Influence of the fractional composition of humus substances on the proportion of water-resistant aggregates

Vplyv frakčného zloženia humusových látok na zastúpenie vodoodolných makro-agregátov

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Abstract

In this study, the influence of humus substances on soil structure of six soils (Haplic Chernozem, Mollic Fluvisol, Eutric Fluvisol, Rendzic Leptosol, Eutric Cambisol, and Haplic Luvisol) of different ecosystems (forest, meadow, urban, and agro-ecosystem) in Slovakia was compared. The influence of the fractional composition of humus substances on the proportion of the fractions of water-resistant aggregates in different ecosystems was assessed. The fractions of free humic acids and those bound with monovalent cations and mobile R_2O_3 (r = 0.387; P < 0.05 and r = 0.415; P < 0.01), humic acids bound to the mineral components of the soil and stabile R_2O_3 (r = 0.477; P < 0.01 and r = 0.396; P < 0.01), and fulvic acids bound to the mineral components of the soil and stabile R_2O_3 (r = 0.504; P < 0.01 and r = 0.333; P < 0.05), had the most positive influence on the formation of larger (1-2 and 2-3 mm) water-resistant macro-aggregates. The amount of the extracted humus substances was the highest in agro-ecosystem > urban ecosystem > meadow ecosystem > forest ecosystem.

Key words: ecosystem, humus substances, water-resistant aggregates.

Abstrakt

V práci bol porovnávaný vplyv humusových látok na pôdnu štruktúru šiestich pôd Slovenska (černozem, čiernica, fluvizem, rendzina, kambizem, hnedozem) rôznych ekosystémov (lesný, lúčny, urbánny a agro-ekosystém). Bol hodnotený vplyv frakčného zloženia humusových látok na zastúpenie frakcií vodoodolných makro-agregátov v rôznych ekosystémoch. Frakcia voľných humínových kyselín a humínových kyselín viazaných s monovalentnými katiónmi a mobilnými R_2O_3 (r = 0,387; P < 0,05 a r = 0,415; P < 0,01), humínových kyselín viazaných s minerálnymi komponentmi pôdy a stabilnými R_2O_3 (r = 0,477; P < 0,01 a r = 0,396; P < 0,01) a fulvokyselín viazaných s minerálnymi komponentmi pôdy a stabilnými R_2O_3 R_2O_3 (r = 0,504; P < 0,01 a r = 0,333; P < 0,05) vplývali najpriaznivejšie na tvorbu väčších (1-2 a 2-3 mm) vodoodolných makro-agregátov. Najvyššie

množstvo humusových látok bolo vyextrahované v agro-ekosystéme, potom v urbánnom, lúčnom a lesnom ekosystéme.
Kľúčové slová: ekosystém, humusové látky, vodoodolné agregáty.
Detailný abstrakt

Pôdna organická hmota a pôdna štruktúra tvoria dynamický systém, v ktorom zohráva dôležitú úlohu charakter samotných organických látok. Humusové látky sú veľmi dôležitými komponentmi pre tvorbu stabilných agregátov. Preto cieľom práce bolo zistiť vplyv konkrétnych frakcií humínových kyselín a fulvokyselín na zastúpenie jednotlivých frakcií vodoodolných makro-agregátov. Aby bol výsledok čo najmenej ovplyvnený vlastnosťami pôdneho typu, boli do pokusu zahrnuté viaceré pôdne typy (černozem, čiernica, fluvizem, rendzina, kambizem, hnedozem), ktoré majú na Slovensku najväčšie zastúpenie, pričom na každom z nich boli lokalizované štyri ekosystémy (lesný, lúčny, urbánny a agro-ekosystém). V prípade agro-ekosystému išlo o reálne výrobné podmienky. Za agronomicky najcennejšie agregáty sú považované vodoodolné makro-agregáty v rozpätí 0,5-3 mm, avšak v rámci tohto rozpätia mali agregáty veľkosti 1-3 mm väčšie zastúpenie pri vyššom zastúpení frakcií humínových kyselín voľných a viazaných s monovalentnými katiónmi, minerálnymi komponentmi a stabilnými R_2O_3. Frakcia voľných humínových kyselín a humínových kyselín viazaných s monovalentnými katiónmi a mobilnými R_2O_3 (r = 0,387; $P < 0,05$ a r = 0,415; $P < 0,01$), humínových kyselín viazaných s minerálnymi komponentmi pôdy a stabilnými R_2O_3 (r = 0,477; $P < 0,01$ a r = 0,396; $P < 0,01$) a fulvokyselín viazaných s minerálnymi komponentmi pôdy a stabilnými R_2O_3 R_2O_3 (r = 0,504; $P < 0,01$ a r = 0,333; $P < 0,05$) vplývali najpriaznivejšie na tvorbu väčších (1-2 a 2-3 mm) vodoodolných makro-agregátov. Agregáty veľkosti 0,5-1 mm, tiež z rozpätia agronomicky najcennejších agregátov, mali vyššie zastúpenie pri vyššom zastúpení humínových kyselín viazaných s dvojmocnými katiónmi. Odlišnosti v množstve vyextrahovaných humusových látok boli pozorované aj medzi jednotlivými ekosystémami. Najvyššie množstvo humusových látok bolo vyextrahované v agro-ekosystéme, potom v urbánnom, lúčnom a lesnom ekosystéme, pričom v prípade lesného ekosystému treba pripomenúť, že išlo o povrchový, nie nadložný horizont.

Introduction

Different fractions of organic matter participate on the formation and stabilization of soil aggregates by various ways (Roberson et al., 1991; Tobiašová, 2011a). Stabile organic components include mainly the humus substances and other macromolecules, which are naturally resistant to microorganisms or are physically protected by adsorption on the mineral surfaces or bound inside the aggregates (Theng et al., 1989). According to Hamblin and Greenland (1977), the humified organic matter is more important for the stability of aggregates such as fresh organic material, which was added to the soil, although in some studies (Cambardella and Elliott, 1992; Chan, 2001) it was pointed out that the labile components, with relation to the stability of aggregates, are more important such as the content of total organic carbon. Humus consists of non-specific and the specific substances. The most common classification of specific humus substances is based on their solubility in dilute solutions of acids and bases (Perminova et al., 2005). Humic acids and fulvic acids include the majority of humus (Tan, 1998). Humic acids represent the fraction, which is insoluble at pH < 2 and fulvic acids are soluble at all pH values (Stevenson, 1994). Tisdall and Oades (1982) ascribe the importance mainly of aromatic humus substances, which are bound with the polyvalent cations and clay particles in the formation of permanent aggregates. According to Spaccini et al. (2004), high concentration of humified organic matter in the aggregates positively affects the biological stabilization of carbohydrates, so that they can be protected from the decomposition by being incorporate into the less polar structures of stabile soil organic matter, such as humus substances. Some studies focus on the impact of the humus substances on the stability of aggregates, but the influence of fractions of humic acids and fulvic acids was not closer studied. Therefore the objectives of this study were as follows: (i) to determine the influence of the fractional composition of humus substances on the proportion of the fractions of water-resistant aggregates, and (ii) to compare the proportion of humus substances in different ecosystems.

Materials and Methods

Characteristics of the territory

The studied areas are located in the west of Slovakia. Haplic Chernozem comes from the locality Močenok, Mollic Fluvisol comes from the locality Horná Kráľová, and Eutric Fluvisol from the locality Šaľa, which are situated on the northern border of the Danube Basin. Geological substrate is characterized with loess, loess loam, and aeolian sands (Pristaš et al., 2000). The average annual temperature of the studied area is 9.8°C and the average rainfall per year is 568 mm. The natural vegetation consists mostly of ash-oak-elm-alder forests and along the river, there are willow-poplar forests, and floodplain forests. In the elevated areas and dunes, xerophilic communities of oak-elm forests are dominant (Korec et al., 1997). The proportion of the crops in the agro-ecosystems is 65% of cereals, 20% of root crops, 5% of oil crops, 5% of forage and the rest are other crops. Haplic Luvisol comes from the locality Veľké Zálužie, which is situated in the Danube Lowland, in the unit of the Danube Plain, concretely in the Nitra Upland. Geological substrate is characterized with the lake and the brackish sediments (clays, gravels, and sands) (Hók et al., 2001). The average annual temperature of the studied areas is 9.3°C and the average rainfall per year is 607 mm (Korec et al., 1997). Nitra Upland is mostly deforested. In the lower parts, oak forests are dominant and in higher parts, beech forests. The proportion of the crops in agro-ecosystems is 60% of cereals, 30% of oil crops, 5% of forage and the rest are other crops. Rendzic Leptosol and Eutric Cambisol come from the locality Pružina, which is situated at the north-eastern foot of the highest peak Strážov, in the valley of the river Pružina. Geological substrate is characterized with the crystalline slates, granites, amphibolites and in the south and southeast, there are mesozoic dolomites, limestones, and slates (Buday et al., 1967). The average annual temperature of the studied area is 8.2°C and the average rainfall per year is 718 mm (Korec et al., 1997). In the forests, beech and oak dominate and in the higher parts these forest are with the addition of fir and higher number of conifers. The proportion of the crops in the agro-ecosystems is 60% of cereals, 12% of oil crops, 12% of root crops, and the rest are other crops. All meadow ecosystems were created by man 30 years ago; and the urban ecosystems are affected by human activity. In case of both, the vegetation cover are grasses.

Experimental details

The experiment included four types of ecosystems, which present different land uses and managements (forest ecosystem, meadow ecosystem, urban ecosystem, and agro-ecosystem) of six soil types (Haplic Chernozem, Mollic Fluvisol, Eutric Fluvisol, Rendzic Leptosol, Eutric Cambisol, and Haplic Luvisol). These are the soils of lowlands and uplands, which have the largest proportion in our country and are intensively agriculturally used (Tab. 1)

Table 1 Basic pedological characteristics of soils

	pH/KCl	CO_3^{2-} %	TOC[g] %	NT[h] $mg.kg^{-1}$	C:N	Sand %	Silt %	Clay %
HC[a]	6.14	2.60	2.146	2126	10.09	23.79	58.03	18.18
MF[b]	6.73	4.74	1.827	1767	10.34	47.56	34.68	17.76
EF[c]	7.23	2.96	1.884	2235	8.43	34.02	47.92	18.06
RL[d]	7.15	7.43	1.620	1240	13.06	39.20	45.76	15.04
EC[e]	6.65	4.14	1.767	1816	9.73	35.05	52.39	12.56
HL[f]	6.77	2.96	1.133	1453	7.80	52.46	35.06	12.48

[a]HC, Haplic Chernozem; [b]MF, Mollic Fluvisol; [c]EF, Eutric Fluvisol; [d]RL, Rendzic Leptosol; [e]EC, Eutric Cambisol; [f]HL, Haplic Luvisol, TOC[g] – total organic carbon, NT[h] – total nitrogen

The agro-ecosystem included four crop rotations for each soil types. 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.

Soil samples and analytical methods used

The soil samples used to determine the chemical and physical properties were collected in three replicates to a depth of 0.30 m and dried in a constant-temperature room of 25±2^{o}C. The soil samples for determination of chemical properties were ground. To determine the stability of the soil structure, soil samples were divided by the wet sieve into size fractions of the net aggregates. From the chemical properties, the total organic carbon (TOC) was determined by wet combustion (Orlov and Grišina, 1981), the fractional composition of humus substances according to method of Ponomareva and Plotnikova (1975). The obtained data were analysed using Statgraphic Plus statistical software. Correlation analysis was used to determine the relationships between the humus substances and water-resistant macro-aggregate fractions. Significant correlation coefficients were tested at P <0.05 and P <0.01.

Results and discussion

The humus substances are one of the components for the formation of stabile aggregates. Individual fractions of humus substances influenced differently the formation of soil aggregates. The formation of water-resistant macro-aggregates was influenced mainly by fractions of humic acids (Tab. 2). In the case of larger fractions of macro-aggregates, the correlation was positive, while in the case

of smaller macro-aggregates and micro-aggregates, the correlations were negative. Sisák (1994) considers that water-resistant macro-aggregates of the 0.5-3 mm size fraction are agronomically the most valuable aggregates. Fractions of these agronomically valuable aggregates of the 1-3 mm size fraction were positively affected particularly by the presence of fractions of free humic acids and those, which are bound with monovalent cations and mobile R_2O_3 (HA 1), humic acids bound with mineral components and stabile R_2O_3 (HA 3) and fulvic acids bound with mineral components and stabile R_2O_3 (FA 3). Conversely, the 0.5-1 mm aggregate fraction, which also belongs to the agronomically the most valuable aggregates, was not affected by these fractions, but by the fraction of humic acids, which is bound with Ca^{2+} and Mg^{2+} and which forms humates (HA 2). According to Tisdall and Oades (1982), mainly the humus substances, which are bound with polyvalent metal ions, participate in the formation of permanent aggregates, and as it can be seen in this case, individual cations can effect the formation of aggregates in various ways.
In the case of larger fractions of the water-resistant macro-aggregates (>1 mm), there was a positive correlation with the fractions of HA 1, HA 3, and FA 3, while in the case of the smaller macro-aggregates (<0.5 mm) and micro-aggregates, the correlation was negative. Six et al. (2000) have suggested that larger aggregates contain higher amount of the organic matter, but it is also subjected higher changes, especially mineralization. In this case, mainly the bindings with the fractions of free humic acids and those, which are bound with monovalent cations and mobile R_2O_3 and humic acids bound with the mineral components and stabile R_2O_3 were formed. Cation Na^+ can affect dispersity of clay (Haynes and Naidu, 1998) and the result of these processes is the destruction of aggregates, but at higher proportion of the fraction HA 1, more monovalent cations are bound to humic acids, through which the destructive effect on the soil aggregates is partially decreased.

Table 2 Correlations between soil organic matter parameters and the contents of water-resistant aggregate fractions

	Aggregate fractions				
	2-3 mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	< 0.25 mm
HA 1[a]	0.387*	0.415**	-0.001	-0.156	-0.316*
HA 2[b]	-0.170	0.247	0.454**	0.225	0.284
HA 3[c]	0.477**	0.396**	-0.186	-0.469**	-0.253
Σ HA[d]	0.281	0.554**	0.238	-0.095	-0.095
FA 1a[e]	0.244	0.122	0.057	0.076	-0.160
FA 1[f]	-0.250	-0.198	0.208	0.524**	0.156
FA 2[g]	0.216	0.029	-0.007	-0.376*	-0.110
FA 3[h]	0.504**	0.333*	-0.167	-0.187	-0.364*
Σ FA[i]	0.247	0.066	0.064	0.010	-0.157

[a]HA 1 - free humic acids and those, which are bound with monovalent cations and mobile R_2O_3, [b]HA 2 - humic acids bound with Ca^{2+} and Mg^{2+}, which forms humates, [c]HA 3 - humic acids bound with mineral components and stabile R_2O_3, [d]Σ HA - sum of humic acids, [e]FA 1a - free “aggressive” fulvic acids, [f]FA 1- free fulvic acids and those, which are bound with monovalent cations and mobile R_2O_3, [g]FA 2 - fulvic acids bound with Ca^{2+} and Mg^{2+}, which forms fulvates, [h]FA 3 - fulvic acids bound with mineral components and stabile R_2O_3, [i]Σ FA - sum of fulvic acids. $^{*}P < 0.05$, $^{**}P < 0.01$

Lower content of the organic matter is for the micro-aggregates characteristic (Sohi et al., 2001; Tobiašová, 2011b), because on their formation, primarily mineral components of the soil participate and as the role of cement agents in them play mainly sesquioxides (Duiker et al., 2003). Therefore, in the case of a higher proportion of the humic acids bound with the mineral components and stabile R_2O_3, there are a lower proportion of the smaller aggregates. Stabile R_2O_3 are previously bound in the humus substances and the formation of aggregates is influenced through them. An interesting fraction among all is the fraction of water resistant 0.5-1 mm macro-aggregates. This fraction was influenced only by the one fraction of the humic acids, which are bound with Ca^{2+} and Mg^{2+} (HA 2). These cations are the main polyvalent cations, which are present in the neutral and alkaline soils and stabilise the organic matter by the formation of complexes, which are more resistant to the oxidation and they also improve the aggregation (Borie et al., 2008). However, if they are bound on the humus substances, their effect is partially decreased which, in this case, supports the higher content of the 0.5-1 mm aggregate fraction.
The highest amount of extracted humus substances (Fig. 1) was in agro-ecosystem, in particular fractions of humic acids and fulvic acids bound with Ca^{2+} and Mg^{2+}. The source of humus substances in agro-ecosystem was mainly farmyard manure, which contains humus substances with high degree of polycondensation (Nannipier, 1993), and the source of bivalent cations was liming.

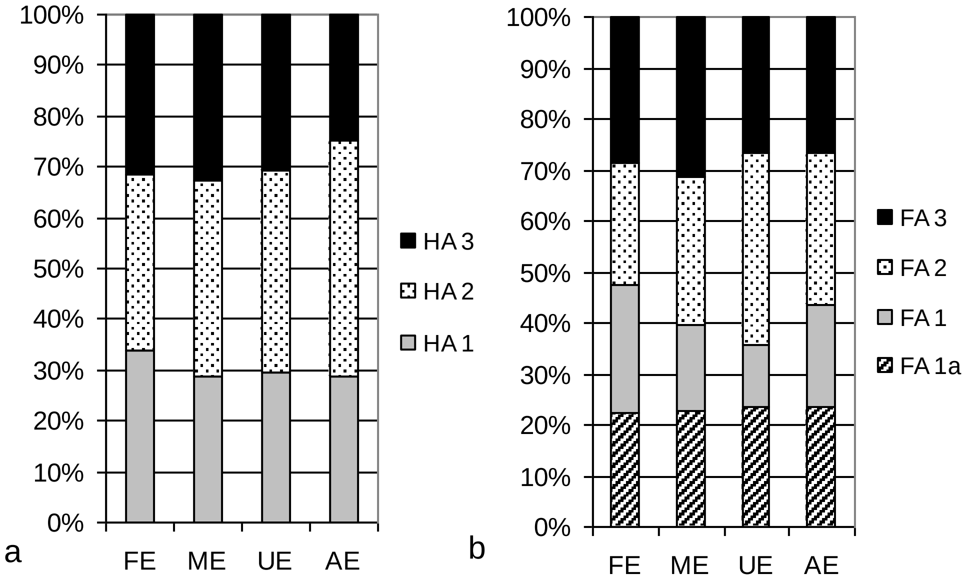

Fig. 1. Fractional composition of humic acids (a) and fulvic acids (b) of different ecosystems
FE - forest ecosystem, ME - meadow ecosystem, UE - urban ecosystem, AE - agro-ecosystem, HA 1 - free humic acids and those, which are bound with monovalent cations and mobile R_2O_3, HA 2 - humic acids bound with Ca^{2+} and Mg^{2+}, which forms humates, HA 3 - humic acids bound with mineral components and stabile R_2O_3, FA 1a - free “aggressive” fulvic acids, FA 1 - free fulvic acids and those, which are bound with monovalent cations and mobile R_2O_3, FA 2 - fulvic acids bound with Ca^{2+} and Mg^{2+}, which forms fulvates, FA 3 - fulvic acids bound with mineral components and stabile R_2O_3.

Conversely, in the forest ecosystem was the lowest proportion of humic acids, especially those bound with Ca^{2+} and Mg^{2+}. In the case of meadow and urban ecosystems, higher amount of extracted humus substances was in the urban ecosystem (Tab. 3).

Table 3 Total organic carbon and humus substances in ecosystems.

	TOC[e] %	ΣHA[f] %	ΣFA[g] %	C_{HA}:C_{FA}[h]
FE[a]	2.046	43.80	30.71	0.84
ME[b]	1.550	44.93	29.81	0.87
UE[c]	1.561	46.77	31.72	0.89
AE[d]	1.305	58.50	34.06	1.04

[a]FE - forest ecosystem, [b]ME - meadow ecosystem, [c]UE - urban ecosystem, [d]AE - agro-ecosystem, [e]TOC – total organic carbon, ΣHA[f] – sum of humic acids, ΣFA[g] – sum of fulvic acids, [h] C_{HA}:C_{FA} – ration of carbon of humic acids to carbon of fulvic acids

The stabilization of formed humus substances in the urban ecosystem can be supported by the various mineral components, which come from anthropogenic sources. Urban soils have high contents of alkali metals, sodium from the winter road maintenance, calcium from building debris (Puskás a Farsang, 2009). Overall, the amount of extracted humus substances in the natural ecosystems (forest, meadow) was lower than in the ecosystems influenced by human activity (Tab. 3). The stability of organic substances in the agro-ecosystem is also supported by mixing of these organic substances with mineral proportion of soils. In natural ecosystems, particularly in the forest ecosystem, labile forms are dominated because the organic inputs are nearly continuous, and their conversion into stabilized forms is a question of longer time period. Moreover, in the forest ecosystem, a part of these substances is accumulated in upper organic horizon (Arevalo et al., 2009), and a part of them, mainly more labile, is washed into deeper parts of soil profile. This is the next reason why higher contents of humus substances were recorded in the agro-ecosystem than in the forest ecosystem.

Conclusion

The fractions of humic acids and fulvic acids, which are bound to the mineral components of the soil and stabile R_2O_3 had the most positive influence on the formation of larger water-resistant macro-aggregates (1-3 mm).
The amount of the extracted humus substances was the highest in agro-ecosystem > urban ecosystem > meadow ecosystem > forest ecosystem.

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