Regression linear analysis showed statistically significant moderate negative dependence (r = -0.418) between content of CO_x and alkaline phosphatase. Trasar-Cepeda et al. (1998), Jordan et al. (1995) and Baligar et al. (2005) mention positive correlations. Significant moderate dependence was detected between available potassium content and urease, acid and alkaline phosphatase. Determined correlation coefficients (Table 4) suggest statistically moderate to significant dependence (Grofík, Fľak, 1990).

T a b l e 4. Correlation coefficients (r) for relationship of soil chemical parameters.

Parameter	Urease	Acid phosphatase	Alkaline phosphatase
pH	0.152	-0.126	-0.104
CO_x	0.033	-0.270	-0.418^{++}
N_{total}	-0.217	0.093	0.051
N_{inorg}	0.005	0.074	0.077
P_{avail}	0.226	-0.128	-0.037
K_{avail}	0.303^{+}	-0.231	-0.023
Mg_{avail}	-0.401^{+}	-0.181	-0.317^{++}

++P< 0.01 +P< 0.05

Conclusion

1. In terms of ecological approaches application in farming, the biologically balanced rotation of crops was applied with adequate proportion of plants that regenerate soil fertility and protect the environment.
2. Agrochemical soil characteristics did not change significantly during the research period. High doses of organic fertilizers had positive effect on soil productivity, and thus indirectly on maintaining soil pH, available nutrients content and retention of humus in soil.
3. The values of activity of phosphatases and ureases changed minimally during the research period and they refer to the values typical for soils with sparse vegetation. At the same time, it was proven that increasing the content of soil organic matter promotes natural protection of soil enzymes.

4. Analysis of variance confirmed the statistically significant effect of experimental locality, with exception of available magnesium. The effect of experimental year had significant effect on tested soil parameters, with the exception of soil pH and content of available phosphorus.
5. Linear regression linear analysis showed statistically significant moderate dependence between content of Cox and alkaline phosphatase, and between available potassium content and urease. Statistically significant dependence was also proven between available magnesium content and urease, acid phosphatase and alkaline phosphatase.

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