IMPACT OF WEATHER EXTREMITIES (EXCESS WATER, DROUGHT) CAUSED BY CLIMATE CHANGE ON SOILS IN HUNGARIAN GREAT PLAIN (SE HUNGARY)

Irén Puskás – Norbert Gál – Andrea Farsang

University of Szeged, Department of Physical Geography and Geoinformatics

Introduction

The generally complex and difficult task of water resource management can be considered even more problematic in the case of Hungary owing to its peculiar geographic location regarding the possible impacts of any sort of climatic changes. Due to this fact and historical river regulation works, Hungary has to face a unique combination of extreme hydrologic symptoms: the spatially extensive, regular appearance of flood, excess water and drought (Fig. 1) (SOMLYÓDY, 2002, JOLÁNKAI et al., 2004).

These negative processes are very disadvantageous from the economic viewpoints, too. In Hungary harmful impacts and financial expenditure of hazard management due to unfavourable meteorological extremities range between 150–180 billion HUF in accordance with government estimates which is almost 1% of the national GDP (JOLÁNKAI et al., 2004). DUNAY – CZAKÓ (1987) note that 36% of the overall agricultural loss originates from drought, followed by hail, floods, and frosts, in order

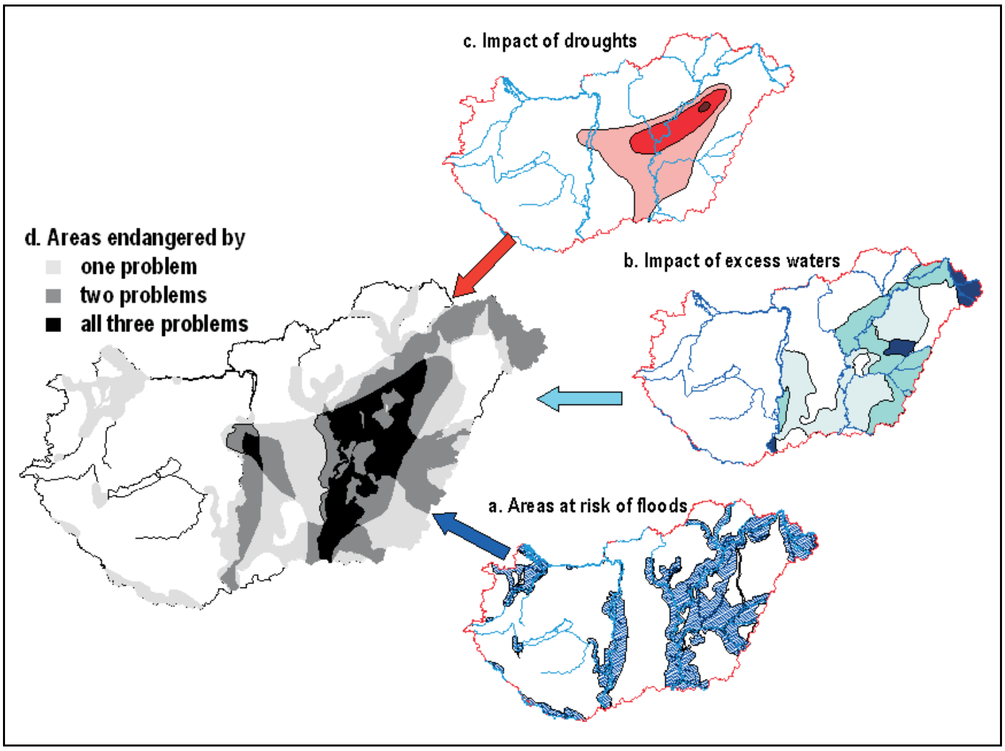

Fig. 1. Areas affected by floods, excess water and draughts in Hungary (SOMLYÓDY, 2002)

1. ábra. Árvízzel, belvízzel és aszállyal sújtott területek Magyarországon of importance. In 2003, due to low precipitation the number of heat-days, when the maximum temperature exceeds 30°C, was 45 in national average and this was breaking earlier records. Damage in the agriculture by drought in 2003 and inland excess water in 2010 was estimated to amount to 50–55 and 15 billion HUF, respectively (FARAGÓ et al., 2010). These alarming signs had been necessitated launching of researches regarding to the nature of climate change and its possible impacts on the Hungarian economy, society and environment (HARNOS et al., 2004).

Drought is a natural phenomenon defined as sustained and extensive occurrence of below average water availability. Drought should not be confused with aridity, which is a long-term average feature of a dry climate. It is also distinct from water scarcity, which constitutes an imbalance between water availability and demand. Contrary to other extreme meteorological events, droughts are the most slowly developing ones and often have the longest duration. The beginning, end and intensity of a drought are hard to estimate (PÁLFAI, 1994; GÁLOS et al., 2007). Three general types of drought may be recognized (EISENREICH, 2005): meteorological droughts (defined on the basis of rainfall deficiency); hydrological droughts (accumulated shortfalls in river flows or groundwater replenishment are of primary importance); agricultural droughts: the availability of water in soil through the growing season is the critical factor. During lengthy droughts, all three categories may combine to increase water stress.

Excess water is a Hungarian "specialty" of ponding water in flood-protected lowland areas. It appears mainly (61%) on arable croplands, typically in locations which used to be wetlands before the river regulations (KONCSOS et al., 2011). PÁLFAI (2001) collected over 50 different definitions for inland excess water ("belvíz" in Hungarian). This large amount of definition reflects the different scientific fields that deal with inland excess water (KOZÁK, 2011; VÁMOSI, 2002). According to PÁLFAI (2001) most of the definitions have a common part, namely, that excess water is a kind of temporary water inundation that occurs in flat lands. Many of the definitions emphasize that in addition to precipitation and snow melting the other substantial source is the groundwater, which emerges on the surface (so called underflooding) (RAKONCZAI et al., 2003). More recently the over-moistening of the soil of arable land is also considered excess water, as it also causes damages (BOZÁN et al., 2009). The development of excess water has two main reasons: On the one hand the constant factors (i.e. geological structure, soil conditions, relief, dead river beds), which create the conditions of development of excess water, and on the other hand the variable factors (i.e. weather and groundwater conditions) and human factors (land use, water management, agricultural techniques, land degradation, over-irrigation and so on), which generate this phenomenon (KÖRÖSPARTI et al., 2009; VÁRALLYAY, 2003). Pedological parameters influence on the formation of excess water besides hydrometeorological, geological or relief factors. But not only the soil parameters can take effect on the formation of excess water, but also excess water can modify the soil parameters - causing appearance of hydromorfical characteristics or physical degradation (RAKONCZAI et al., 2011). Furthermore, the soil parameters can be modified in different way over the drought and excess water (GÁL – FARSANG, 2012).

The main natural resource of Hungary is soil therefore its protection is a fundamental obligation for the state and the farmers, too. The frequency of the above mentioned weather extremities have increased due to the global climate change which takes effect also on the soil properties.

In the light of all this information, the major aims of the present study can be summed up as follows:

- to define some good markers of drought influenced on soils and evaluate their applicapbility;
- in order to trace changes in the soil conditions and detect influence of drought on the soils by qualitative and quantitative comparison of the reference and our data;
- to determine the way and strength of the indications of soil properties reflecting the modification;
- to identify the soil properties which influence on the formation of inland excess water;
- to estimate the effects of excess water on the soil structure of Chernozems of the best quality in Hungary;
- to determine penetration resistance and relative moisture of soil in definite points of a grid in the study field in order to create a multilayer map from soil compaction data.

Material and methods

Investigation of drought

After survey of the available data and maps of several parameters (annual average precipitation, aridity indices by Pálfai, temporal and spatial changes in the groundwater level, monitoring wells, water balance, vegetation modification etc.) and former studies as well as reference data (Kreybig map 1933–1951, TIM points in 1992, 1999), the pilot areas optimal from the viewpoint of the drought influence on soils could be delineated: in Danube–Tisza Interfluve, within Bács-Kiskun county, Bugaci Sand Ringe and Bácskai Loess Plain. The climate is warm and dry with an annual mean temperature ranging between 10.3 and 10.5 °C. Aridity index is 1 in the case of both pilot areas. Average annual solar radiation is between 2040 and 2060 h per annum with a mean annual precipitation of 520 mm (DÖVÉNYI, 2010). Pilot sites in Danube–Tisza Interfluve are depicted in Fig. 2 where significant sinking in the groundwater level can be noticed. Two most typical soil types (Arenosol, Chernozem) of the region were sampled (FAO et al., 2007).

For the physical and chemical analysis of soils, 62 samples were taken from the horizons of four profiles in summer, 2011. After drying and separation of coarse components, further analyses were carried out: The pH (H_2O) was recorded using a digital pH measuring device of Radelkis type. The carbonate, total salt content were determined via Scheibler type calcimetry and recording the electric conductivity of fully saturated soil samples, respectively. The humus content was measured after H_2SO_4 digestion in the presence of 0.33 M $K_2Cr_2O_7$ by Helios Gamma UV-VIS spectrophotometer. The mechanical composition was determined by the yarn test of Arany (BUZÁS et al., 1988).

Investigation of excess water

With a multitemporal analysis of Landsat TM–ETM images (04/2000, 06/2006 and 07/2010), the study area covered temporarily by inland excess water was defined (on the South Hungarian Great Plain). In the process of appointing the study field, agrotopographic (scale: 1:100 000, 1982) and Kreybig soil maps (scale:1:25000, 1933–1951), regional hydraulic regimes by Almási and inland excess water frequency maps by Pálfai were considered (Fig. 4).

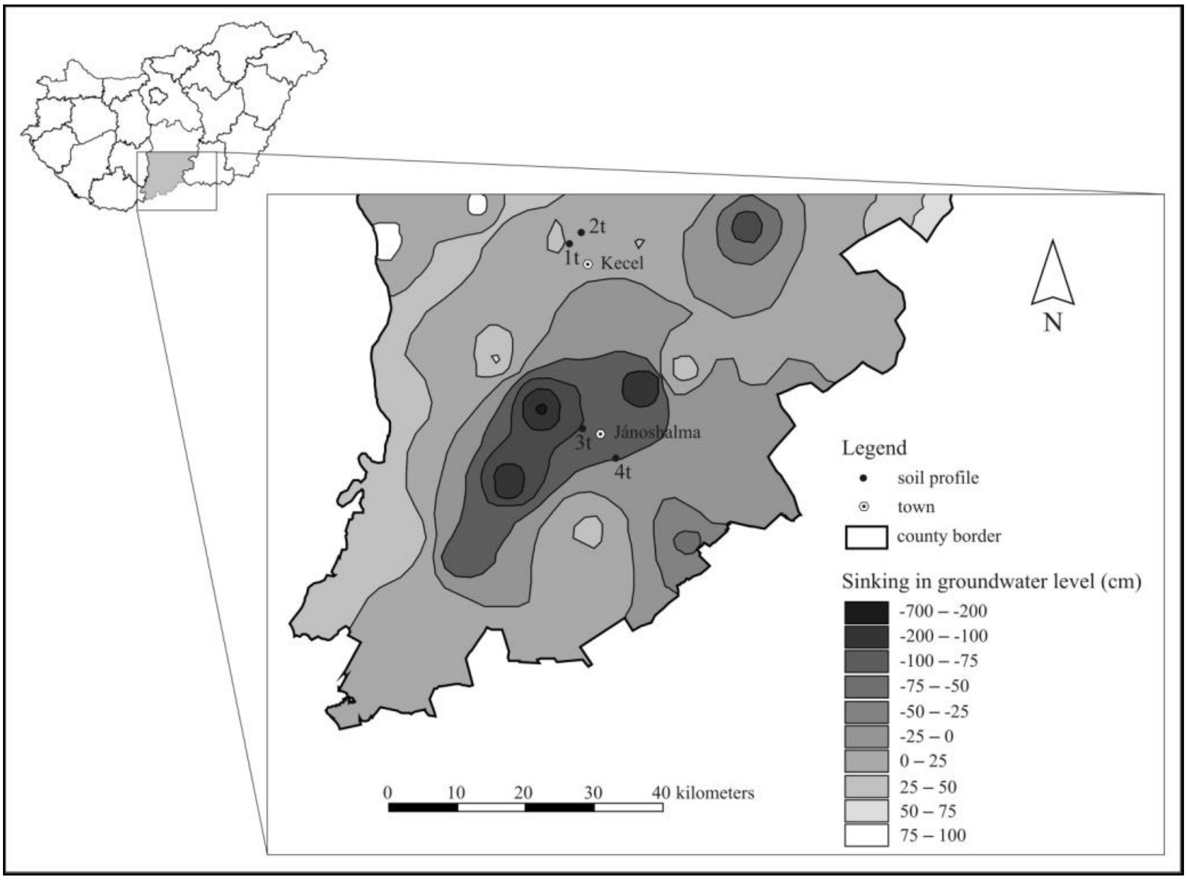

Fig. 2. Location of sampling points and sinking in groundwater in our pilot area
2. ábra. A mintavételi pontok elhelyezkedése és a talajvízszintcsökkenés mértéke a mintaterületen

In July, 2011 soil samples were collected along a 700 meters long catena at each 50 meters from the depth of 0–5 cm, 10–15 cm and 20–25 cm on the 45 hectares of study field with calcic chernozem soil type.

Particle size distribution was measured by MSZ-08-0205:1978 2. Hungarian Standard and agronomic structure was identified with dry sieving – 9 classes of structural aggregates were separated (>20, 20–10, 10–5, 5–3.15, 3.15–2, 2–1, 1–0.5, 0.5–0.25 and <0.25 mm); mean weight diameter (MWD) was calculated from the mean size of aggregate-fractions according to rate of weight of aggregate-fractions. Penetration resistance and relative moisture of soil were determined at the depth of 60 cm in definite points (n=117) of a 25x25 m grid on the 45 hectares of study field using 3T System hand penetrometer in order to create a multilayer-map from the soil compaction data (Fig. 3). Figures, maps were created with Microsoft Excel, Surfer 8, ArcView 3.2 and ERDAS 8.4.

Fig. 3. Hand penetrometer

3. ábra. Kézi penetrométer

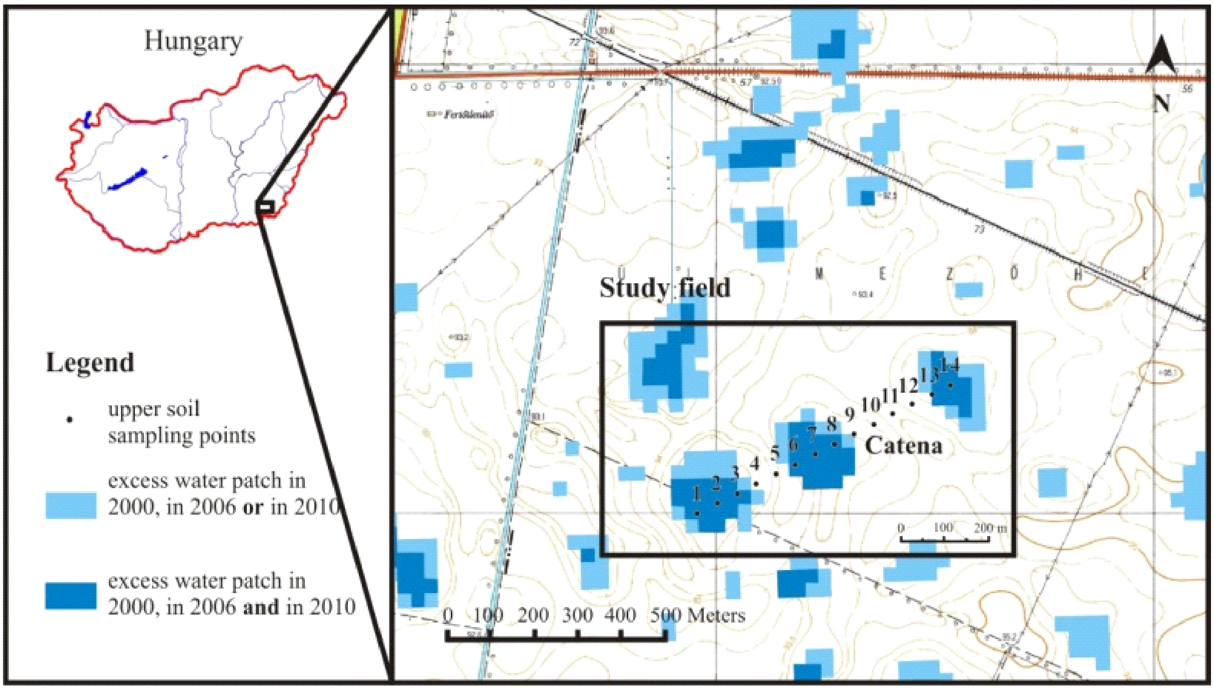

Fig. 4. Study field with inland excess water patches and the appointed catena

4. ábra. A belvízzel borított területek és a felállított katéna elhelyezkedése

Results and discussion

Evaluation of results considering drought

First of all, it is very relevant to investigate other influencing factors beside the climatic ones (for exp. land use, genetic soil types, vegetation cover, relief etc.). All the pilot sites used to be under agricultural cultivation in the 1950's according to the map by Kreybig. The rye, wheat, maize and alfalfa, carrot were produced in Arenosol of sites No. 1, 2 with enough good productivity and in Chernozem of sites No. 3, 4, respectively. In 1992, 1999 and at present, sites 3, 4 are also under intense cultivation, whereas sites No. 1, 2 are utilized as meadow and fallow, respectively. Thickness of humus horizon strongly depending on the cultivation period and methods can provide very useful information about the humification conditions. Based on these values, Arenosols as arable land can be supposed to have been provided with more fertilizers in the 1950's than nowadays as meadow and fallow. Consequently, it can be established that land use of sites 1, 2 was altered the most with time passing. Besides, it is important to stress significance of the soil genetic type since different genetic types can buffer variously: the Chernozems have better buffering capacity than the Arenosols. Furthermore, the groundwater sinking (which fact is unambiguous according to the data of groundwater wells typical of our studied area) exerted the most considerable effect on soils as in the last 60 years this phenomenon was general in our pilot areas.

As far as the soil properties are concerned, 3 categories can be differentiated: The *weak indicators* of the drought belong to the first category. The *mechanical type* of profiles corresponds to the given genetic soil type (Table 1). As a matter of fact, the coarse sand, sand, sandy loam are dominated in the horizons of Arenosols (Profile No. 1, 2). Distribution of this property along the profiles has not shown considerable alteration compared to reference data since appreciably texture change needs very long period or continuously monotonous, same effect. The minimum and maximum *humus contents* range between 0.3 and 4.6 % (Table 1). In accordance with the averages, profile 2 can be classified as having extremely poor humus content (<1%), while the majority (No. 1, 3, 4) has poor humus content (1–2%) (SPONAGEL et al., 2005). In Chernozem topsoils, humus has been increasing since 1950's due to the constantly cultivation. All these prove that this property is mostly dependent on the type of the land use and cultivation.

The *moderate indicators* of the drought can be classified into second category. The *carbonate* content minimum and maximum values of profile 1, 2, 3, 4 range 15–23%; 2.9–33%; 10–35%; 4.6–31%, respectively (Table 1). Considering average profile values, one (No. 3) can be placed in the category extremely calcareous (>25%) (FAO, 2006). This outlier is mostly the result of prevailing loess bedrock as a significant source of high carbonate content. More three profiles can be classified as highly calcareous (10–25%) due to the mainly sandy loam, loam texture. In the Chernozems there is a gradual increase in carbonate content both in time and space (towards the bedrock from topsoils downward). The reason for this is the leaching of carbonate phases from the upper soil horizons (Fig. 5, Profile No. 3a). The minimum and maximum *pH(H_2O)* of the profile 1, 2, 3, 4 are between 8–9; 8.2–8.5; 7.7–9.1; 7.7–8.5, respectively (Table 1). Based on the average values of pH(H_2O), all the profiles can be classified as strongly alkalescent soils. The correlation between recorded pH values and carbonate content is obvious: the high carbonate content results in large pH values (Fig. 5, Profile No. 3b).

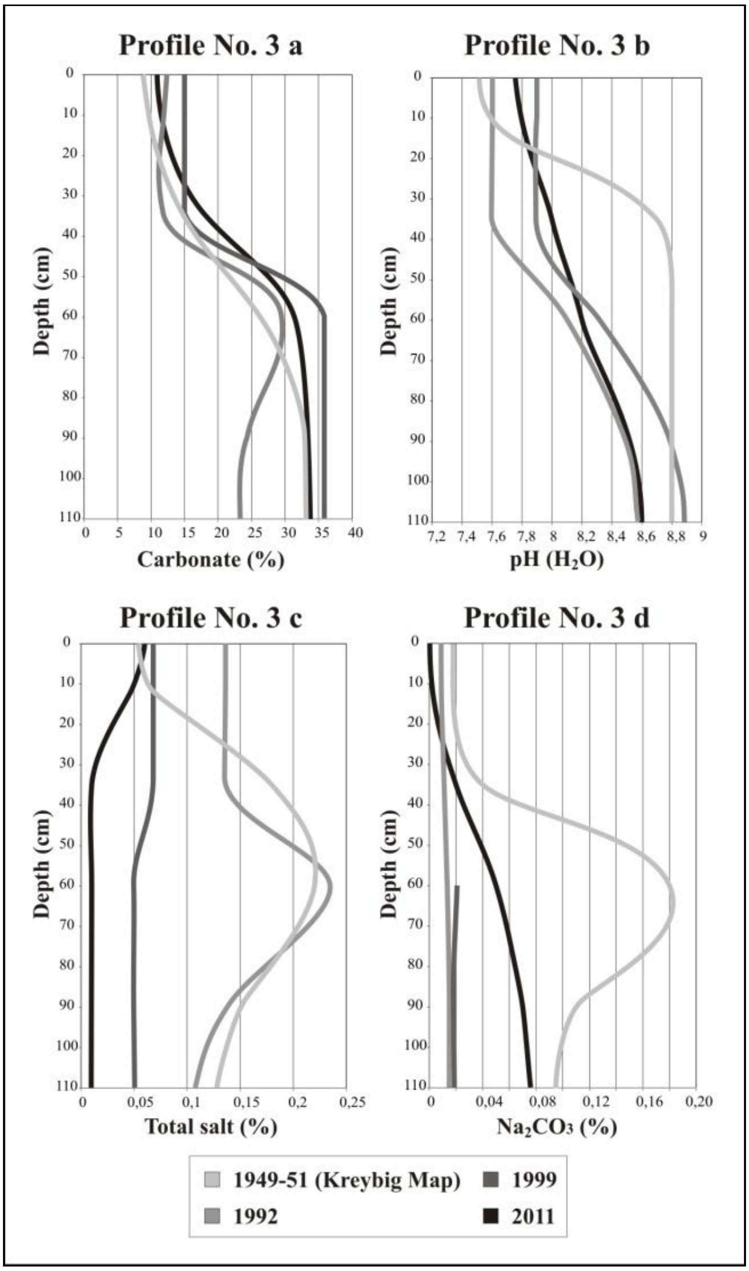

Fig. 5. Some studied properties as indicators of drought on the example profile 3

5. ábra. Néhány vizsgált paraméter a 3. szelvény esetében

Table 1. Mechanical soil type, humus content, carbonate, pH (H_2O), total salt and Na_2CO_3 of the studied profiles

1. táblázat. A vizsgált talajminták fizikai féleség, humusz- karbonáttartalom, pH (H_2O), összsó és Na_2CO_3 értékei

Mechanical soil type	Profile 1	Profile 2	Profile 3	Profile 4
Mean	20	24	36	22
Minimum	55	29	45	46
Maximum	32	26	42	38
Standard deviation	11.2	1.7	3.5	6.1
Humus content (%)				
Mean	1.3	0.6	1.5	1.5
Minimum	0.3	0.3	0.5	0.7
Maximum	4.6	0.9	3.4	2.7
Standard deviation	1.4	0.2	1.0	0.8
Carbonate (%)				
Mean	19.2	10.5	25.8	19.1
Minimum	15	2.9	10	4.6
Maximum	23	33	35	31
Standard deviation	2.5	10.5	8.9	8.8
pH (H2O)				
Mean	8.72	8.4	8.4	8.21
Minimum	8	8.2	7.7	7.7
Maximum	9	8.5	9.1	8.5
Standard deviation	0.34	0.09	0.4	0.3
Total salt content (%)				
Mean	0.01	0.007	0.02	0.02
Minimum	0.01	0.00	0.01	0.01
Maximum	0.02	0.01	0.07	0.03
Standard deviation	0.00	0.00	0.02	0.01
Na_2CO_3 (%)				
Mean	0.05	0.04	0.05	0.04
Minimum	0.02	0.02	0.00	0.00
Maximum	0.11	0.08	0.1	0.07
Standard deviation	0.03	0.02	0.03	0.02

Two properties can be categorized into the group of *strong indicators*: The minimum and maximum *total salt content* of the profile 1, 2, 3, 4 are between 0.01–0.02; 0.00–0.01; 0.01–0.07; 0.01–0.03 %, respectively (Table 1). The average values of all the profiles fell into the category free of salt (<0.05%). On the contrary, according to the reference data it can be claimed that the salt contents used to be significantly higher in the past than today: they could be categorized into moderately saline category (0.15–0.4%). Based on an example profile (No. 3), this change with passing time can be traced (Fig. 5, Profile No. 3c). The groundwater level is likely to have been higher in the 1950's causing more salt concentration in the soil. However, owing to the considerable sinking in groundwater level at our sites caused by drought the salt content strongly lowered (Fig. 2). *Na_2CO_3* contents are corresponds to the total salt values (Table 1). The profiles used to contain significant amount of Na_2CO_3 as an unambiguously indicator of the sodification in the past. However, nowadays sodification can not be observed in the profiles (Fig. 5, Profile No. 3d).

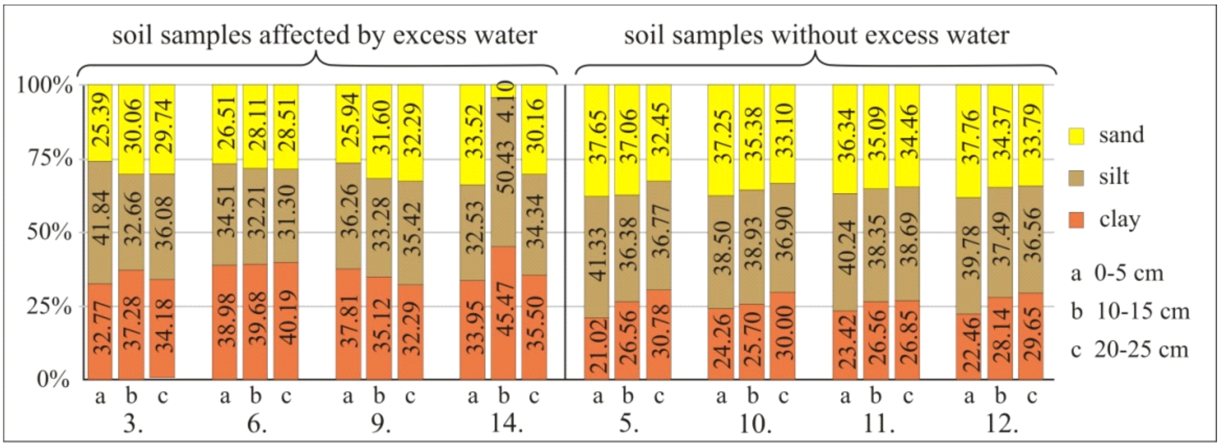

Fig. 6. Particle size distribution of upper soil samples

6. ábra. A feltalajminták szemcseeloszlása

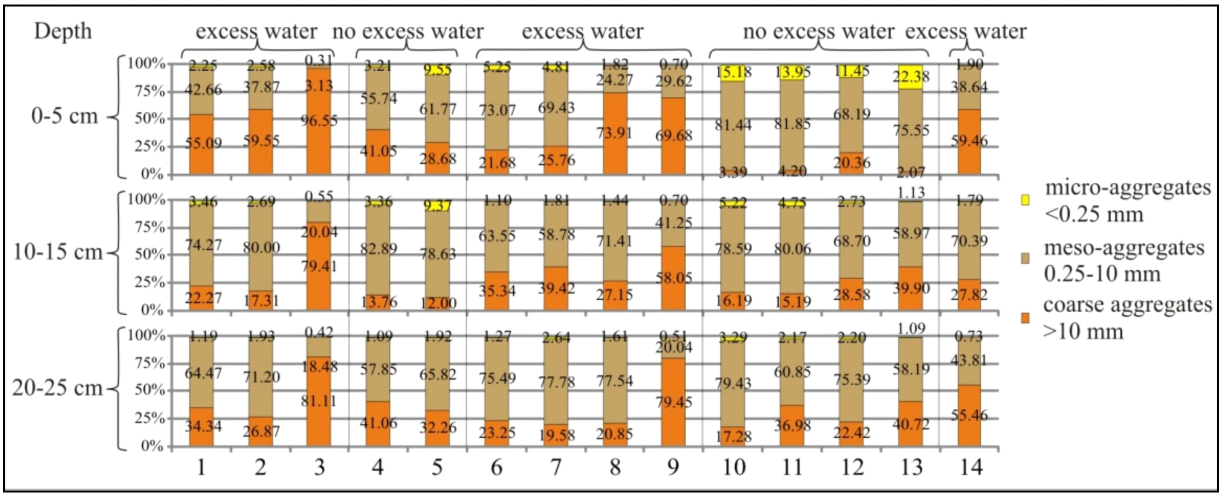

Fig. 7. Aggregate-size distribution by dry sieving (No 1–14: studied profiles in catena)

7. ábra. Agronómai szerkezet száraz szitálással (1–14: a katéna vizsgált szelvényei)

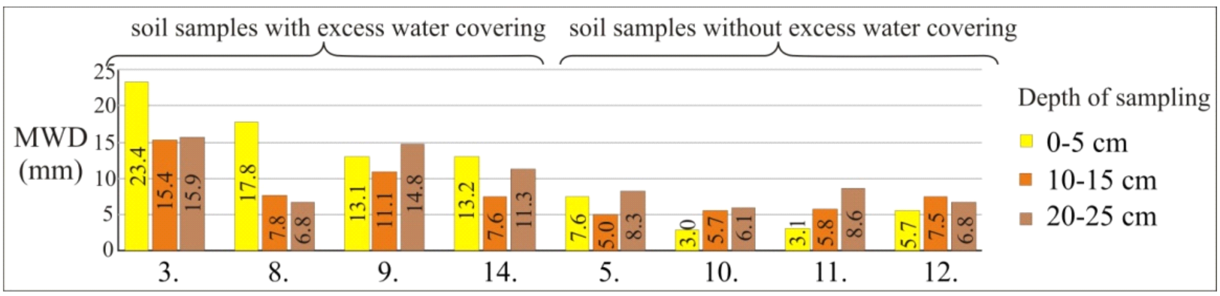

Fig. 8. Mean weight diameter (MWD) of soil aggregates

8. ábra. A feltalajminták agronómiai szerkezetét jelölő KSÁ értékek mélységgel történő változása

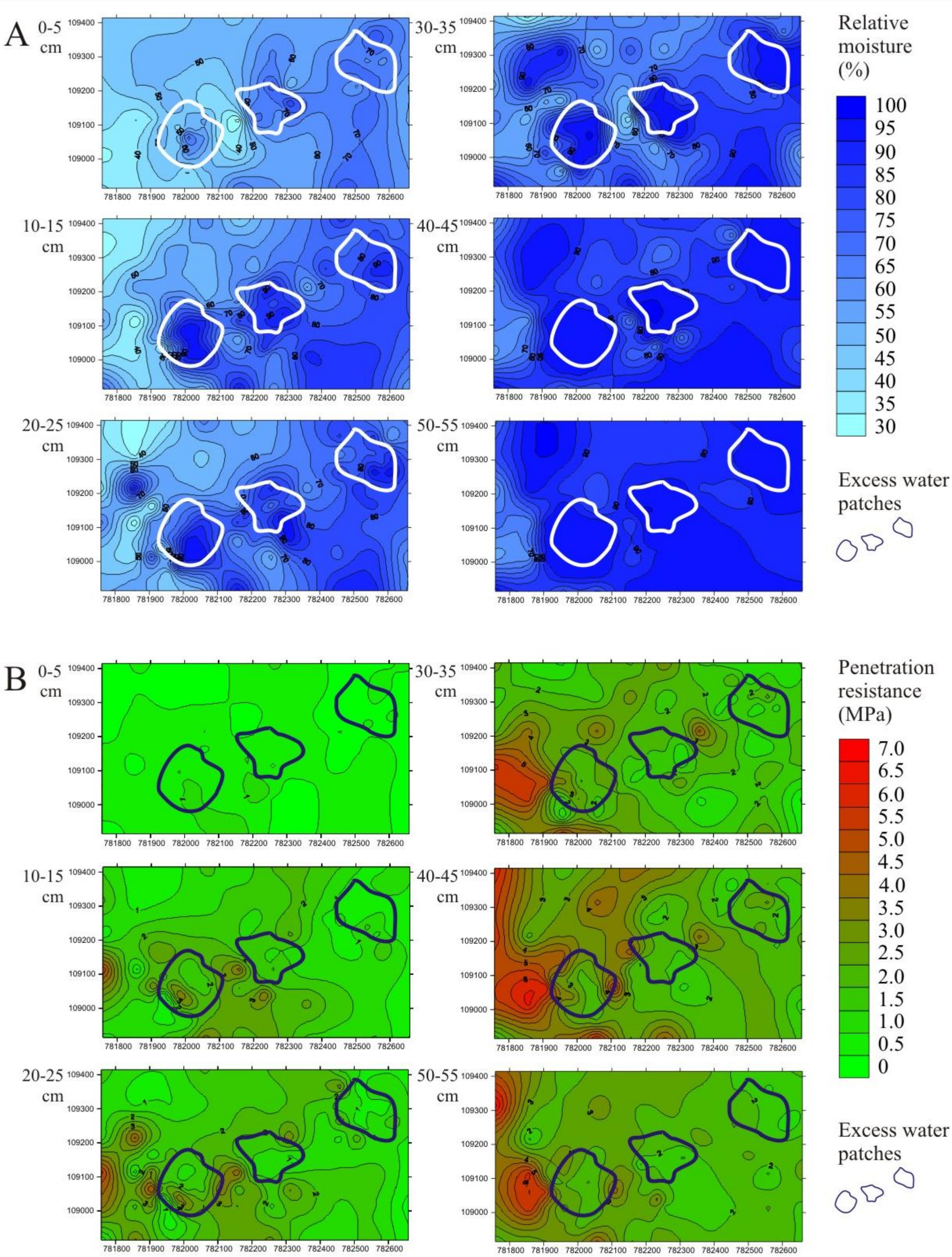

Fig. 9. Relative moisture content (A) and penetration resistance (B) maps measured by penetrometer in different depths

9. ábra. A különböző mélységben mért relatív nedvességtartalom (A) és penetrációs ellenállás (B) értékek interpolációs térképei

It is relevant nowadays to find relation between drought and soils since the drought can pose a serious threat of the soils, resulting in the appearance of new characteristics in soils. The above mentioned parameters were investigated in order to learn more about the different forming effects by the climate on two (Chernozem and Arenosol) soil types. Compared reference data in the 1950's, 1992, 1999 and our data of the pilot area, it can be established that significant change in soil properties can be observed mainly in the case of the total salt and Na_2CO_3 contents. (However, carbonate can be considered to be good indicator in the case of only Chernozems). However, it is very crucial to pay attention of the influencing factors like groundwater sinking, land use change, genetic soil type that in many cases basically determine the characteristics and direction of the given processes and resilience, modifying, facilitating or buffering capacities of the studied soils. Consequently, the latters can be applied well as soil indicator of drought since some well reflect the modifications caused by drought.

Evaluation of results considering inland excess water

The results were evaluated from the smallest particle to largest aggregates. Particle size distribution of soil samples affected by excess water (3., 6., 9., 14.) shows differences comparing the distribution of samples without water effect (5., 10., 11., 12.) – the ratio of clay fraction is higher (34,50–39,62%) in the soil samples covered temporarily by excess water then the ratio of samples without excess water (25,61–31,29%) (Fig. 6).

Thus, texture group of excess water soils is silty clayic loam instead of silty loam. In clayic soils, swelling is caused by wetting period due to excess water, and during drying period crust forms appear. Agronomic structure is degradated by crusts – thus, proportion of coarse aggregates is higher in the case of soil samples temporarily covered by excess water (Fig. 7).

Considering the agronomical structure, it is obvious negative effect of the inland excess water on soil stucture. In Fig. 8 mean weight diameters of some soils samples are presented. MWD indices are higher in the cases of excess water soils because their structure was modified by crusting in the wetting-drying cycles, especially in 0–5 cm depth. Soils covered by inland excess water with moderate MWD indices (mean=13.2 can be classified into coarse aggregates, whereas ones without inland excess water indicates excellent crumb sturcture (MWD index = 3.0–8.6 mm).

The pattern of sampling points is showing the pattern of inland excess water patches. Penetrometer sampling points were categorized into 3 groups. Compaction can be observed above 2.5 MPa penetration resistances. All 3 profile types show compaction especially in 35–45 cm deep zone which shows the depth of plough-sole.

In Fig. 9 relative moisture data of study area are presented in 6 different depths. The inland excess water pattern defined by remote sensing methods coincides with the areas where the highest relative moisture content was measured by 3T System hand penetrometer. Relative moisture data in excess water patches are higher than ones of excess water free areas.

For the first sight, measured penetration resistance and therefore compaction values of excess water affected areas seem to be lower than ones of excess water free areas. This can be explained by the higher relative moisture content caused by excess water. The fact complicates the evaluation, that penetration resistance data of different areas only can be compared if they are normalized into an equivalent state, level of relative moisture content. Thus, a function between relative moisture and compaction data is needed in the future in relation with bulk density data.

Conclusion

The drought in the Danube–Tisza Interfluve has resulted in the appearance of new characteristics in the studied soils with passing time. These transformations of different degree in the soils can clearly be observable in the horizontal and vertical modification of the original soil characteristics. However, it is obvious to pay attention to other influencing parameters beside genetic soil type such as land use change, cultivation period and intensity, groundwater level since they together are responsible for changes in soil properties. The studied soil properties indicate in what way and to what extent they can reflect drought effect on soils. Different ways and strength of their indication can be differed. The way can be seen either in a change in their recorded concentration values or the alteration of their vertical distribution in the profiles. According to the strength strong (salt, Na_2CO_3), moderate (carbonate) weak (mechanical soil type, humus, $pH(H_2O)$) categories could be determined.

The particle size distribution of the examined soil samples affected by excess water can be characterized with high proportion of clay fraction, thus their texture is clayic silty loam. The inland excess water results in a peculiar dynamics of wetting drying which might lead to appearance of crusts changing the agronomic structure of soil. Mostly coarse aggregates (>10 mm) are typical of the aggregate size distribution of samples of excess water patches – the MWD indices are above 13 mm which indicate the degradation of soil structure and hereby the loss of multifunctionality. In our further research, relations and functionality between soil relative moisture content, penetration resistance and bulk density will be carried out to compare the penetration resistance values of areas with different relative moisture content.

Acknowledgement

Special thanks to Tamás Fábián (†) for the sampling process.

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