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URBAN SOILS: COMPLEX EVALUATION AND CLASSIFICATION OF SOILS IN SZEGED

Summary of PhD thesis

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1. Precendents, objectives

Soil sciences have to pay greater attention to urban soils within anthropogenic soils since urban areas have expanded worldwide and are now occupying more and more lands which formerly were under agricultural and natural use. As the proportion of urban population is continuously increasing, soon the first time in history the dominant residence of mankind is going to be the city. Increasing urbanization, industrialization, the impact of human activities result in soil contamination, soil degradation and soil formation from anthropogenic parent materials. Consequently, the management of urban soils has become more and more important by now, especially if considering that the quality of living in cities and urban functions highly depend on the conditions of these soils. In order to characterize the modified use in an urban environment, these soils have to be described, and their functions and chemical, physical properties have to be assessed and measured. Results can serve as a useful basis for the prediction of soil development and transformation, or the need for soil protection and soil revitalization.

The peculiarity of these modified soils is their special genesis, which occurs among special conditions not present in natural systems. The same goes for the physical, chemical and biological composition of urban soils since anthropogenic activities in cities result specific urban patterns. Consequently, research on urban soils can generally be divided into two approaches, complementing each other. One approach is the research on the genesis of urban soils, the other one is the research on the contamination and disturbance, which may negatively affect the quality of human life.

Combining both of the above approaches, the objectives of my research can be summed up as follows:

1. to examine the physical and chemical properties different from those of natural soils in order to find some excellent markers of human influence on urban soils;
2. to classify the individual soil horizons into natural and anthropogenic groups using geostatistical methods;
3. to determine the concentration of heavy metals (Co, Cu, Ni, Pb, Zn, Cr, Cd) in these soils enabling a classification according to the toxic properties recorded in the WRB(World Reference Base for Soils Resources, 2006), plus to identify the origin of these elements (anthropogenic vs. geogenic);

4. to trace the changes of the previously tested urban diagnostic properties in profiles sampled along a section from the city centre towards the peripherals;
5. to survey the mezofauna communities (Oribatid mites, Collembolans) of soils in city, suburban and peripheral zones in order to get information on the quality and quantity characteristics of urban and natural soils;
6. Finally, to classify the identified soils in accordance with the system of the WRB(2006) as well as to present some typical urban profiles.

2. Materials and methods applied

Szeged proved to be an ideal sampling area for the research since both the intensive artificial infill following the 1879 Great Flood and other anthropogenic activities (e.g. frequent filling, mixing, accumulation of rubbles and household wastes in depressions etc.) owing to expansion of urban functions have been defining the morphology of soils here. Consequently, original soil types can hardly be found in the city.

For the physical and chemical analysis of soils 124 samples were taken from the horizons of 25 profiles in the city and its peripherals (as control samples) during 2005 and 2006. The location of urban profiles influenced by human activities was determined by considering the degree and type of anthropogenic activities: The profiles were sampled at sites affected by different extent of artificial infill. Selection was made according to maps depicting the thickness of infill in the city area (1. profiles fully made up of infill; 2. so-called mixed profiles consisting of considerable amount of infill material and buried soil horizons; 3. natural profiles located in the peripherals of the city). Furthermore, the profiles represented sites having different land uses (e.g. park, built-in area, unpaved road, plot, orchard, abandoned area etc.).

The artefact content (m/m %) was determined before soil sample preparation. After drying and separation of coarse components, samples were crushed and sieved through a mesh of 2 mm for further analysis: The pH (H_2O, KCl) was recorded using a digital pH measuring device of Radelkis type. The carbonate content of dry soil samples given in percentage was determined via Scheibler type calcimetry. The total salt content of the soils was determined by recording the electric conductivity of fully saturated soil samples. The organic content was measured after H_2SO_4 digestion in the presence of 0.33 M $K_2Cr_2O_7$. The quality of humus was given by the humus stability coefficient (K value). The total nitrogen content was measured using nitrogen distilling device type Gerhardt Vapodest 20. The mechanical composition was determined by the yarn test of Arany.

Average topsoil samples were also taken at every individual profile (at a depth of 0-10 cm covering an area of 2-4 m^2) to assess the total heavy metal content. The total metal content was measured using an AAS type Perkin Elmer 3110 following a full digestion with aqua regia. For the identification of metal origin beside the soil fraction metals were also determined from the coarse components (in topsoils and along the entire vertical section of three anthropogenic profiles) to get the enrichment factor [EF= metal content of soil fraction (< 2 mm) / metal content of coarse component (> 2 mm)] given by Rosenkranz.

The presence of the mesofauna in the soil is the greatest during spring and autumn. Consequently, soil samples for investigation of soil fauna were taken in October 2006 at 10 sites (next to 9 profiles and 1 other site) representing three zones (city, suburban, peripheral zone). For the analysis of the soil fauna topsoil samples (0-5 cm) were applied, which were collected from two 30x30 cm quadrates at each sampling site. The extraction of the tiny soil microarthropods in isopropyl-alcohol was carried out using a modified Balogh extractor within 5-6 hours after sample collection. Then the samples were treated with saturated NaCl suspension and filtered with a vacuum sieve. The extracted animals were sorted and identified under a binocular stereomicroscope. Then some basic biological properties (i.e. abundance, dominance, taxon diversity, Sørensen similarity index, MPG ratios) of mesofauna elements (Oribatid mites, Collembolans) and their community structure were surveyed.

The measured data were processed and evaluated by EXCEL 2003 and SPSS 11. for Windows. In order to separate the anthropogenic and natural horizons within the individual soil profiles, a discriminant analysis was applied. The goal of the analysis was to discriminate the groups via a linear combination (so-called discriminant function) of variables typical of the soil horizons, and using these equations to predict the future place of new samples (ungrouped horizons) within the classification.

3. Results

3.1. First of all, the physical and chemical diagnostic properties were examined in favour of three aims: Firstly, the characterization of the impact of urbanization on profiles was attempted with as many diagnostic properties as possible. Secondly, a statistical analysis was carried out on the basis of the measured values. Thirdly, by using the determined parameters the studied soils were classified according to the WRB(2006) system.

It is to be claimed that all the soil parameters except total salt content are excellent markers of human influence. This can be seen either in a change in their concentration or the alteration of their vertical distribution in the profiles:

- A high amount of ***artefacts*** can generally be observed in the profiles subjected to considerable disturbance, while the original natural profiles are either free of artefacts or have only negligible amount of these components. However, the disturbed horizons are not always characterized by elevated artefact concentrations as this property is highly dependant on the quality and quantity of the infill;
- The yarn test by Arany, referring to ***mechanical soil types***, yields lower values in case of urban soils in contrast to the natural soils on peripherals of the city. The horizons of infill in the city are dominated by sand, sandy loam and loam, while those where the original soil conditions were preserved are dominated by clayey loam and clay. The abrupt textural changes are mostly characteristic of artificial horizons in contrast to the gradual textural change of natural horizons;
- It is to be claimed that the ***humus content*** proves to be good marker of human activity by the alteration of its vertical distribution in the profiles. The high degree of surface cover, the high artefact content, physical and chemical degradation result in poor microbial activities and as such lower humus concentrations in the soils of Szeged. The quantitative evaluation is not so much expressive since the humus content of anthropogenic profiles is low (excluding only some horizons) similarly to that of natural profiles. On the other hand, the distribution of this parameter along individual profiles shows a considerable difference: Along natural profiles, humus content is congruent with the regular tendency characteristic of original genetic soil types in contrast to the irregular fluctuation of humus content in profiles fully made up of artificial infill. A duality can be observed in the case of mixed profiles, where the change of humus content is congruent with that of natural soils from the appearance of the "A" horizon of the original buried soil;

- The distribution of extremely poor, poor ***total nitrogen*** along the studied profiles shows similar tendencies, indicating the strong relation of nitrogen and humus.
- The ***humus stability coefficient*** (K value) is also an excellent marker of urban soils: the horizons with considerable amount of artificial infill are characterized by very low K values, indicating the prevalence of raw humus components, i.e. fulvic acids not yet subjected to humification. However, original natural soil horizons have higher K values referring to the dominance of high-quality humic acids.
- The distribution of ***carbonate content***, characterized by category of strongly and moderately calcareous, shows more significant variation. It has an irregular fluctuation considering the anthropogenic horizons of profiles, whereas in case of natural horizons it is congruent with the regular tendencies present in original genetic soil types. The highest carbonate values were experienced in case of the mixed profiles on Phaeozem, where both natural horizons of very high carbonate content and artificial horizons having considerable amount of carbonate content occurred. In such profiles, there is a gradual downward increase in the carbonate content towards the bedrock from the first natural soil horizon. This phenomenon can be explained by the leaching of carbonate.
- The ***pH*** values strongly depending on carbonate content were classified into slightly alkaline and alkaline categories. pH values of natural and anthropogenic horizons are very similar. However, there is significant difference in the pH change along the profiles. A tendency for acidity is clearly discernible from the differences of the pH(H_2O) and pH(KCl) values. There seems to be a greater tendency for acidity in those soil horizons, where there was a significant reduction in the carbonate as a result of leaching;
- Concerning ***total salt content*** it was found that its value has not increased in the soils of Szeged due to intensive human activities (e.g. road salting).

3.2. After surveying the diagnostic properties, their geostatistical evaluation (***discriminant function analysis***) was also carried out. This was necessary in order to classify the questionable horizons of mixed (natural and anthropogenic) profiles. For this purpose, horizons of truly anthropogenic and natural origin were used. Two groups were established with the help of field observations, the analysis of the chemical, physical properties, and maps showing the thickness of artificial infill in the city: The category of artificial infill was marked by group variable 1, while that of the original soil was marked by the group variable 2. The samples of uncertain origin were marked as ungrouped. With the help of the linear combination of predictor variables (the recorded diagnostic properties of the individual horizons), i.e. their discriminant function the horizons of uncertain origin were classified into the above-mentioned two groups. Based on the discriminant function coefficients of identical prefix a discriminant diagram was created, on which two separated clouds of data points can be identified corresponding to the samples of groups 1 and 2. The elements of group 2 are located in a narrower zone reflecting the similarity, homogeneity of properties of these horizons. However, elements of group 1 are situated in a wider zone, consequently, a significant difference, heterogeneity can be suggested in their case. An imaginary line can be drawn between group 1 and group 2 along which the horizons falling to the category "ungrouped" can be classified into the above detailed two groups. Out of the 51 samples identified as ungrouped 100 % were correctly classified. 28 were put into group 1, while 23 into group 2. The significance of the procedure from a pedological point of view is that a clear borderline can be established between the natural and anthropogenic soil layers for mixed profile. Furthermore, the classification can be extended to profiles of unknown origin by using the properties of their horizons. This analysis clearly justifies the formerly discussed differences in the observed properties of the two groups. Artefact, humus and carbonate content and values of yarn test show the highest differences.

3.3. The anthropogenic and lithogenic origin of ***heavy metals*** in the soils of Szeged were distinguished according to the enrichment factor given by Rosenkranz: Based on this analysis, Pb, Zn, Ni and Cu are of anthropogenic origin, while Co, Cr and Cd are of lithogenic origin. The vertical variation of heavy metals in the anthropogenic profiles shows an irregular fluctuation since each infilled horizon contains a different amount of heavy metals depending on the original concentration in the applied material.

According to quantitative analyse, it was established that anthropogenic metals (Zn, Pb, Cu) mostly originating from urban traffic were found in a toxic concentration in the city, whereas the concentration of Ni, Cr and Cd exceeded the B threshold limit value in the orchards of the outskirts and on agricultural areas in peripherals. Following the quantitative evaluation of elements, congruently with the proposal of the WRB(2006) those profiles were marked by the suffix Toxic, where the concentration of any metal element exceeded the limit values in the topsoil.

3.4. Based on ***profiles*** (No. 22., 1., 13., 2., 15., 21.) ***located along a section*** moving from the city centre towards the peripherals, the spatial change of diagnostic properties turned to be unambiguous: The most altered profiles (No. 22., 1., 13.) of the section contain nothing but infill horizons with extraordinary features (e.g. coverage by artificial objects, high amount of artefacts, poor humus quality, mostly sand, sandy loam texture, abrupt colour and textural changes, intensive compaction, toxic metals, irregular fluctuation of diagnostic properties along the profiles etc.). In their case the original genetic soil type can not be identified at all. Moving towards the peripherals of the city features typical of natural soils appear. In the case of mixed profiles (No. 2., 15.) situated between the city centre and the peripherals, the extent of human impact decreases, both anthropogenic and natural characteristics (e.g. appearance of original genetic horizons, lower amount of artificial cover and artefacts etc.) are present. Most of the diagnostic properties (e.g. mechanical soil type, K value, carbonate and pH content etc.) of the orchard profile located in the outskirts (No. 21.) can be considered natural, but a higher amount of humus and nitrogen were found due to intensive agricultural activities.

3.5. A general demand of soil research is to evaluate the effect of human activity by applying biological indicators, as physical and chemical parameters can not completely describe the quality of urban soil. Based on the ***Oribatida*** investigation, the number and abundance of taxa increase from the city towards the semi-natural habitats of the peripheral zone. In accordance with the above, the lowest abundance values were experienced in the city zone, being an order of magnitude lower than elsewhere. The similarity analysis based on the Sørensen index showed that there were more common genera in terms of the suburban and the peripheral zone, than in case the city and the suburban or the city and the peripheral zones. MGP-I analysis was applied in order to evaluate the stability of the Oribatid mite community in the 3 urban zones. It shows that the patterns in the peripheral and suburban zones were similar, while that of the city zone differed from both. All of these reflect well the extreme character of city zone taxa.

The abundance pattern of ***Collembolans*** corresponded well to that of Oribatid mites. The diversity and abundance of Collembolans were the lowest in the city zone.

It can to be claimed that the intermediate, transitional areas between the city and the peripheries show a greater diversity. It seems that this intermediate zone is stable and heterogeneous enough to constantly provide the species for the city and the peripheral areas. The concentric structure of Szeged is also important in ensuring a gradual transition between the city and the peripheral areas. Since there is no contiguous industrial zone, the intermediate area between the city and the peripheries can be a significant buffer and refugium for soil microarthropods.

3.6. With the help of the above-mentioned parameters, the studied soils of Szeged were assigned into the classification system of ***WRB(2006)***, which

classifies the soils of urban and industrial areas as an individual soil group (under the term Technosols) for the first time. Note that soils have not been classified according to WRB in none of the Hungarian cities up till now.
First of all, the expression, thickness and depth of horizons were checked and compared to the requirements of the WRB diagnostic categories. Subsequently, the described diagnostic categories were compared to the requirements of reference soil groups (32) in the WRB Key. I went through the Key systematically, starting at the beginning and excluding one by one all soil groups for which the requirements were not met. The given soil belongs to the first soil group for which it met all the specified requirements. On the second level of the WRB classification, qualifiers were used. Each profile was provided with the suitable qualifiers chosen from a set given for the examined soil group. Based on the evaluation and statistical analysis of diagnostic properties, in accordance with the WRB(2006) nomenclature three main soil types can be identified in Szeged with respect to the degree of human influence:

- Profiles in the peripherals (No. 16., 17., 18., 19., 24., 25.) representing the original genetic soil type and profiles in orchards (No. 20., 21., 23.) with some modifications were classified as soils ***slightly*** and ***moderately*** influenced by human activities. These profiles were classified into Phaeozem, Fluvisol, Gleyosol, Arenosol, Solonetz natural soil groups and received the suitable qualifiers [e.g.: the profile No. 17 → Calcic Phaeozem (Anthric, Abruptic, Calcaric, Pachic, Epiarenic; the profile No. 23 → Gleyic Fluvisol (Calcaric, Humic, Eutric, Hyperclayic, Toxic)]. The "weakness" of WRB(2006) in terms of the suffix Toxic was proved through the example of the Fluvisol profile No. 23. This was the only profile where the topsoil concentration of four heavy metals exceeded the B threshold value. The topsoil of another Fluvisol profile (No. 19) also contained toxic metal concentration (in the case of two metals). However, there is not a Toxic suffix among the qualifiers of the Fluvisol soil group. Consequently, I suggest that the Toxic qualifier has to be involved the qualifiers of Fluvisol and all other soil groups since not only urban soils but natural soils in the peripherals can be contaminated by atmospheric deposition, surface runoff and agricultural activities.
- Mixed profiles (No. 2., 3., 7., 10., 12., 14., 15.) on outskirts fell into the category of ***strongly modified*** soils. After their classification into the WRB(2006) it can be established that the their names do also reflect their dual nature: The upper part of profiles was generally assigned into the Technosol soil group and was provided with the suitable qualifiers. The lower part composed of buried horizons was described with the

Thapto- specifier and -ic added to the reference soil group name of the buried soil [e.g.: profile No. 10 → Ekranic, Endofluvic Technosol(Toxic, Densic, Epiclayic)(Thapto-Fluvisolic); profile No. 3 → Urbic Technosol (Calcaric, Ruptic, Toxic, Epiarenic)(Thapto-Phaeozemic)]. The upper parts (Technosol) of these profiles are mostly characterized by suffixes Ekranic and Urbic and prefixes Toxic, Ruptic and Calcaric.

- Profiles ***completely altered*** by a very intensive human influence (No. 1., 4., 5., 6., 8., 9., 11., 13., 22.) were placed into the group of Technosols due to the considerable transformation of their diagnostic properties (e.g. coverage by artificial objects, intensive compaction, horizontal and vertical variability, usually high amount of artefacts, anthropogenic parent material etc.). Transformations were best reflected by suffixes such as Ekranic, Urbic (Linic in case of one profile). Among the suffix qualifiers Calcaric, Ruptic, Densic and Arenic were used the most frequently. Furthermore, I found that three of the nine studied profiles were not situated in the city centre. Consequently, the location of these profiles in the city centre is not necessary since local influences can overwhelm the effect of artificial infill. Considering all the profiles, two of them in city centre can be consider to be the most anthropogenic: profile No. 11 [Ekranic Technosol (Ruptic, Toxic, Endoclayic)] and profile No. 22 [Urbic Technosol (Calcaric, Ruptic, Densic, Arenic)]. It can be claimed that profile No. 11 with "technic hard rock" has the least chance to experience pedogenetic processes since the horizons are covered by thick, surface artificial object, and isolated from the outside world. However, in case of profile No. 22 with dense vegetation and without surface artificial object, the high amount of artefact inhibits pedogenesis.

According to the above-mentioned facts, I assume that WRB(2006) can be applied well to the classification of soils in Szeged since some qualifiers (excluding Toxic) well reflect the local modification of diagnostic properties.

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