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The effect of organic matter on the structure of soils of different land uses

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ABSTRACT

In this study, the soil structure of two soils (Haplic Chernozem and Eutric Fluvisol) of different land uses (forest, meadow, urban and agro-ecosystem – consisted of four crop rotations) in Slovakia was compared. The soil aggregate stability was determined with a dependence on the chemical composition of plant residues. The quantity and quality of the organic matter was assessed through the parameters of the C and N in size fractions of dry-sieved and water-resistant aggregates. The soil structure of the forest ecosystem was evaluated as the best of all of forms of land use. Differences in the soil structure under the grass vegetation of a meadow (natural conditions) and urban ecosystem were also recorded. The agro-ecosystem was characterised by a higher portion (55.95%) of the most valuable (agronomically) water-resistant aggregate size fraction of 0.5–3 mm. Values of the carbon management index showed that the larger water-resistant aggregates were, the greater were the changes in the organic matter ($r = -0.680$, $P < 0.05$). In addition, a smaller content of dry-sieved aggregates of the 3–5 mm size fraction was observed with higher contents of soil organic carbon (SOC) ($r = -0.728$, $P < 0.05$) and labile carbon (C_L) ($r = -0.760$, $P < 0.05$); there were also greater changes in the soil organic matter and vice versa, higher contents of SOC ($r = 0.744$, $P < 0.05$) and C_L ($r = 0.806$, $P < 0.05$) greater contents of dry-sieved aggregates of size fraction 0.5–1 mm. The soil structure of agro-ecosystem was superior at a higher content of cellulose ($r = -0.712$, $P < 0.05$) in the plant residues. The higher content of cellulose and hemicellulose in the plant residue of a previous crop was reflected in a smaller C_L content in the water-resistant aggregates ($r = -0.984$, $P < 0.05$). A correlation was observed between a high content of lignin in the plant residue and a smaller SOC content in the water-resistant aggregates ($r = -0.967$, $P < 0.05$). Lastly, a higher content of proteins in the plant residues ($r = 0.744$, $P < 0.05$) supported a greater content of dry-sieved aggregates of the 0.5–1 mm size fraction.

1. Introduction

Degradation of soil physical properties is closely linked with the reduction of its organic matter concentration, which is essential to aggregation (Zeytin and Baran, 2003), and the latter is critical to stabilisation of carbon (C) pool through physical protection within aggregates (Balabane and Plante, 2004). The stability of soil aggregates depends not only on the quantity, but also on the quality, of the input of organic matter (Tisdall and Oades, 1982; Šimanský and Zaujec, 2009). Different fractions of organic matter participate in the formation and stabilisation of soil aggregates in different ways (Roberson et al., 1991); furthermore, the soil structure of agro-ecosystems is different from the soil structure of natural ecosystems. In natural ecosystems, factors such as soil type and texture composition contribute to the formation of the soil structure, whereas in agro-ecosystems, humans alter the soil structure through the burial of various crop residues (Zaujec and Šimanský, 2003), the application of organic fertilisers (Tejada and Gonzalez, 2005), and cultivation (Atkinson et al., 2009). The sustained addition of crop residue increases the organic carbon content, particularly in the surface layer of soil, which supports the creation of a new soil layer with better and more stable aggregates (Martínez et al., 2008). Crop rotation also affects the percentage share of water-resistant aggregates of sizes from 2.00 to 6.30 mm and <0.25 mm and mean weight diameter (Šimnaský et al., 2008; Martins et al., 2009). The distribution of aggregate fractions has shown that the soil under natural vegetation has a higher aggregate stability (83% of the soil matrix in macroaggregates) (Barreto et al., 2009). The objectives of this study were as follows: (i) to compare the soil structure in two soils under different land uses, (ii) to assess the quantity and quality of the organic matter through the parameters of carbon and nitrogen in size fractions of dry-sieved and water-resistant aggregates, and (iii) to determine the influence of the chemical composition of plant residue on soil aggregate stability.

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2. Materials and methods

2.1. Characteristics of the territory

The studied areas are located in the Podunajska lowland. Localities of Eutric Fluvisols (WRB) (agro-ecosystem, forest ecosystem, and meadow ecosystem) are present on the Podunajska flat, all of the ecosystems of Haplic Chernozems (WRB) and the urban ecosystem on the Podunajska hill. Geological substrates of the Podunajska lowland are neogene clays, sands and gravels, which are covered with loess and loess loam in most such areas. Fluvial sediments are found along the rivers Vah and Nitra. The relief of the Podunajska plain is monotonous. On the Podunajska flat, the relief is mostly wavy and covered with loess and loess loam. In some places above the surface, neogene rafts of clays, sands or gravels are found. The Podunajska hill is covered with valleys and neogene formations. The sampling places on the Eutric Fluvisols are situated near the flat areas on the Vah and Nitra rivers. Localities of Haplic Chernozems are situated on slight slopes with exposure to the SW (forest and meadow ecosystems and agro-ecosystem) and to the NE (urban ecosystem). The average annual temperatures of the studied areas are 9.7 °C (Nitra), 9.8 °C (Sala), 9.7 °C (Mocenok), and 10.4 °C (Komjatice), and the average rainfall per year is 580 mm (Nitra), 568 mm (Sala), 560 mm (Mocenok), and 566 mm (Komjatice) (Korec et al., 1997).

2.2. Experimental details

The experiment included four types of ecosystems, which present different land uses and management (FE, forest ecosystem; ME, meadow ecosystem; UE, urban ecosystem; AE, agro-ecosystem) of two soil types (HC, Haplic Chernozem; EF, Eutric Fluvisol) (Fig. 1). The agro-ecosystem included four crop rotations for the Eutric Fluvisol (EF-01–04) and Haplic Chernozem (HC-01–04). The forest ecosystems were natural forests with human control; the meadow ecosystems were created by man 30 years ago; and the urban ecosystems presented soils of urban landscape (grasses in a town influenced by human activities). The fields in agro-ecosystems were located in different farms under real production conditions. The vegetation in the forest, meadow and urban ecosystems was described by the dominating trees and herbs with dependence on the soil types and areas. In the drier areas of the Podunajska lowland, oak forests exist, and along the Vah River, floodplain forests are preserved. In the forest ecosystem on Haplic Chernozem, the dominating tree was *Quercus daleschampii*; the shrub vegetation was represented by *Crataegus laevigata*, *Hedera helix*, *Prunus spinosa*, and *Robinia pseudoacacia*; and the herbal community was represented by *Geranium robertianum*, *Viola sylvatica*, *Veronica chamaedrys*, *Glechoma hederacea*, *Pulmonaria officinalis*, *Asarum europaeum* and various types of grasses. In the forest ecosystem on the Eutric Fluvisol, the dominating trees were *Alnus glutinosa*, *Populus nigra*, and *Salix alba*; the shrub vegetation was represented by *Swida sanguinea*; and the herbal community was represented by *Urtica dioica*, *Lamium maculatum*, *G. hederacea*, *Galium verum*, *Ficaria bulbifera*, *P. officinalis*, *Symphytum officinale*, *Stellaria holostea*, *Impatiens noli-tangare*, *Ranunculus repens*, and *Chelidonium majus*. In the meadow ecosystem on the Haplic Chernozem, the dominating species were the plant grasses, *Thlaspi perfoliatum* and *Trifolium hybridum*. In the meadow ecosystem on Eutric Fluvisol, the diversity of plants was higher and, in addition to the grasses, *Taraxacum officinale*, *Trifolium repens*, *Carduus personata*, and *Medicago lupulina* were also dominating herbs. In the urban ecosystem on the Haplic Chernozem, the vegetation consisted mostly of grasses with the presence of other herbs, such as *Amarantus retroflexus*, *Cirsium arvense*, *Tanacetum vulgare*, *Raphanus raphanistrum*, *Tithymalus cyparissias*, *Vicia hirsute*, *Melilotus alba*, *Convolvulus arvensis*, *Berteroa incaca*, and *Achillea millefolium*; on the Eutric Fluvisol, in addition to the grasses, there were herbs such as *Geranium pratense*, *Cichorium intybus*, *T. officinale*, *Lotus corniculatus*, *Anthyllis vulneraria*, *T. repens*, and *A. millefolium*. The vegetation in the agro-ecosystems is given by the crop rotations (Table 1).

2.3. Soil samples and analytical methods used

The soil samples for soil structure determination were collected in three replicates to a depth of 0.30 m in four different ecosystems (forest, meadow, urban and agro-ecosystem); in the agro-ecosystems, collections were also made in different fields with different crop rotations and different applications of farmyard manure (Table 1). All of the samples were taken from a depth of 0.3 m, dried in a constant-temperature room of 25 ± 2 °C, and for chemical analyses also grinded. The basic chemical properties of the soils in the individual variants are characterised in Table 2. The soil organic carbon (SOC) was determined by wet combustion (Orlov and Grišina, 1981), the total nitrogen (NT) was determined by the Kjeldahl method (Bremner, 1960), the pH of the soil was potentiometrically measured in a supernatant suspension of a 1:2.5 soil:liquid mixture. The liquid is either 1 mol dm^{-3} KCl (pH$_{KCl}$) (van Reeuwijk, 2002). Carbonates were determined by volumetric methods (using a simple calcimeter), based on the CO_2 evolution after reactions with HCl (diluted with water in a 1:3 ratio) (Allison and Moodie, 1965). The cation exchangeable capacity (CEC) was determined according to the Pfeffer method (Jackson, 2005), and the sum of exchangeable cations

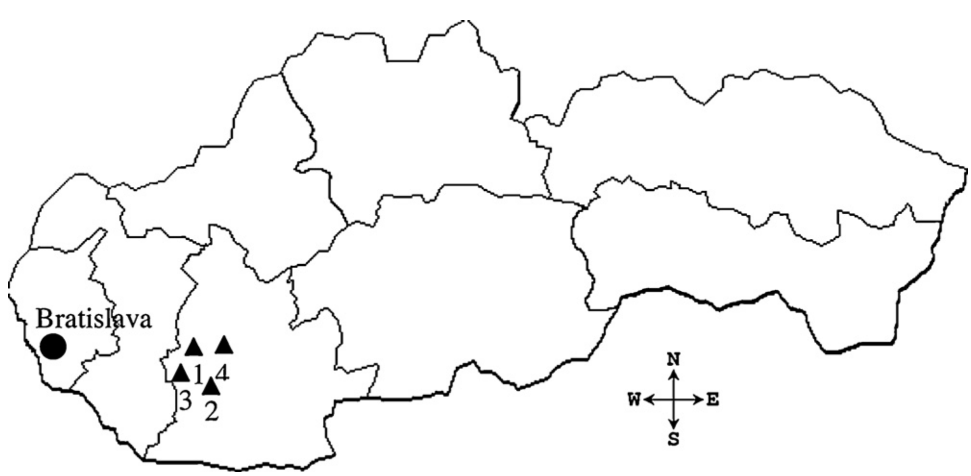

Fig. 1. Localities of the Haplic Chernozem (1 – Močenok, 2 – Komjatice) and Eutric Fluvisol (3 – Šal'a, 4 – Nitra).