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Evaluation of Soil Quality Parameters Development in Terms of Sustainable Land Use

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1. Introduction

Soil is a vital natural source and, at the same time, has an economic and eco-social potential. It allows the production of food and raw materials, recycles waste, creates forest-agricultural land, filters and retains water, allows the usage and valorisation of sun energy, ensures the cycle and balance of substances in nature, maintains diversity of plant and animal species. It primarily shapes the quality of the environment; it is the resource and cultural heritage of the Earth; it ensures the life and social being of the population. Agricultural activities realised in landscape affect natural resources. A rational usage of renewable and non-renewable resources which are not retrieved in real time is an essential precondition.

The farming system is the most widespread environmental technology with its positive and negative consequences. It utilises essential natural resources and, at the same time, influences other natural environments. Therefore, ecologisation of farming is a priority of farmers as well as environmentalists. Respecting the principles of soil sustainability and other components of environment is the basic precondition for life sustainability.

A United Nations [UN] conference on environment and development (Rio de Janeiro, 1992) prioritised sustainable development, which is presented in a global development programme for the end of the 20th century and especially for the 21st century (Agenda 21). The concept of sustainable development of agriculture includes such practices in farming which respect ecological aspects in growing plants and ethology of livestock in rearing, do not enhance damage in ecological land stability, respect environmental protection, including surface and underground water and monitor the quality of agricultural produce.

Sustainable agriculture is based on the principle of agriculture being a biological process which, in practice, should imitate key characteristics of the natural ecosystem. It strives to

bring diversity into agro-ecosystem, recycle nutrients efficiently and maintain the priority of sunlight as a source of energy for agro-ecosystems.

Specific manifestations of soil require different approaches. In soil protection, these must be ecological (biological) approaches, as this is the only way to achieve sustainable development of ground cover and the resulting economical and social development and environmental balance in society.

Sustainable use of soil takes soil-ecological conditions into consideration and is realised in such a way and in such intensity, which gives rise to neither negative changes in soil, nor establishes trends for the development of negative characteristics in soil. The essential principle of sustainable farming system is its protection from any degradation by natural or man-induced influences. Sustainable development of soil use also encompasses the protection of the soil acreage to such an extent which ensures that all soil functions are employed.

In a number of European countries, sustainable use of soil is realised according to the principles of International Federation of Organic Agriculture Movements [IFOAM] and is referred to as ecological soil management. When introducing ecological systems of soil management, the main criterion is the application of knowledge in the functioning of natural ecosystems, which are typical of plant and animal variety and sunlight is the exclusive source of energy. In cultural (artificial) agro-ecosystems, the structure is disrupted by man drawing the production past the limit of the agro-ecosystem. The ecological system focuses on theoretical elaboration of farming arrangement in sensitive areas (the protection of underground and surface water zones, polluted zones, national parks, protected natural areas and soils heavily endangered by erosion). Continued protection of nature and natural resources is at the forefront; therefore, significant intensifying constituents of conventional agriculture (high dosage of fertilisers, full usage of pesticides, annual subsoil ploughing, major hunts, high ratio of grain crops, intensive breeding, heavy automation) are replaced by technologies with strong economical and ecological components (tillage minimisation, anti-erosive crop rotation, monitoring of plant nutrition, integrated a biological protection of plants, minimal automation, free-range breeding).

According to Organisation for Economic Co-operation and Development [OECD], an indicator is a parameter or a value derived from several parameters. It provides information about a particular observed phenomenon from the viewpoint of its quantitative or qualitative characteristics, present in a give time and area, in the environment as a whole, or its individual components by the qualitative parameters of these components influencing the health condition of the population, as well as the structure and function of the ecosystem in the area in question. From the above stated, it results that there are a number of horizontal and vertical causal links between individual environmental indicators. The "sustainability indicator" can, thus, be defined as a measurable factor, whose imbalance negatively influences the long-term performance of the whole production system. Stable agriculture has a time and space dimension. The time scale depends on the adaptability of the system (usually 5 to 10 years, or more); space can be given by the borderlines of soil-

climatic units or areas. Stability indicators should be applicable to the evaluation of the main components of sustainable agriculture. Attention is mainly paid to the level of farming and its productivity regarding the ecological soil potential, maintaining diversity of plant species as well as the protection of natural resources, social-economic viability related to the regional and world economy.

From the viewpoint of agricultural practice, the stability indicators regarding productivity of agricultural production and ecological aspects of farming systems have been explored in most detail. The guaranteed yield on the level of the ecological potential of location (without further input increase), the ability of the system to return to the initial performance in a short period of time after a natural disaster, achieving a relatively high efficiency of water and plant nutrition utilisation, maintaining the soil quality environment (organic mass, soil organisms, nutrients), reliability of the methods used in integrated plant protection, ensuring the quality of water resources, maintaining the level of underground water without major fluctuations, and protecting natural resources are considered quantifiable biophysical indicators of sustainable productivity (Klír, 1997). With regard to the evaluation of ecological sustainability, the most significant indicators are maintenance and improvement of biodiversity in managed, as well as adjacent natural ecosystems, maintaining the environmental quality and avoiding pollution limit excess (Virmani & Singh, 1997 as cited in Fazekašová, 2003).

It is impossible to select universal soil parameters with regard to their suitability for sustainable soil and is subject to specialised discussions. A significant role in the selection of parameters is played by their variability in time, related to parameter stability. The following soil parameters can be distinguished: stable (such as soil depth or granularity), relatively stable (the salt content, the content of organic mass in soil, heavy metal contamination), relatively dynamic (pH, the content of nutrients), and dynamic (soil humidity and temperature, microbial activity, etc.). Stable and relatively stable parameters dominantly influence soil quality, while relatively dynamic and dynamic characteristics are more connected to its short-term changes.

Soil parameters indicate the state of soil ecosystem characteristics, which especially reflect production, buffering, filter and other soil functions. From this view, the structure of soil profile (the soil class), soil type, soil depth, skeletal nature, the content and quality of humus substances, accessible nutrient supply, soil reaction, the content of foreign substances in soil, and soil edaphon seem to be of highest importance.

Soil quality cannot be judged directly; it must be determined from the changes of its parameters. It is more accurate to evaluate the range of appropriate indicators rather than to use a single one. Soil quality is significantly affected by physical, chemical, biological and biochemical properties sensitive to changes in the environment and land management. With regard to physical properties, there are bulk density, porosity, water retention capacity, soil temperature, etc. In the group of chemical characteristics, total carbon and nitrogen content, soil reaction and content of available nutrients are observed. Evaluation of biological parameters focuses on microbial biomass and its activity, soil respiration,

potentially mineralised nitrogen, the activity of soil enzymes, etc. Soil enzymatic activity can be used as a microbial indicator of soil quality, since the activity of soil enzymes is closely related to essential soil characteristics. It indicates changes sooner than other soil characteristics and can be an integrating soil-biological index reflecting soil use (Javoreková et al., 2008; Šarapatka, 2002). Wick et al. (2002) considers selected enzymatic activities as suitable indicators for long-term soil monitoring and quality assessment (Miralles, 2007; Geisseler, 2009). A decrease in soil quality is obvious from the values of critical load of risk substances. When evaluating the content of heavy metals in soil, attention must also be paid to their bio-accessibility (Bujnovský & Juráni, 1999).

The chapter deals with a synthetic and comparative analysis of scientific findings regarding the development of soil quality parameters in the conditions of a sustainable farming system. Based on the research carried out between 1997 and 2010 on a model area situated in a marginal region of north-eastern Slovakia (48° 57' N; 20° 05' E), the development of soil indicators are evaluated, focusing on physical (bulk density and soil porosity), chemical (soil pH, inorganic nitrogen, available phosphorus, potassium, magnesium and organic carbon content) and biological parameters (activity of acid and alkaline phosphatase and urease), as well as the presence of risk substances in the soil ecosystem (heavy metal content - Cd, Ni and Pb).

2. Evolution of soil parameters

At present, there is little knowledge with regard to soil development in the conditions of sustainable farming systems whose principles lie in soil maintenance. There is a major effort to increase its natural productivity by as closed a cycle of nutrients as possible with the highest possible reduction of external, mainly energetic and chemical, inputs (Lacko-Bartošová et al., 2005; Fazekašová, 2003). The present findings can hardly be compared to other research due to the different soil-ecological conditions in which they were obtained. The issue of universal methods for all soil types remains a universal problem within the research of soil development. Unless this area is unified, objective comparison will remain on a regional level. Soil parameters are usually determined only in relation to specific topsoil. Certain physical and chemical parameters in subsoil cannot be neglected, since they guarantee soil functions (Fazekašová, 2003).

2.1. Methods

The research project was carried out between 1997 and 2000 and 2008 and 2010 under production conditions in the investigated area situated in a marginal region of north-eastern Slovakia (48° 57' N; 20° 05' E). Here, the ecological farming system has been applied since 1996. The area is situated in the Low Tatras National Park at an altitude ranging from 846 to 1492 m above sea level. In terms of geomorphological division, it is a part of sub-assemblies of the Kráľovohoľské Mountains (Michaeli & Ivanová, 2005). The whole area is situated in a mild zone with a sum of average daily temperatures above 10 °C ranging from 1600 to 2000 and average precipitation of 700-1200 mm (Fig. 1).

The soil conditions are relatively homogeneous, the largest area being represented by Cambisols, mostly moderate and strongly skeletal, mainly in the subsoil, medium-weight and heavy in granularity (loamy sand, loam, clayey loam). Cambisols are the most common soil type occurring in Slovakia. From an ecological viewpoint, Cambisols are valuable for their irreplaceable ability to retain and accumulate atmospheric fallout and also for their filtration attributes. From the relief viewpoint, the majority of the land is situated on slopes, soil is often eroded and, thus, surface water resources are threatened. With regard to pollution, there is an assumption that heavy metals are transported to crops (due to the acidity of these soils). In the current crop structure, cereal acreage represents 33.3 %, potatoes 16 % to 18 % and fodder crops 49.8%. Crops are rotated 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 fertilised with manure dosage of approximately 30 t ha^{-1} once in two years. The permitted phosphorous and potassium mineral fertilisers have not been added in the past five years. The permanent grassland and arable land were fertilised with liquid organic fertiliser 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 %).
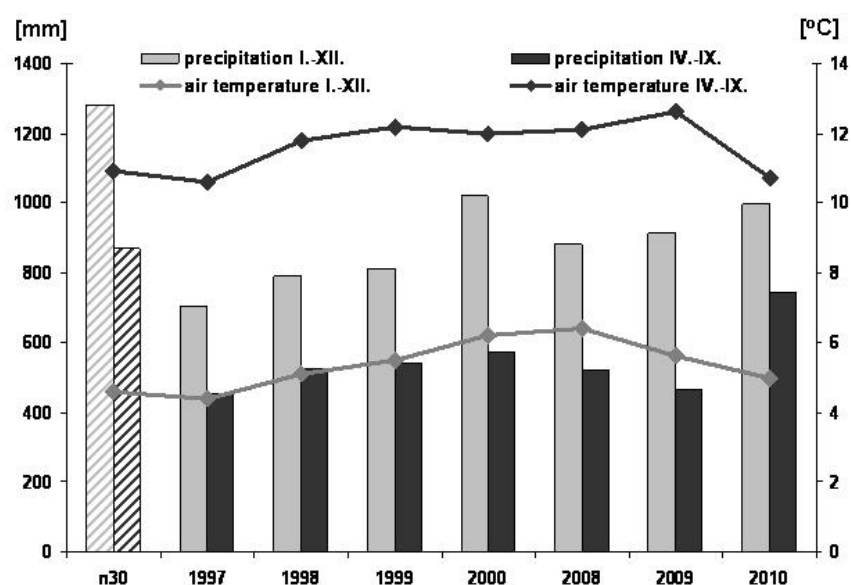

Figure 1. The course of average air temperatures (°C) and sum of precipitation (mm) during the observed period in the observed area situated in a marginal region of north-eastern Slovakia

Soil samples for physical, chemical and biological soil properties and heavy metal content determination were obtained in spring time in a connected stand on five permanent research sites, from the depth of 0.05 m to 0.15 m. Part of the soil samples were air-dried, sieved (sieve with 2 mm size opening), homogenised prior to the analysis and used for measurements of chemical and biological soil characteristics and heavy metal content. From the physical soil properties, soil bulk density and soil porosity were studied and evaluated in a Kopecky

physical cylinder with a capacity of 100 cm³ (Fiala et al., 1999). From the chemical soil characteristics, soil pH in 1M CaCl₂ solution was monitored and evaluated, as well as inorganic nitrogen, available phosphorus, potassium, and magnesium with Mehlich III and organic carbon content (Fiala et al., 1999). The available heavy metal content (Cd, Ni and Pb) of the samples was determined in 2M HNO₃ solution using atomic absorption spectrophotometer (Matúšková & Vojtáš, 2005). The following biological soil characteristics were monitored: activity of acid and alkaline phosphatase (Grejtovský, 1991) and urease (Chaziev, 1976). The obtained data were tested by mathematical-statistical methods from which analysis of variance and regression analysis were used (the Statgraphics software package).

2.2. Evolution of physical soil parameters

The changes in physical characteristics of soil not only result from meteorological factors, yearly farming plan, or from the course of vegetation, but also depend on the employed farming system. Larson and Pierce (1991) confirmed that soil quality can be evaluated and the sustainability of a system assessed on the basis of essential physical indicators.

Soil granularity, and especially the ratio of clay particles, primarily influences physical, hydro-physical and chemical characteristics. The soils in the monitored localities according to the content of clay particles based on Novák's classification (Fulajtár, 2006) are of loamy-sandy, loamy and clay-loamy category (Tab. 1.).

Diameter of particles [%]	Studied locality				
	I.	II.	III.	IV.	V.
> 0.25	31.3	14.5	11.5	32.5	16.0
0.25–0.05	21.6	15.5	18.9	13.9	14.9
0.05–0.01	27.8	32.4	24.3	22.2	31.3
0.01–0.001	15.5	29.3	3.3	24.0	2.6
< 0.001	3.8	8.3	11.0	7.4	8.2
I. Category	19.3	37.6	45.3	31.4	37.8
Soil	loamy sand	loam	clayey loam	loam	loam

Table 1. Particle grain-size composition of soil [%] in the monitored area situated in a marginal region of north-eastern Slovakia in depth 0.05–0.15 m.

Bulk density as an integral value of soil granularity, humus content and anthropogenic impacts on soil should not exceed the limits given for individual soil types (Tab. 2.).

Soil texture	Sandy	Loamy sand	Sandy loam	Loam	Clayey loam and clay	Clay
Bulk density	≥ 1.70	≥ 1.60	≥ 1.55	≥ 1.45	≥ 1.40	≥ 1.35
Porosity	≤ 38	≤ 40	≤ 42	≤ 45	≤ 47	≤ 48

Table 2. Critical values of bulk density soil [t.m⁻³] and porosity [%] for different of soil texture (Líška et al., 2008)

Long-term research has shown that ecological soil farming regulates bulk density of soil. The measured values of bulk density were in the range of 0.94 to 1.35 t.m^{-3} (Fig. 2.), in 1997 to 2009, there was a moderate decrease and values comparable to average figures for the given soil type and category according to Líška et al. (2008) were achieved (Tab. 2.), with the exception of 2010, when a mild increase in bulk density was measured. At the same time, this parameter proved to change under the influence of the water content and meteorological exposure (Kotorová, Šoltýsová & Mati, 2010). In 2010, in comparison to the previous years, precipitation reached higher values (Fig. 1.).
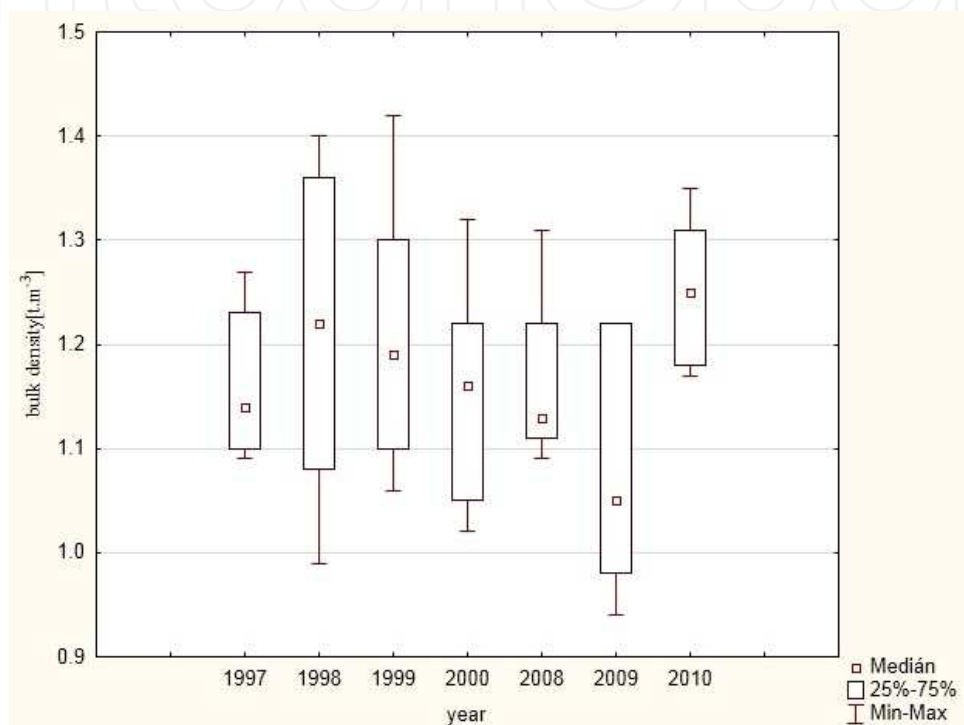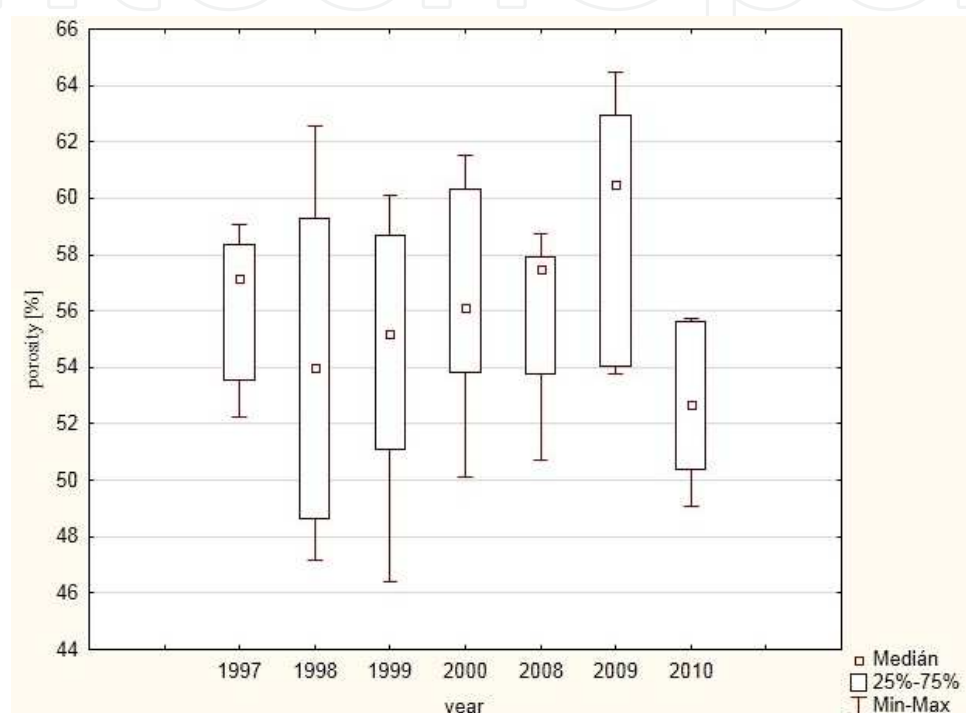

Figure 2. Bulk density of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

General porosity is closely related to bulk density. From the total pore volume, which should not fall below 38 % for sandy soil and below 48 % for clay-loam soil (Líška et al., 2008), the share of non-capillary pores rapidly releasing gravitational water and allowing good air exchange between soil and climate should be sufficient. The share of non-capillary pores (Pn) in comparison to capillary pores (Pk) should be higher in heavy soils.

As can be seen from Fig. 3., the values show that, in the observed timeframe, porosity levels ranged between 46.43 and 64.49 %. 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).

A statistically significant effect in the monitored year and locality on all observed soil physical parameters was confirmed by an analysis of variance (Tab. 3.).

Parameter	Min.	Max.	Mean	Standard error	Source of variability	d. f.	F-Ratio	P
bulk density [t.m^{-3}]	1.04	1.35	1.18	0.016347	year	6	8.33	++
					locality	4	28.39	++
porosity [%]	49.15	60.56	55.52	0.617864	year	6	8.24	++
					locality	4	28.41	++

Table 3. Analysis of variance of soil physical parameters in the monitored area situated in a marginal region of north-eastern Slovakia
++P< 0,01 +P< 0,05

Figure 3. Porosity of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

2.3. Evolution of chemical soil parameters

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

The soil pH is an important factor for soil fertility despite the fact that its values change dynamically, depending on so-called internal and external factors. It influences the buffering and filtering capacities, the quality of organic substances, nutrient accessibility for plants and the production of biomass in most crops grown. A majority of arable crops suit the range of slightly acidic to slightly alkaline soil pH – 6 to 7.5 (Krnáčová, Račko & Bedrna,

1997). A pH value lower than 5.5 is undesirable and requires ameliorative lime treatment. Similarly, from the viewpoint of productivity, alkaline soils (pH>8.4) are limiting and require appropriate measures.

In the course of monitoring the model area, the values of soil pH ranged between 5.1 and 7.2. The average values of soil pH increased moderately and were in the category of slightly acidic to neutral soil pH (6.3 – 6.9) (Fig. 4.).

This can be assigned to the ecological farming system, as physiologically acidic mineral fertilisers were not applied. On the contrary, organic fertilisers (manure at the dosage 30 t ha^{-1} and liquid organic fertilisers at the dosage 3000 l ha^{-1}) were applied. The organic matter positively influences the buffering capacity of soil, which is why the soil reaction was stabilised. Nevertheless, it is necessary to pay continuous attention to soil reaction, since soil is naturally acidified through acid atmospheric fallout as well as calcium intake by plants.
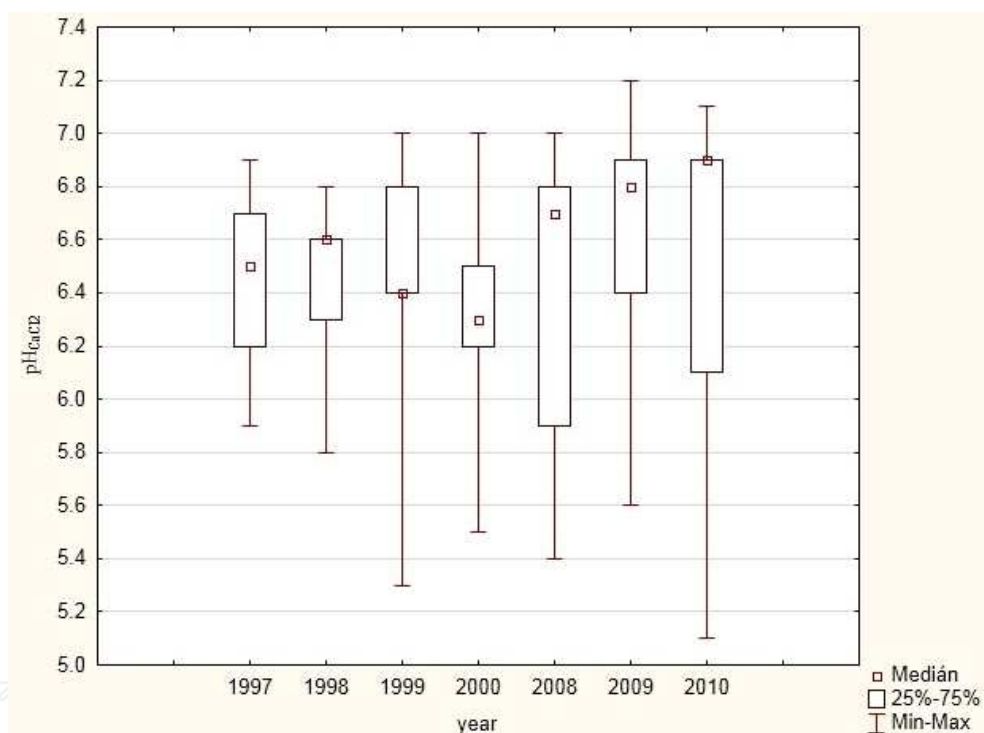

Figure 4. Soil reaction (pH/CaCl$_2$) in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

Nitrogen, phosphorus and potassium are the most important nutrients. Their supply to soil can be realised in various ways; fertilisation being of most importance. A lack of essential nutrients is rapidly reflected in the level of plant production. Nitrogen in soil is restored as part of its natural cycle. Its additional supply is necessary for intensified harvest, when its natural supply is not sufficient in order to achieve the targeted harvest. The supply of phosphorus and potassium by fertilisation is related to their supply in soil. Their supply in soil is not exhaustless; moreover, when constantly utilised, they are not naturally renewable.

According to Bielek (1998), there is a small probability that an increase in the total nitrogen content has a positive effect on soil fertility. This only applies to productive and highly productive soils. For soils with low production capacity, a reciprocal ratio between the total nitrogen content and soil fertility is typical. From the total nitrogen in soil, 95 % to 98 % is bound in organic forms; fertility functions determine mechanisms of its accessibility to plants. It is mainly organic nitrogen mineralisation, or, more specifically, that part of mineralisation which prevails over carbon immobilisation related to fertility. Inorganic nitrogen only represents a small part of total nitrogen and its content in the season is subject to frequent and fast changes, resulting from natural and anthropic factors. The concentrations of the main forms of mineral nitrogen (ammonia, nitrates) result from pure mineralisation and frequent nitrification of nitrogen in soil. In our research carried out in natural conditions, medium to highly favourable content of inorganic nitrogen in topsoil has been observed (Fig. 5.) in spite of the fact that in the soil-ecological conditions of the investigated area (a mild zone with a sum of average daily temperatures above 10 ºC ranging from 1600 ºC to 2000 ºC and average precipitation of 700-1200 mm), the nitrogen mineralisation is less intensive (the optimum temperature for an intensive process is 28-30 ºC); therefore, even with a high total content of nitrogen, the content of mineral (i.e. immediately available) nitrogen may not be high. The assumption is that by adding high doses of organic fertiliser, the total nitrogen content will increase. However, including legumes 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 later available for the crops grown in the following period (Jurčová & Torma, 1998; Kováčik, 2001).
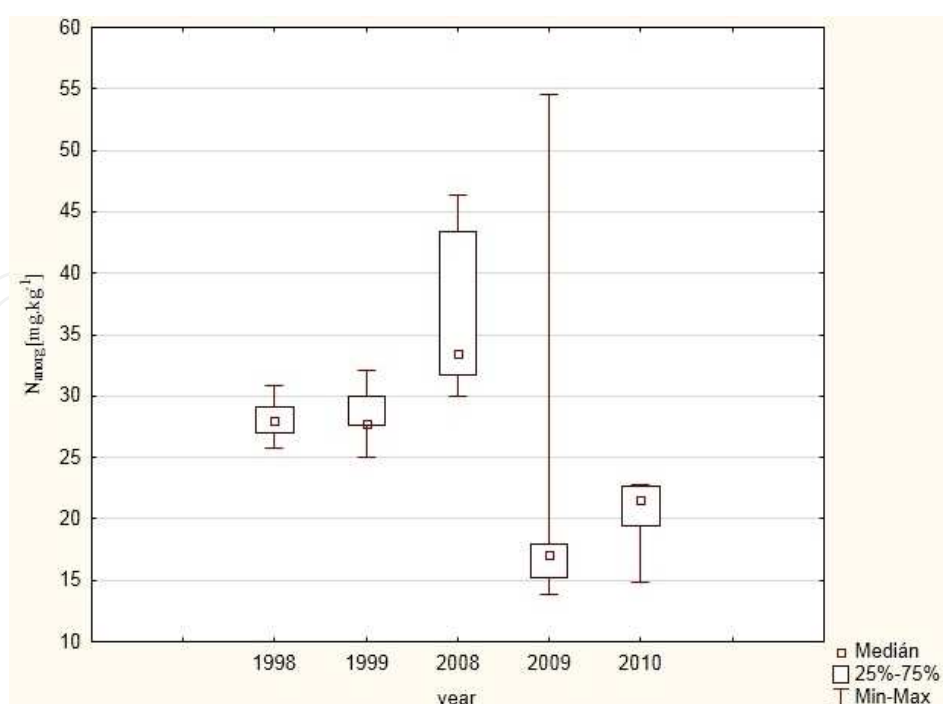

Figure 5. N_{anorg} content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

Phosphorus is firmly fixed in soil and its proportion is relatively stable and dependent on soil reaction values. Between 1997 and 2010, the value of soil pH did not significantly change in the investigated area. With regard to the above, the proportion of available phosphorus changed only minimally (Fig. 6.).
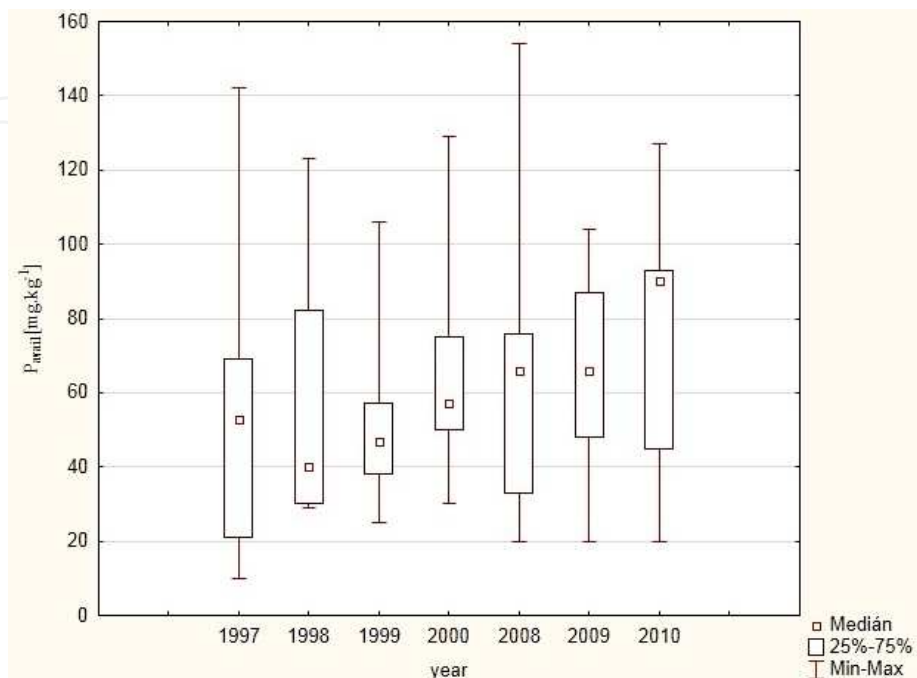

Figure 6. P_{avail} content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

In the observed period, the proportion of potassium and magnesium was relatively stable (Fig. 7. and Fig. 8). Due to the grain structure of the soils (medium and heavy soils), these nutrients are bound to soil particles and are not prone to soil washing in spite of high precipitation throughout the year.

Organic mass determines the soils quality, as it binds soil particles, stabilises soil (by which the risk of erosion decreases), increases water retention and cationic exchange capacity and reduces the negative impact of pesticides, heavy metals and other pollutants. A high proportion of organic carbon alone cannot guarantee a high yield; however, the influence of soil carbon on productivity increases when the levels of carbon decrease below 1%. With a content C_{org} 1.0 to 1.5, productivity decreases by 15 % and with content C_{org} under 1.0 %, it decreases by as much as 25 %. The most significant parameter is the ratio of humin acids and fulvene acids. This ratio is considered highly favourable, if it is higher than 2, satisfactory in the range between 1 and 2, and unfavourable if lower than 1. With regard to biological activity of soil, so-called non-specific humus substances play a significant role. These are a source of nutrients for soil microorganisms, participating in important cyclic biochemical processes (Hraško & Bedrna, 1988).

The content of humus in soil is a parameter prone to significant changes in the long-term. The application of high amounts of organic fertilisers and incorporating perennial fodder

crops in the crop rotation influenced the preservation of humus content. The measured C_{ox} values ranged from 2.16 to 3.92 (Fig. 9.), which, when conversed to humus (conversion coefficient 1.724), are medium to good humic soils (Vilček et al., 2005).
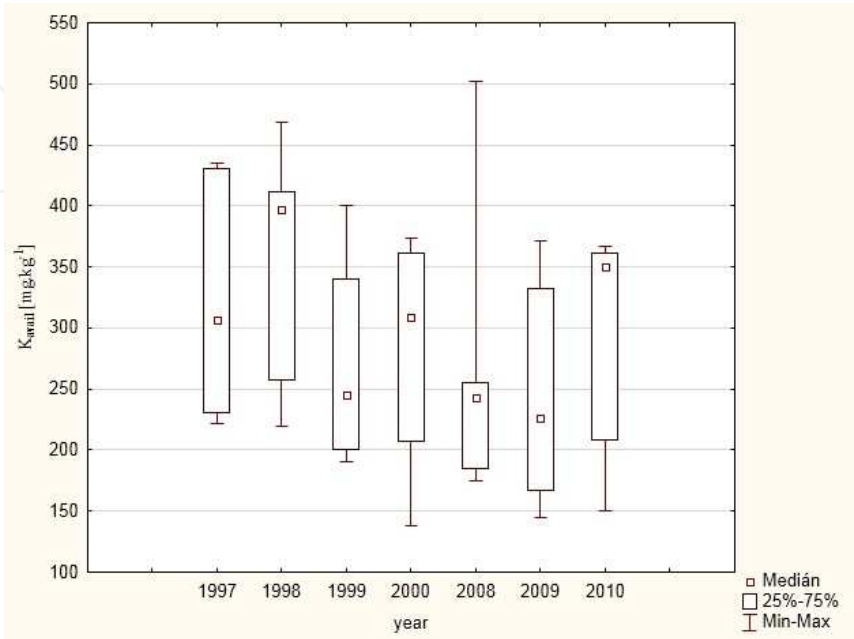

Figure 7. K_{avail} content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics
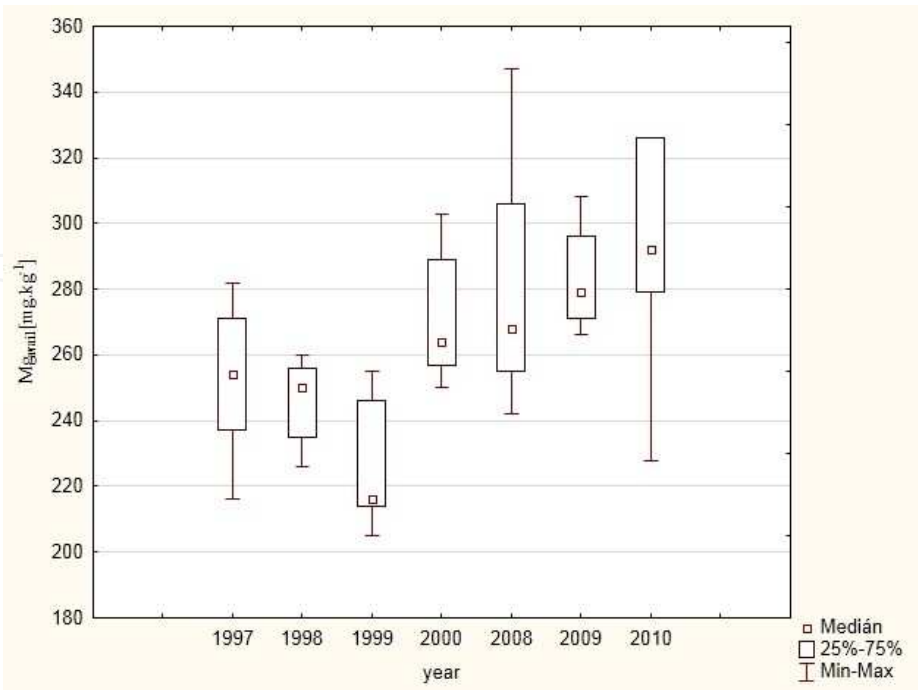

Figure 8. Mg_{avail} content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics
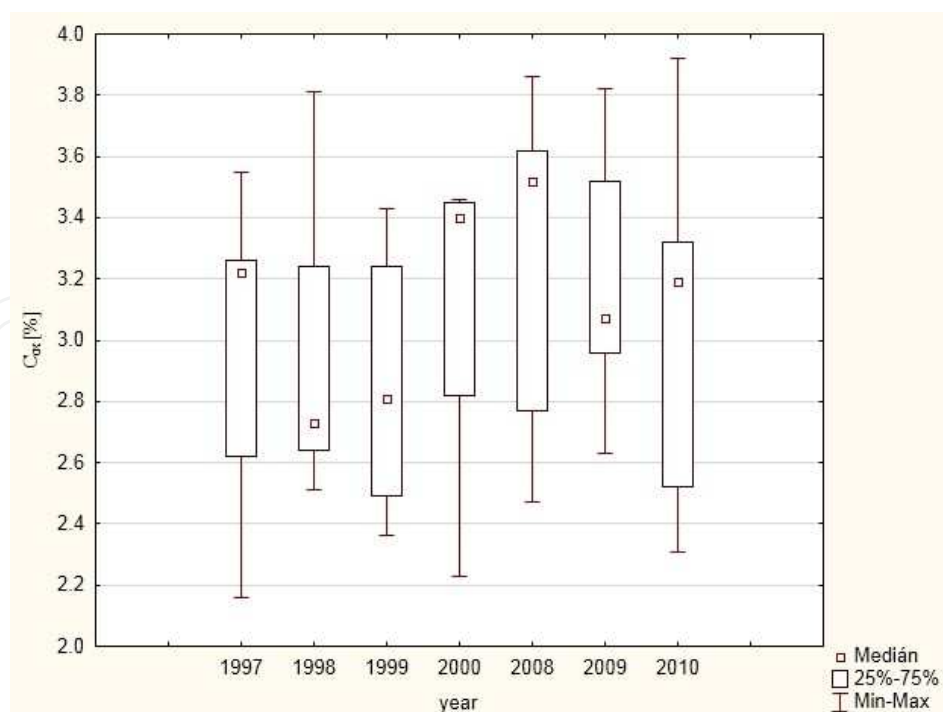
Figure 9. C_{ox} content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

A statistically significant effect of the monitored year on all observed soil chemical parameters was confirmed by an analysis of variance (Tab. 4.). The influence of the monitored locality on soil chemical parameters was also statistically significant, with the exception of N_{anorg}.

Parameter	Min.	Max.	Mean	Standard error	Source of variability	d. f.	F-Ratio	P
pH/CaCl$_2$	5.77	7.13	6.41	0.083124	year	6	0.82	-
					locality	4	24.51	++
C_{ox} [%]	2.25	3.61	3.03	0.084802	year	6	1.46	-
					locality	4	23.99	++
N_{anorg} [mg.kg^{-1}]	16.76	40.50	27.52	1.698623	year	6	12.77	++
					locality	4	2.22	-
P_{avail} [mg.kg^{-1}]	19.97	127.88	64.63	3.494827	year	6	3.02	++
					locality	4	121.06	++
K_{avail} [mg.kg^{-1}]	168.59	427.98	290.91	12.5772	year	6	5.87	++
					locality	4	43.46	++
Mg_{avail} [mg.kg^{-1}]	215.98	301.43	265.0	4.918103	year	6	17.52	++
					locality	4	3.73	++

Table 4. Analysis of variance of soil chemical parameters in the monitored area situated in a marginal region of north-eastern Slovakia
++P< 0,01 +P< 0,05

2.4. Evolution of biological soil parameters

The information on biological soil parameters is not as plentiful as it is in the case of physical and chemical parameters, 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 great number of enzymes in soil, depending on the diversity of soil organisms and the conditions of organic substances transformation.

Soil enzymes regulate the functioning of the ecosystem and play key biochemical functions in the overall process of organic matter decomposition in the soil system (Sinsabaugh et al., 1997). They are important in catalysing several important reactions necessary for the life processes of micro-organisms in soils and the stabilisation of soil structure, the decomposition of organic wastes, organic matter formation and nutrient cycling (Dick et al., 1994 cited in Makoi & Ndakidemi, 2008).

Enzymes are present in the cells of living organisms in soil (bacteria, fungi, algae, and soil fauna) and plant roots. Micro-organisms are the major source of enzymes in soil. The amount and quality of enzymes in soil is dependent on their characteristics, volumes and forms of organic matter and the activity of micro-flora. Enzymatic soil 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). The activity of soil enzymes can be enhanced by using organic fertilisers (Burns, 1978; Iovieno et al., 2009; Chander et al., 1997). The urease enzyme belongs to the hydrolases group of enzymes and is responsible for the hydrolysis of urea fertiliser applied to the soil into NH_3 and CO_2 with the concomitant rise in soil pH. This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilisation. Due to this role, urease activities in soils have received a lot of attention since it was first reported, a process considered vital in the regulation of N supply to plants after urea fertilisation (Makoi & Ndakidemi, 2008).

Soil urease originates mainly from plants and micro-organisms. It can be found as a free enzyme in soil solution, and yet more often firmly bound to soil organic mass or minerals, as well as inside living cells (Klose & Tabatabai; 2000; Alef & Nannipieri, 1995). Its activity depends on soil humidity (Baligar et al., 2005), pH, humus proportion and quality (Tabatabai & Acosta-Martínez, 2000) and the total nitrogen content (Nourbakhsh & Monreal, 2004). At the same time, an increased sensitivity to excess content of heavy metals (Kromka & Bedrna, 2000) and a negative effect of triazine herbicides on the activity of enzymes (Belińska & Prangal, 2007) was shown.

Phosphatases are a broad group of enzymes that are capable of catalysing hydrolysis of esters and anhydrides of phosphoric acid. In soil ecosystems, these enzymes are believed to play critical roles in P cycles (Speir et al., 2003) as evidence shows that they are correlated to P stress and plant growth. Apart from being good indicators of soil fertility, phosphatase enzymes play key roles in the soil system (Dick et al., 2000 cited in Makoi & Ndakidemi, 2008).

Soil phosphatase has certain typical characteristics. It depends on the substratum and its concentration. Two optimums levels, acidic and alkaline, are often present (Burns, 1978). An optimum pH of soil phosphatase is influenced by a great number of factors.

Soil pH differs from the pH optimal for phosphatase activity. Soil phosphatase can be inactive if the differences between soil pH and optimum enzyme pH are too great (Chaziev, 1976). The activity of soil phosphatase is higher in soils with high humidity in comparison to dry soils or soils with normal humidity. Phosphatase activity declines with an increasing soil depth, which is caused mainly by lower biological activity in lower soil profiles. Inorganic phosphate, copper, mercury and vanadium also have a considerable inhibitory effect on soil phosphatase activity (Burns, 1978; Speir et al., 2003).

There was minimum fluctuation in the measured values of soil enzyme activity in the observed period. The urease values ranged from 0.43 to 0.67 mg NH_4^+ - $N.g^{-1}.24$ hour^{-1}, and the values of acidic and alkaline phosphatase between 236.8 and 336.5 µg $P.g^{-1}.3$ hour^{-1} (Fig. 10., Fig. 11. and Fig. 12.). These are values typical for sparse-vegetation soils (Burns, 1978).
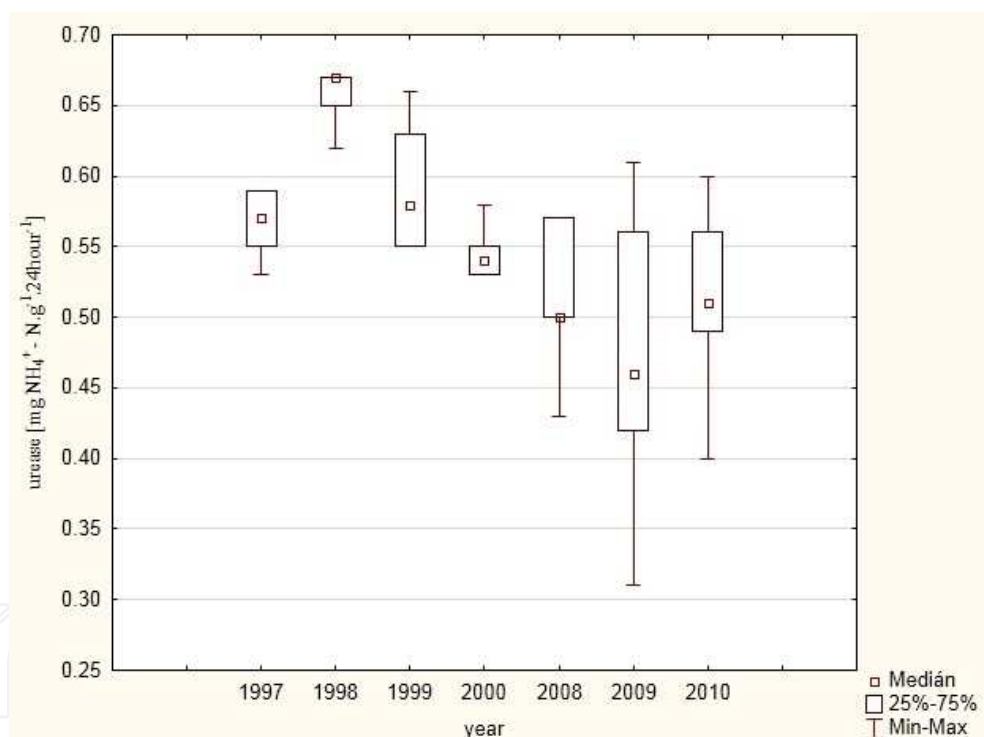

Figure 10. Urease activity of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

At the same time, a higher activity of soil enzymes in lower temperatures was confirmed (the area is situated in a mild district with a sum of average daily temperatures above 10 °C ranging from 1600 to 2000 and average precipitation between 700 and 1200 mm) and organic fertilisers and soil organic mass stimulate the activity of soil phosphatase and significantly enhance the protection of natural soil urease (Chaziev, 1976; Bremner & Mulvaney, 1978).
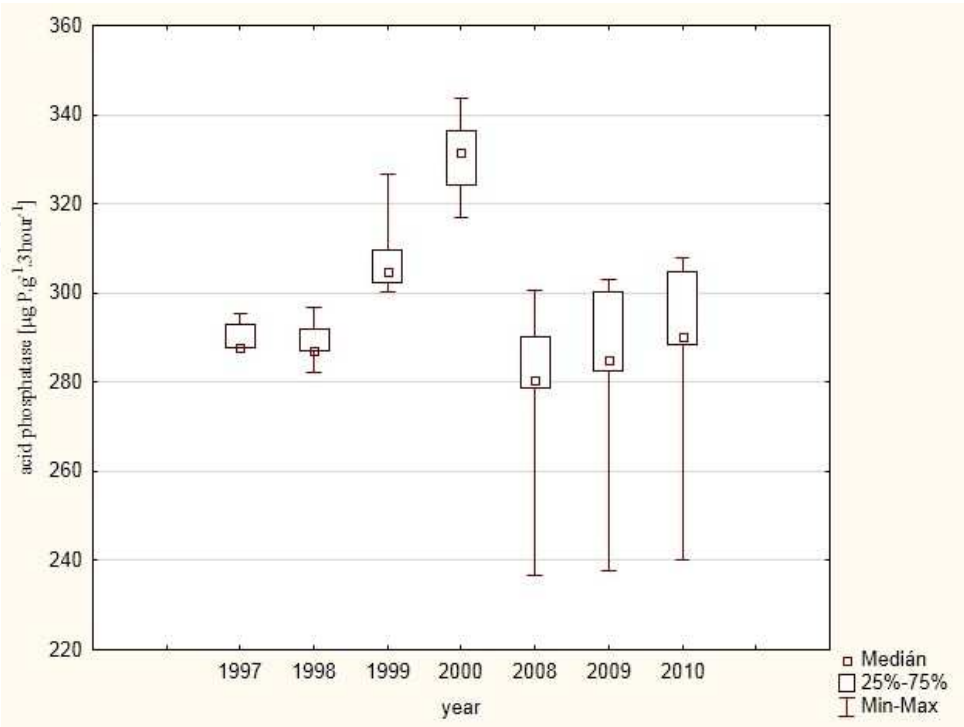
Figure 11. Acid phosphatase activity of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics
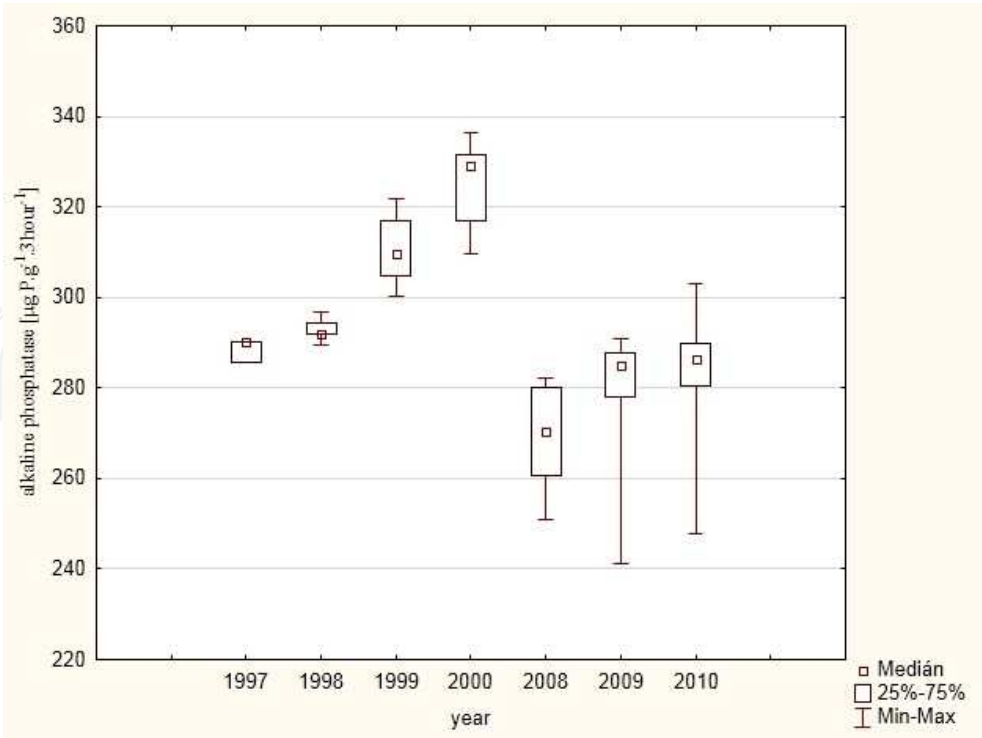

Figure 12. Alkaline phosphatase activity of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

A statistically significant effect of the monitored year and locality on all observed soil biological parameters was confirmed by an analysis of variance (Tab. 5.).

Parameter	Min.	Max.	Mean	Standard error	Source of variability	d. f.	F-Ratio	P
urease [mg NH_4^+ - $N.g^{-1}$ .24hour^{-1}]	0.454	0.674	0.551	0.007954	year locality	6 4	44.07 33.12	++ ++
acid phosphatase [μg $P.g^{-1}$ .3hour^{-1}]	271.23	306.77	294.91	2.65001	year locality	6 4	36.16 15.85	++ ++
alkaline phosphatase [μg $P.g^{-1}$ .3hour^{-1}]	264.35	329.33	291.97	1.96567	year locality	6 4	75.50 16.39	++ ++

Table 5. Analysis of variance of soil biological parameters in the monitored area situated in a marginal region of north-eastern Slovakia
++P< 0,01 +P< 0,05

2.5. Concentration of heavy metals in soil

An increase in inputs employed in the farming system has gradually brought about the need for studying and evaluating their potential negative influence on soil environment and production quality. Monitoring soil contamination with various degrees of biotoxicity is an important area. Fertilisers, especially industrially produced, are considered (including rock slackening, atmospheric decline and waste stock) a significant source of risk elements in soil (Beneš, Benešová, 1993). The system of farming, including the use of fertilisers, can also indirectly affect the acceptability of risk elements for plants (Beneš, 1993).

Loading agricultural soil with harmful substances is serious, since soil is not only the key to agricultural production but also has filtration and buffering capacities. Soil considerably influences the composition and quality of underground water and provides a living environment for soil micro-organisms (Tischer, 2008; Gulser, 2008). It could be assumed that accumulating higher concentrations of heavy metals in soil is a potentially serious danger to the food chain (Torma et al., 1997). It is especially toxic elements and organically highly-persistent substances that are among harmful substances entering soil.

Heavy metals as a large group of polluters are a serious problem in all components of the environment, including soil. As a great number of these have considerable toxic effects, their highest allowed concentrations are defined for the soil system, similarly to those for air and water. It is extremely difficult to define limit concentrations of heavy metals for soil, since, in contrast to air and water, soil is an extremely heterogeneous system and mobility of inorganic contaminants, closely related to the intake by plants, depends on several soil

factors. The approaches towards the determination of metal concentration limits in soil vary significantly in individual countries. In some countries, the definition of limits for heavy metals concentrations is based on soil use (these are defined as so-called trigger and action values), or, possibly, on eco-toxicological data in so-called standard soil and limit values for the total and dissolvable concentration of heavy metals in soil (Barančíková, 1998; Makovníková et al., 2006).

Toxicity of heavy metals varies; it decreases in the following line Hg>Cd>Ni>Pb>Cr and their influence is enhanced by their non-degradability. Soil is only presented as a passive acceptor of heavy metals; it becomes the source of polluting other components of the environment and the food chain. Changes in soil properties are responsible for the mobilisation of metals, especially pH, humus content and quality and the proportion of clay fraction (Barančíková, 1998).

With regard to the above findings, the content of the following risk elements was observed in the conditions of sustainable use of soil: lead, cadmium and nickel (in the leachate 2M HNO_3) (Fig. 13., Fig. 14. and Fig. 15.). The evaluation showed that the content of dangerous elements in soil did not reach maximum permitted values for the Slovak Republic (Act No. 220/2004 Coll.) and the measured values corresponded with natural contents of the observed elements in soil and base rocks (Makovníková et al., 2006). At the same time, in ecological systems, no anthropogenic pollution by applying chemical substances and sediments in soil is present.
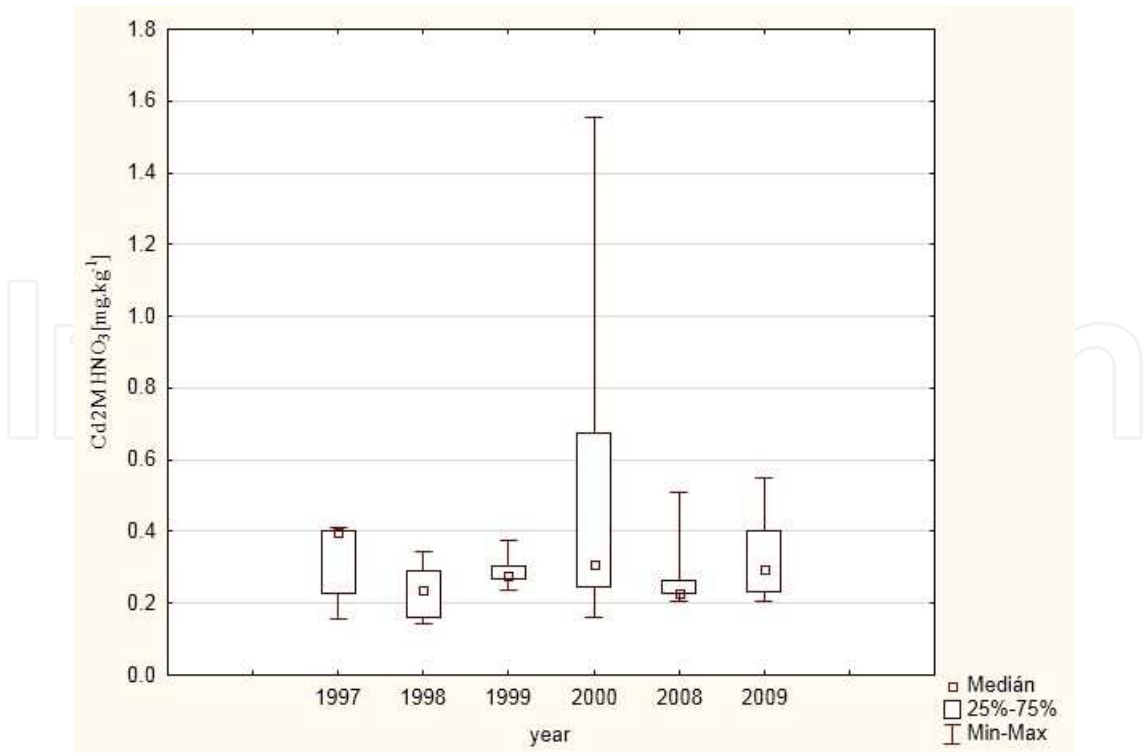

Figure 13. Cd content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics
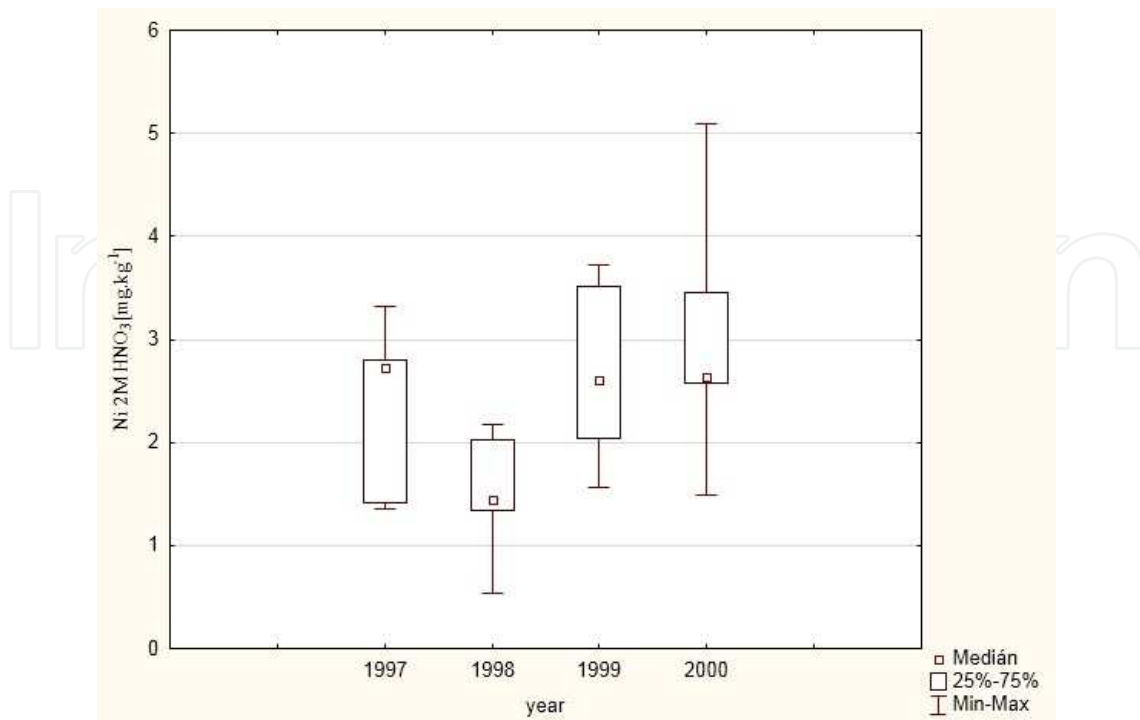
Figure 14. Ni content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics
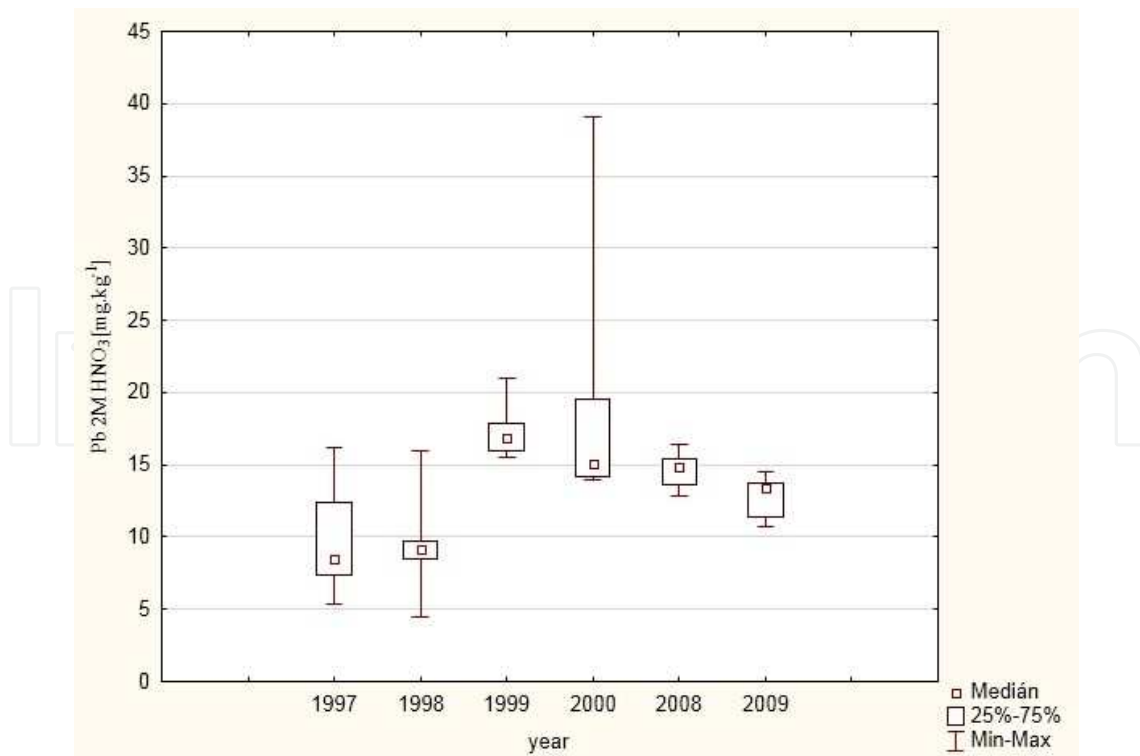

Figure 15. Pb content of soil in the monitored area situated in a marginal region of north-eastern Slovakia expressed by descriptive statistics

A statistically significant effect of the monitored year and locality on observed heavy metal content of the soil was confirmed by an analysis of variance (Tab. 6.).

Parameter	Min.	Max.	Mean	Standard error	Source of variability	d. f.	F-Ratio	P
Pb 2M HNO₃ [mg.kg⁻¹]	7.77	22.18	14.11	0.823555	year	6	12.30	++
					locality	4	22.01	++
Cd 2M HNO₃ [mg.kg⁻¹]	0.129	0.697	0.343	0.037233	year	6	9.37	++
					locality	4	19.69	++
Ni 2M HNO₃ [mg.kg⁻¹]	0.934	3.436	2.392	0.140375	year	6	24.08	++
					locality	4	25.20	++

Table 6. Analysis of variance of the heavy metal content of the soil in the monitored area situated in a marginal region of north-eastern Slovakia
++P< 0,01 +P< 0,05

3. Conclusion

The farming system is the most widespread environmental technology with its positive and negative consequences. It utilises essential natural resources and, at the same time, influences other natural environments. Therefore, ecologisation of farming is a priority of farmers as well as environmentalists. Respecting the principles of soil sustainability and other components of the environment is a basic precondition for life sustainability. Sustainable agriculture is based on the principle of agriculture being a biological process which, in practice, should imitate key characteristics of the natural ecosystem. It strives to bring diversity into agro-ecosystems, recycle nutrients efficiently and maintain the priority of sunlight as a source of energy for agro-ecosystems. Sustainable use of soil takes soil-ecological conditions into consideration and is realised in such a way and in such intensity, which gives rise to neither negative changes in soil, nor establishes trends for the development of negative characteristics in soil. It is impossible to select universal soil parameters for sustainable soil, which is why the area is subject to specialised discussions. A significant role in the selection of parameters is played by their variability in time, related to parameter stability. Stable (such as soil depth or granularity), relatively stable (the salt content, the content of organic mass in soil, heavy metal contamination), relatively dynamic (pH, the content of nutrients) and dynamic (soil humidity and temperature, microbial activity, etc.) parameters are more connected to its short-term changes. Soil quality cannot be judged directly; it must be determined from the changes of its parameters. It is more accurate to evaluate the range of appropriate indicators rather than to use a single one. Soil quality is significantly affected by physical, chemical, biological and biochemical properties sensitive to changes in the environment and land management. At present, there is little knowledge with regard to soil development in the conditions of sustainable farming systems. The present findings can hardly be compared to other research due to the different soil-ecological conditions in which they were obtained. The issue of universal methods for all soil types remains a universal problem within the research of soil development. Unless

this area is unified, objective comparison will remain on a regional level. Soil parameters are usually determined only in relation to specific topsoil. Certain physical and chemical parameters in subsoil cannot be neglected, since they guarantee soil functions.

The present results showed development of selected soil parameters during long-term monitoring on a model area situated in a marginal region of north-eastern Slovakia where an ecological farming system was applied. Soil physical properties change not only under the influence of weather conditions, crop year, vegetation pass, but also under the influence of applied management systems. During the year and growing season, bulk density value also varies depending on water availability in the soil, weather and farming methods. The research showed that soil physical properties get adjusted after long-term application of an ecological farming system and the measured values were stabilised, reaching levels comparable with the average values for the soil type. Agrochemical soil characteristics did not change significantly during the research period. High doses of organic fertilisers had a positive effect on soil productivity, and, thus, indirectly on maintaining soil pH, the available nutrient content and retention of humus in soil. In spite of this, it is necessary to continuously pay attention to soil reaction, because soil is naturally acidified through acid atmospheric fallout as well as calcium intake by plants. Values of selected heavy metals in the monitored period did not exceed the limit values published in Act No. 220/2004 Coll. The values of activity of phosphatase and urease changed minimally during the research period and they refer to 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. Analysis of variance confirmed a statistically significant effect of the monitored year on all observed soil parameters. The effect of the observed locality, with the exception of $pH/CaCl_2$, C_{ox} and N_{anorg}, on other soil parameters was also statistically significant.

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