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The varying effect of water erosion on chemical and biochemical soil properties in different parts of Chernozem slopes

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ABSTRACT

In recent decades erosion processes have influenced agricultural soil quality worldwide. In the Czech Republic the situation is made even worse by the fact that, in the post-war period, considerable changes occurred in land use during collectivisation of farm land, along with a significant increase in the average size of farmed plots. This led us to observe the changes in chemical and biochemical soil properties in the intensively farmed Chernozem region of south Moravia. According to the erosion/deposition model, 48 localities with erosional, depositional and control areas were chosen where soil samples were then taken from among maize crops. These samples were then analysed and the results were statistically processed. From the results of analysis of chemical properties relating to basic nutrients and soil organic matter, it is apparent that, in depositional areas of slopes, supplies of potassium and phosphorus were higher in comparison with erosional areas. The opposite trend was evident in calcium, where statistically significant higher levels were found in erosional areas of slopes, which is linked to the chemistry of soil-forming substrate. This trend also influenced pH. Differences were also found in characteristics relating to soil organic matter. Overall carbon and nitrogen content was significantly higher in depositional areas. There was a statistically conclusive difference in quality of organic matter in these areas expressed by the carbon content of humus matter, carbon in humic acids and the C:N ratio. The content and quality of organic matter influence biological and biochemical soil properties. In enzymes there was statistically higher activity of dehydrogenase, acid phosphatase, urease and nitrate reductase in depositional areas compared with erosional areas.

The results obtained indicate considerable differences in soil properties within individual plots of land, especially between erosional and depositional areas of slopes, and the conclusions of the study are applicable in planning anti-erosion defences and management measures in agro-ecosystems.

1. Introduction

Soil erosion, especially caused by water, is a serious world-wide environmental problem with a significant influence on production. The situation is no different in Europe and in the Czech Republic, as is evident from research data. The European Environment Agency (EEA) estimates that 12% of land in Europe is affected by water erosion. Panagos et al. (2015) describe an average yearly loss of arable land in Europe of up to 2.46 t/ha, while overall yearly loss in EU countries is estimated at 970 Mt. Globally, it is estimated that water erosion mobilises 28 Pg soil per year (Quinton et al., 2010). In the Czech Republic, according to the latest figures (Collective, 2015) water erosion threatens more than 50% of agricultural land. Erosion reduces the soil's fertility, affects its productivity and has an influence on physical and chemical characteristics of the soil (Rhoton et al., 2002; Lal, 2003).

Damage to the surface of the soil, caused by raindrops, running water and deposited material, reduces infiltration and increases surface runoff (Pilgrim et al., 2010) during which the upper parts of the soil, including layers containing organic matter and nutrients, are translocated (Smith et al., 2001; Liu et al., 2003; Evans and Brazier, 2005). Thus, not only removal, but also deposit of material occurs on agricultural land. This means a redistribution of not only a significant proportion of mineral content and nutrients, but also soil organic carbon, to lower areas of a slope, with subsequent deposition (Lal, 2005; Heckrath et al., 2005; Zhang et al., 2006; Papiernik et al., 2007; Dungait et al., 2013). The quantity of C mobilised by erosion processes is described e.g. for the area of England and Wales, in figures of 0.20–0.76 × 10^{12} g C yr^{-1} (Quinton et al., 2006; Quinton et al., 2010). There are numerous factors influencing the fate of carbon in the soil as a result of erosion, transportation and deposition processes, and these are discussed in a review by Kirkels et al. (2014).

Research has shown that soil erosion can change not only the

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physical and chemical characteristics of the soil, but also biological characteristics such as microbial composition, abundance and activity (Xu et al., 2010; Hiltbrunner et al., 2012). This is also shown in research by Huang et al. (2013), which describes a significant reduction in microbial abundance as a result of water erosion. There are far more micro-organisms living in the surface layer of soil, which is transported, than in subsoil. Spatial distribution of micro-organisms to depositional areas of land has been recorded (Fierer et al., 2003). Some studies describe how erosion processes have negative implications for erosional areas of a slope, and can have a positive influence on depositional areas, in terms of organic carbon as well as other soil characteristics (Ritchie et al., 2007). This could be in the form of plant nutrients, which are transported and lost along with eroded soil (Pimentel et al., 1995; Chambers et al., 2000; Palmer and Smith, 2013). This may be a factor which reduces microbial biomass and enzyme activity in erosional areas (Li et al., 2015b). This can affect mineralization of organic matter which is ensured in the soil by an extensive community of organisms with a wide range of metabolic processes enabled by enzyme activity (Nannipieri et al., 2002). Besides micro-organisms, we can also include enzymes among the main driving forces in soil biological processes (Stott et al., 2010; Jia et al., 2005). Enzyme activity is a more vital contributor to soil quality than soil nutrient (Dick, 1997), as all biological transformations in the soil are dependent on, or influenced by enzymes which are present in this environment (Tabatabai, 1994). Enzyme activity in the soil environment is influenced by disturbance processes, including erosion. The relationship between activity and disturbance is evaluated by Saiya Cork et al. (2002), and the actual influence of erosion on enzyme activity in degraded soil is described by e.g. Garcia and Hernández (1997), Moreno-de las Heras (2009).

Our research focused on an intensively-farmed Chernozem region, an area of the Czech Republic under the greatest threat of erosion. Especially as a result of post-war collectivisation of land and subsequent changes in farming methods, which led to reduction in grassland and an increase in average field size in this area (Šarapatka and Štěrba, 1998), over extensive areas of land it is possible to identify erosion-threatened and damaged areas of slopes, depositional areas and parts of slopes on which erosion is insignificant. There is very little information in published literature on the influence of erosion processes on chemical and biochemical properties in extensive Chernozem land subjected to the aforementioned changes in land use and farm management. The aim of our research was therefore to evaluate the long-term influence of erosion processes, on different parts of slopes, on selected chemical properties relating to soil organic matter and basic nutrients, as well as on biochemical properties expressed by the activity of selected soil enzymes, with the consequent possibility of application of the results in planning anti-erosion measures and management interventions in agroecosystems.

2. Materials and methods

2.1. Selection of localities for erosion research

The research was carried out in a Chernozem area in South Moravia, Czech Republic, in the years 2013–2016 (Fig. 1). This area spans five districts, with a Chernozem acreage of 179,000 ha, which is about 38% of the national agricultural land fund.

With the use of a map of estimated pedologic-ecological units (EPEU), which is the main basis for the qualitative differentiation of soil, climatic condition and agricultural land in the Czech Republic (Szturc and Podhrazska, 2013), defined on the basis of agronomically important, e.g. climatic region, main soil unit, slope, exposure, stoniness and soil depth, and is to a scale of 1:5000 or in digital form, plots of land with Chernozem soil type were selected, in chosen cadastral areas, on which maize had featured significantly in the crop rotation during the sampling period.

On the areas of land chosen by means of the EPEU map, and erosion-threatened land identified by the Universal Soil Loss Equation (USLE/RUSLE) (Wischmeier and Smith, 1978; Renard et al., 1997), specific sampling locations were then selected with the use of the USPED model (Unit Stream Power - based Erosion Deposition) which predicts the spatial distribution of erosion and deposition rates for a steady state overland flow with uniform rainfall excess conditions for transport capacity limited case of erosion process (Mitasova et al., 1996; Mitas and Mitasova, 1998). Apparent locations with various intensities of erosion and deposition processes are expressed on a logarithmic scale (Fig. 2).

2.2. Evaluation of soil properties and enzyme activity assay

Representative and homogenous soil samples were taken from 48 localities (in erosional and depositional areas, and also in pre-erosion areas – as a control) (Fig. 1) in maize crops, after selection of localities by means of the EPEU database and the models described in point 2.1, from the 0–30 cm layer using an Eijkelkamp soil probe according to International Standard (ISO 10381-1, 2002). For chemical analysis soil samples were air-dried and sieved for fractions smaller than 2 mm (ISO/DIS 11464, 2004), for biochemical analysis the samples were sieved as soon as possible after sampling and analysed (ISO 10381-6, 2009). In the acquired samples, soil properties were determined by means of the following procedures. C org. was determined after oxidation with a surplus solution of potassium dichromate in a sulphuric acid environment, measuring the colour intensity by spectro-photometry (ISO 14235, 1998; Zbíral et al., 2011). Quality of organic matter was expressed by the proportion of humic acids and fulvic acids after extraction using an alkaline sodium pyrophosphate solution, with subsequent spectro-photometric measurement. The fractions of humus material were determined by means of a modified procedure according to Kononova and Bělčiková (1961), where C content of overall humic substances was determined by vaporisation of pyrophosphate leachate, the C content of fulvic acids was then determined in the acidified leachate, and C content of humic acids was determined after dissolving in a NaOH solution. To determine $N_{tot.}$, the sample was oxidised with nitrogen peroxide in a concentrated sulphuric acid environment. After mineralization the digest was distilled into boric acid and the content of nitrogenous material was then determined by titration with a H_2SO_4 solution (ISO 11261, 1995; Zbíral et al., 2011). The soil reaction was determined as pH/H_2O and $pH/CaCl_2$ (ISO 10390, 2000; Zbíral and Honsa, 2010). Available nutrients (Ca, Mg, K and P) were determined by means of Mehlich 3 extraction solution (Mehlich, 1984; Zbíral and Honsa, 2010), with subsequent determination by means of atomic absorption spectrophotometry, atomic emission spectrophotometry and photometry.

Soil enzyme activity was measured in naturally moist samples by means of the spectrophotometric method. To determine protease activity casein was used as substrate and, subsequently, blue complex was measured colorimetrically (Ladd and Butler, 1972). In order to evaluate urease activity the soil samples were incubated with a urea solution. Released ammonia ions were extracted in a potassium chloride solution and measured colorimetrically (Tabatabai and Bremner, 1972). To determine activity of nitrate reductase, soil samples were incubated using KNO_3 as substrate. After incubation the released nitrite was extracted and measured colorimetrically (Abdelmagid and Tabatabai, 1987). Cellulase activity was evaluated using CM-cellulose as a substrate. Oligosaccharides cause a reduction in potassium ferricyanide, which reacts with iron sulphate to produce a compound of potassium ferrocyanide, and this was measured colorimetrically (Schinner and von Mersi, 1990). Phosphate activity was measured using *p*-nitrophenyl phosphate as a substrate. The *p*-nitrophenol produced was extracted and measured photometrically (Tabatabai and Bremner, 1969). Dehydrogenase activity was monitored using triphenyl-tetrazolium chloride. The triphenyl formazan produced was extracted and measured photometrically (Ross, 1970).