Sand grain mineralogy and morphology under forest and grassland/arable fields in Eastern Hungary

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Land use is changing in most places of the Great Hungarian Plain (KOVÁCS, 2011), which might occur at the centennial, decadal or more frequent scales. From time to time socio–economic–legal conditions prefer one particular land use type to all others. In the European Union a current incentive is to establish tree plantations on arable lands (EU, 1999) to preserve as much carbon in plants and soils as possible, preventing a great increase in CO_2 emission in Europe.

The effect of land use changes on surface formations depends on several factors. Tree plantations have much larger/longer cycles than arable lands. Perennial trees keep on growing and result in taller, deeper and greater biomass distribution (roots, stem and leaves) as compared to annual crops.

Differences in the depth distribution of several soil and subsoil characteristics [e.g. carbon, soil moisture, soil reaction (JOBBÁGY & JACKSON, 2004a,b)] between tree plantations and arable land are quite remarkable, in contrast with that of mineralogical characteristics.

In classical pedology the grains of skeletal sandy soils are the "invariable", while "colloids" and organic fragments are the "variable" components; and mineral grains are not altered by the variation of natural and anthropic conditions. The question arises whether living beings (their presence and activity) have put their footprints on the mineral grains during the lifetime of trees or not.

For this reason, in three sites of the East Hungarian (Tiszántúl) sandy region, a detailed mineralogical and morphological study of sand grains was followed. Examining the 0.1–0.2 mm grain size of the 0–100 cm sandy soil layer from forest and control fields of the three sample areas (30 samples, 22,509 sand grains), six mineralogical and morphological features (quartz/feldspar ratio, limonite grains, gypsum grains and coatings, unabraded grains, etch pits and brown films on sand grains) were selected, which could help the identification of these "footprints" and the processes making difference between the particles derived from the forest and the control area. The answer to the above presented question is not just academic, but it helps in deciding whether the (re)forestation of some grassland in this region would be useful or not under climatic changes in progress. Authors present pioneer-

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ing work on the detection of the mineralogical changes resulting from afforestation of alluvial lowlands. This paper has been refocused based on their previous report (BALOG et al., 2013b).

Materials and methods

Location, geological and morphological setting. – The investigated area (Eastern Hungary, Tiszántúl) is located near to Debrecen. Agricultural fields and grasslands alternate there with forest plantations [oak (Quercus robur), black locust (Robinia pseudoacacia) and poplar (Populus x. euramericana)].

The Tiszántúl region is part of the Pannonian Basin, the largest Intra-Carpathian sedimentary domain, with pre-Hercynian metamorphic basement and with Cretaceous, Paleogene, Neogene and Quaternary sediments. The last sediment accumulation occurred during the Late Pleistocene and Early Holocene. In this period, a huge quantity of sandy sediments from Northern and Eastern margins of the Pannonian Basin were carried by secondary water flows drained by the Old Tisza river and were spread over by the wind along the Hungarian-Romanian state border. Therefore, the morphology of this region is characterized by the presence of fluvio-eolian relief: flat floodplains in alternance with sand dunes and troughs, at 100–130 m altitude above sea level (DÖVÉNYI, 2010).

Sampling and analyses. – Three forest plots with three grassland/arable land control areas (Mikepércs, Hajdúsámson and Nyírbogát) were sampled down to 6–9 m depth with spiral auger. For mineralogical analysis, samples were dried, disintegrated and sieved into 0.1–0.2 mm fractions. These boreholes traversed three levels of the fluvio-eolian sediments: 1. 0.4–0.6 m thick dark brown or dark grey silty sand with 0.3–5.5% humus content; 2. 2–8 m thick yellow and grey, fine grained sand with or without silty embeddings, limonitic and carbonatic zones; and 3. yellow silt or sandy silt, representing the buried relief of the Upper Pleistocene loess. The depth of groundwater is 3.5–6.5 m under the forest plots and 2.5–4.0 m under the control.

It was supposed that the expected changes of sand grains are observable mainly in the root zone of the plant of the vegetation type. For this reason, 30 sand samples (3 pilot areas × 2 land use types × 5 depth categories) of the 1.0 m topsoil (from each 20 cm) were collected and analysed.

The appropriate grain size fraction for mineralogical and morphological studies with optical mineralogical microscope (10–25× magnification) is the Ø 0.1–0.2 mm fraction, with minimal composite grain and clayey-limonitic concretion content. The mineralogical composition is based on grain counting, which can be considered as a volumetric evaluation. The percentage occurrences of minerals and morphological characteristics were calculated based on the total numbers of sand grains. From each sample, five fields (100–250 grains) were examined, resulting in 764 grains per sample in average, and 22,509 grains in total. By optical means, the mineralogical composition and the morphology of the grains (e.g. quality of the grain surface) were observed. The accuracy of the optical mineralogical composition was controlled by X-ray diffractometry analyses (sample: Mikepércs, 40–60 cm depth).

Due to the huge number of individual observations, statistical methods were used for the interpretation. With the help of Shannons' Entropy and Student Test, the differences among the sampled 20 cm thick layers of each borehole, the differences between forest and control boreholes and among the three sampling areas were emphasized. Data were lognormal transformed.

Results and discussion

Mineralogy

The sand samples contain minerals, rock fragments, secondary mineral phases and plant fragments.

Minerals

Quartz (71–82% of total number of grains) (metamorphic, volcanic) is the dominant mineral of the samples, that forms colourless, or milky white, yellowish, pink and light grey, smooth, anhedral, irregular or slightly rounded sand grains.

Feldspars (8–11%) are white, yellowish, light orange or pink, with smooth-silky surface, forming hemihedral or anhedral grains with nacreous cleavage facets. The amount of feldspar grains is 8–9 times less than the amount of the quartz ones.

Micas (1.2–2.3%) (muscovite: colourless or slightly yellowish, biotite: brown-green or greyish brown) appeared as a few (1–4) flakes per microscope field, as rounded or angular, irregular sheets, often adhered to a quartz grain.

Chlorite (0–0.1%) forms rare green, nacreous, translucent, irregular sheets with brown, oxidized margins.

Amphibole and/or (weathered) pyroxene (0.6–2.6%) are dark or greyish green, rounded prism-like, silky grains, often with limonitic films.

Dark minerals (0.6–2.4%) (magnetite, hematite or ilmenite) are opaque, black grains with metallic reflexes. Smooth ones are probably older, rounded limonite balls and the angular, peat-like, black pieces can be coal fragments reworked from Miocene or older deposits.

Heavy minerals (0.6–1.2%) (epidote, titanite, zircon, garnet, apatite, rutile, tourmaline, sillimanite and zoisite) were found nearly in all microscope fields. The total amount of accessories is not higher than 1%, but they mark the original rock of these sands: the Transylvanian and the Northern Carpathian Metamorphic Belt.

Rock fragments

Rock fragments appear mainly as composite grains in the 0.1–0.2 mm fraction, the amount of these grains reaches max. 6%.

Volcanic rock fragments (0.9–3.5% of the total number of grains). The most frequent composite grain type is the rhyolite pumice fragment: white-yellowish, well-rounded grains with smooth surfaces, often coating feldspar or quartz grains.

The dark grey, brown or greenish, fine grained, well rounded grains seem to be more or less weathered, intermediary or basic igneous rock fragments, often with limonitic crusts.

Metamorphic rock fragments (0.9–2.2%) form loess-like or irregular, well or medium rounded, grey, green or yellowish-brown grains of mica schists, mica bearing quartzites, chloritic schists, sericitic schists and feldspar bearing (probably gneissic) rock fragments as rare composite grains in the sand samples.

Other rock fragments (0.1–0.7%) are rare, insulated, rounded, grey grains of lens-like, fine shales and clayey-silty rocks, chert balls and a few, marl or marly limestones.

Secondary minerals

In the 0.1–0.2 mm sand fraction a few grains of newly formed (after sedimentation) mineral grains were identified as "secondary mineral phases".

Limonite (0.7–2.5% of the total number of grains) is represented by shell-like, deep brown, smooth crust fragments and reddish or ochre brown, soft, irregular-angular, spongy grains with cellular structure and containing fine, silty quartz fragments.

Gypsum (0.1–2.05). White, silky, hemihedral crystals and fragments of crystals, with nacreous reflexes, and light grey, irregular crust fragments were identified.

Carbonate: only three white, yellowish, fine grained crust fragments appear in the Nyírbogát control borehole, at the 0.8–1.0 m depth.

Plant fragments (0.2–0.9%). In all samples of the 0–20 cm depth and in a few from below the 20 cm depth fresh root threads, leaf and grass pipe fragments occur, and in forest plots, black, partly humified particles appear.

The above presented mineralogical composition is a volumetric evaluation. The equivalence of these data with the weight percent mineralogical composition was verified by X-ray diffractometry analyses (sample: Mikepércs, oak forest, 40–60 cm depth). There is a positive difference between the quartz quantities (because the silica of the composite grains are evidenced as quartz by diffractometry) and a notable negative difference in the case of gypsum (perhaps due to counting error).

Morphology

The shape of the sand grains and the quality of their surface was observed by visual, optical means.

Roundness

Sand grains show different degrees of abrasion. By visual observation four categories were distinguished: 1. angular, scaly, *unabraded fragments (7–13%)* with sharp edges and pointed corners; 2. subangular grains with *slightly abraded (36–56%)* edges and points; 3. *sub-rounded grains (21–41%),* with well-abraded, blunted edges and 4. *rounded (6–11%),* close spherical or elliptical grains. "Softer" feldspar grains and rock fragments are more rounded than the quartz ones.

Grain surface

Channels and moulds (1.0–3.1% of the total number of grains) were observed on some quartz grains, under binocular microscope. They mark silica dissolution and precipitation effects during fluvial, sweet water transport and deposition (KINGSLEY & DORNKAMP, 1973).

Etched grains (0.7–6.9%). By optical observation, some grains show lace-like margins and rough surfaces. At 100× or greater magnification, groups of etch pits appear. They reshape both the abraded surfaces and the silica scales and nodules.

Fractured grains. On a few Ø ~0.2 mm grains a fine network of fissures can be observed.

Gypsum crusts and "thorns" (0.4–3.3%). A few grains are covered with thin, shiny, nacreous gypsum film, with/without spear-like "thorns" of the same mineral.

Black films (0.7–3.5%). On the cavities of some grains, shreds of black films appear. It seems that these films are the remainder of older coatings with iron oxide, coal or humic material, which were abraded during the transport of the grains.

Brown films (8–30%). Relatively many grains are coated with light, reddish brown or ochre brown films, which cover all of the irregularities and the black film fragments as well.

Interpreting the analytical results

Statistical methods

It is necessary to separate the local and the regional factors. Statistical methods were applied to test our hypotheses: 1. Is the sandy skeletal material of these soils homogenous? 2. If not, what kind of factor causes the lack of homogeneity? 3. Are they influenced by the depth of the sample? 4. Are they influenced by the nature of the vegetal cover?

Informational Entropy. Informational Entropy is the numerical expression of the uncertainty of the randomly variable members of a collectivity. The Shannon entropy qualifies the expected value of the information contained in the given analytical data.

In a collectivity of the analytical data, n (x_1, x_2, x_3,…x_n) random variables are formed, the measure of uncertainty is defined by the equation (RÉNYI, 1961):

$$H(X) = \frac{1}{\bar{x}} \Sigma p(x_i) \log_b p(x_i)$$

where: *i* indicates the number of variables appearing with $p(x_i)=1/n$ probability. In our case, the total number of the samples is 30, therefore $p(x_i)=1/30$. Summing up the probabilities of each term multiplied with two-based logarithm (b=2) of the probability, the degree of the uncertainty of the analysis is estimated. Highly incongruent analytical data are characterized by high H(X) values, and vice-versa, those with low values prove the homogeneity of the tested collectivity.

H(X) values for six mineral components of all 30 sand samples are less than 0.5%, i.e. with 99.5% accuracy. Similarly, the informational entropy for the main morphological characteristics was calculated, resulting in H(X) values between 0.2–0.6%. Therefore, the sampled 0.0–1.0 m belongs to the same, homogenous sandy formation (details are provided in BALOG et al., 2013b).

Student Test. The informational entropy proved the regional homogenous composition of the sand. The Student test of different sample groups evidenced the local differences.

The Student test discriminates the groups of N_i, N_j samples based on x_i, x_j average values and s_i, s_j dispersions of the given analytical data:

$$t = \frac{|x_i - x_j|}{\sqrt{N_i s_j + N_j s_i}} \sqrt{\frac{N_i N_j (N_i + N_j - 2)}{N_i + N_j}} > t_{adm}$$

If the value of t is higher than t_{adm}, the tested collectivities differ significantly; alternatively they do not present significant difference.

In our case, each microscopic field was considered as a "sample". Therefore, if the Student test value is below the limit for the given sample number and confidence level (i.e. 10 microscopic fields, 95%, t_{adm}=2.315), there is no significant difference among the forest and control samples, and alternately, the differences are significant. Note that the Student test is applicable only for normal (and lognormal) distribution of the values.

In 150 microscopic fields of six borehole samples – by χ^2 calculus for (log)normal distribution – 12 variables were tested, out of which 10 variables show lognormal distribution. The Student test indicates that – considering 6 characteristics (q/fp ratio, the number of observed limonite grains, the number of observed gypsum grains and coatings, the number of unabraded and etched grains and the number of grains covered with brown (limonitic) film) – there are significant differences between the forest and control areas, which result from the differences in their mineralogical and morphological features.

Mineralogical and morphological differences

Knowing that the samples were collected from a regionally extended, homogenous sand formation, the local differences can be attributed to local causes, i.e. differences in the microclimate and in the biological activity of vegetation. For observing the physical and biological processes under forest and grassy/arable plant cover, six characteristics of the sand grains were selected:

The quartz/feldspar (q/fp) ratio. – As the main mineral components of the sand come from metamorphic and acidic volcanic rocks, the quartz/feldspar ratio varies between straight limits, it is probable that the increase of them is tied to the "consumption" of feldspars (Fig. 1). Thus, mainly in the root zone, by the decomposition of feldspar grains, clay mineral particles are generated together with the fragmentation of the grains along the cleavage lines. All of these weathering products drop through the Ø 0.1–0.2 mm fraction, and fall into the finer grain size fractions (Table 1).

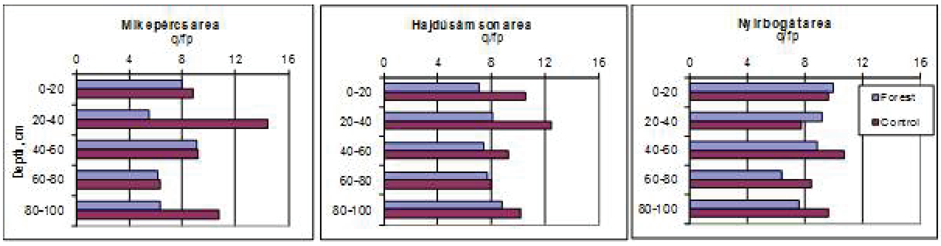

Fig. 1
Changes in the quartz/feldspar (q/fp) ratio in samples taken from the 0–100 cm drillings of the forest and control sample areas (Mikepércs, Hajdúsámson and Nyírbogát)

Limonite grains. – Iron hydroxide marks the intensity of the oxidation of Fe^{2+}, present in silicates and – mainly in upper soil levels – in plant fragments (SCHWERTMANN & CORNELL, 2000) (Table 1). In the first case, Fe^{3+} forms iron hydroxide colloids that pass in weakly crystallized ferrihydrite pellets and pseudomorphoses under plant tissues. SCHWERTMANN et al. (1968), as well as DAHANAYAKE and KRUMBEIN (1986) underlined that oxidation is a biological process, caused by the activity of bacteria and fungi. Therefore, the amount of limonite grains indicates the intensity of biological activity. In Hungary, the presumed biological iron oxide accumulation, together with trace element concentrations were described in the Kömlő area by FÜLEKY and KALMÁR (2013).

Gypsum grains and gypsum coatings. – In the whole Tiszántúl region, Ca-poor sandy deposits appear: missing Ca-carbonate, Ca^{2+} appears in silicates (as plagioclase, pyroxene, etc.) or in organic matter. Similarly to the iron compounds, the (biological) decomposition of the vegetal fragments, Ca^{2+} and SO_4^{2-} ions are generated, resulting in gypsum and other sulphates (SZABÓ, 1992). These grains and grain coatings in the samples are considered as the indication of increased biological activity (Table 1).

Unabraded grains. – Because of the splint-like, sharp edged grains that seem to be pieces of bigger ones, it is probable that *in situ* fragmentation of grains has occurred in the sand deposit. Such processes were described in the Siberian permafrost region (VELICHKO & TIMIRIEVA, 1995) or in hypersaline desertic environment (MIHÁLCZ & UNGÁR, 1954; WHITNEY, 1993). It is supposed that in the studied

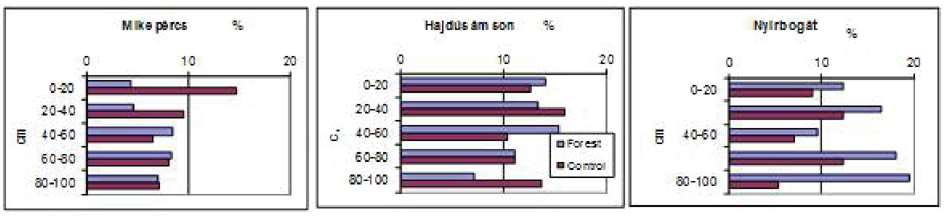

Fig. 2
Changes in the frequency (%) of unabraded grains in the samples taken from the 0–100 cm drillings of the forest and control sample areas (Mikepércs, Hajdúsámson and Nyírbogát)

areas: 1. biological and meteorological fragmentation has taken place, and 2. the intensity of fragmentation differs in forest and grass-covered plots (Fig. 2, Table 1).

Etch pits on sand grains. – Irregular cavities modifying the "geological" grain surfaces represent the places of consumption of silica *after* the deposition of the sand. WOUATONG et al. (2013) described such cavities as etch pits in condition to form tropical weathering crusts. In a temperate climatic zone, the dissolution of silica can be produced only by biological activity (WILDING et al., 1977). Therefore, it is probable that the intensity of the phenomenon differs under forest and grassy vegetal cover (Table 1) due to the more extensive roots of grasses (CHEN et al., 2000).

Brown films on grains – the thin and soft coatings that cover both the "geological" surface of the grains and the biological marks on them – seem to be the last precipitation of iron hydroxide colloids, humic colloids or both of them. The number of these grains varies, indicating the intensity of the recent biological activity (Table 1).

Fissured grains. – On some sand grains fine fissures were observed visually. Magnification of the microscope was insufficient for detailed observations, or for statistics. Fortunately, in the Mikepércs control area sample, a few grains with typical frost fissures were identified. Considering the rate of soil formation around Mikepércs (Debrecen: 1.0 m soil forming during 10,010 years; SÜMEGI, 2005), the observed material (sand grains from 0–1 m) had formed after the last Ice Age, thus the observed fissures are very likely to have been created by contemporary climatic impact. The kind of fissures described by VELICHKO and TIMIRIEVA (1995) were presented by BALOGH et al. (2013a) previously in the Jászfelsőszentgyörgy model area.

These characteristics show similarities or differences between the samples originating from forest and grassy/arable control areas, as follows:

Visible differences occurred between the 35-year-old oak forest stand and grassland in Mikepércs in the case of limonite, unabraded grains and grains with brown film coating.

Differences were mainly found between the black locust plantation and the control area (Hajdúsámson) in the case of q/fp ratio and the frequency of brown films on the grains (Fig. 3). There were only slight differences in the frequency of the unabraded grains and etched ones.

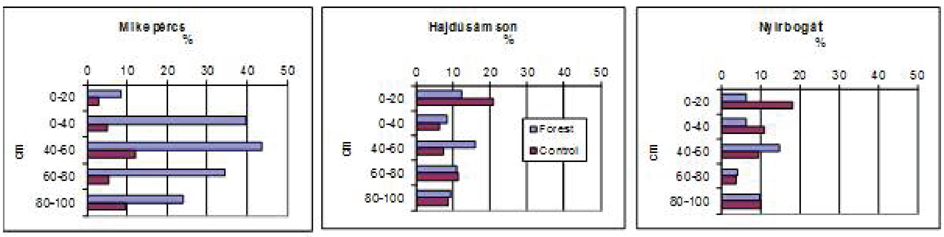

Fig. 3

Changes in the frequency (%) of grains coated with brown films in the samples taken from the 0–100 cm drillings of the forest and control sample areas

In the Nyírbogát sample area significant differences were detected only in the case of the frequency of unabraded grains and of brown grains. The Student test t = 8.8 and 10.5 values indicate an accentuated gypsum accumulation under the main root zone of the 26-year-old poplar plantation, while t = 6.6 at 0–20 cm depth marks the accentuated fragmentation of the grains in the grassy control area.

These observations were summarized in Table 1.

Table 1
The differences between characteristics of the forest (F) and control (grassy/arable) (C) sites located in Mikepércs, Hajdúsámson and Nyírbogát

Characteristics	Mikepércs	Hajdúsámson	Nyírbogát
Quartz/feldspar (q/fp) ratio	F > C	F >> C	F > C
Limonite grains	F >> C	F ~ C	F ~ C
Gypsum grains and coating	F > C	F ~ C	F > C
Unabraded grains	F > C	F > C	F >> C
Grains with etch pits	C > F	C > F	F > C
Brown films on grains	F >> C	C > F	F >> C

Summary

Related to ongoing (re)forestation in the Great Hungarian Plain the short-term influence of changing land cover was studied on the grains of skeletal sandy soils. In three sampling areas with forest and grassy/arable control plots, the 0.1–0.2 mm grain size fraction of samples taken every 20 cm from the 0–100 cm sandy soil layer (totalling 22,509 grains) were separated and described with optical mineralogical microscope. In order to distinguish sand grains of forest-covered and control areas (grassland/arable land), the results of mineralogical and morphological observations were compared. It was revealed that the amount of feldspar grains is 8–9 times less than the amount of the quartz ones. The increase in the quartz/feldspar (q/fp) ratio is tied to the "consumption" of feldspars: the intense consumption of potassium by trees. Under the forest-covered fields, the number of in-situ crushed grains increased. Grains with etch pits are frequent in samples from the grasslands (except in Hajdúsámson). In samples of forest-covered areas a greatly increased number of brown grains with limonite and/or humus films were observed. The gained results can be useful in proving earlier land use in forested fields.

Keywords: sand grain mineralogy, sand grain morphology, forest, grassland

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