ADVANCED EVALUATION OF SPATIAL INHOMOGENITY OF LIGTH SANDY SOIL

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Abstract

The aims of our study was to survey the spatial distribution of physical and water management properties of soils in order to evaluate the effect of high precipitation intensity on orchards and to supply complex research evaluation activities for further studies. The main goal is to establish such a precision decision support system, with which the water management properties of soil can be meliorated, and can be reduced the effect of high precipitation intensity on orchards. The examinations were carried out at an intensive apple orchard in Debrecen-Pallag. The examination site is the part of the Experimental Pomology Site and Study-Farm of the University of Debrecen, Centre of Agricultural Sciences and Engineering, Faculty of Agronomy. Grain-size distribution, upper limit of plasticity according to Arany, element content by X-Ray fluorescence spectrometry, maximum and minimum waterholding capacity, water capacity of gravity pores, soil density acidity, electric conductivity of soils were measured to obtain appropriate information on the physical and water management properties of the soil.

Based on the results, the accurate spatial positions of those sites were characterized where soil loosening should be implemented in 30-40 cm depth. Spatially precise soil physical barriers were determined for micro-irrigation system. Based on the micro-element content and pH, the accurate spatial positions of those sites were selected where melioration and micro-nutrient fertilization is needed.

INTRODUCTION

It can be forecast with high probability that in future water will be the determining (hopefully not limiting) factor of food security and environmental safety in the Carpathian Basin (Somlyódy, 2000; Várallyay, 1988, 1989b, 2001, 2002). Consequently, the increase in water use efficiency will be one of the key issues of agricultural production, rural development and environment protection and the control of soil moisture regime will be an imperative task without any other alternatives (Somlyódy, 2000; Várallyay, 1988).

The negative water balance in the Carpathian Lowland: 450-600 mm precipitation vs. 680-720 mm potential evapotranspiration is equilibrated by horizontal inflow (on the surface as runoff, in the unsaturated zone as seepage; and in the saturated zone as groundwater flow), which leads to the accumulation of the weathering products of the large catchment area. In addiction to the hardly predictable atmospheric precipitation pattern, the two additional reasons of extreme soil moisture regime (the simultaneous hazard of waterlogging or overmoistening and drought sensitivity) are:

- the heterogeneous microrelief of the „flat" lowland;
- the highly variable, sometimes mosaic-like soil cover and the unfavourable physical and hydrophysical properties of some soils (mainly due to heavy texture, high clay and swelling clay content, or high sodium saturation: ESP).

The average annual precipitation may cover the water requirement of the main crops even at high yield levels. But the average shows extremely high territorial and temporal variability – even at micro-scale. Under such conditions a considerable part of the precipitation is lost by surface runoff, downward filtration and evaporation. The limited water resources and the increasing frequency of extreme hydrological events (floods, water-logging, over-moistening and drought) due to the high territorial and temporal variability of atmospheric precipitation; the heterogeneous (micro) relief; and the unfavourable physical/hydrophysical characteristics of soils are pressing to improve agricultural water use efficiency and necessitates an efficient control of soil moisture regime in the Carpathian Basin (Pálfai, 2000; Somlyódy, 2000; Várallyay, 1989b). The increasing water demand must be satisfied from these limited resources. The annual precipitation will not be more in the future and its unfavourable territorial and time distribution will not turn better. On the contrary, an opposite tendency has been forecast: increasing risk (frequency, intensity) of extreme weather events and soil moisture situations. The available quantity of surface waters (rivers) will not increase, particularly in the critical low-water periods. A considerable part of the subsurface waters (especially in the lower parts of the Basin) cannot be used for irrigation because of their poor quality (salinity, alkalinity, sodicity).

Soil is the largest potential natural water reservoir: 350-400 mm/0-100 cm soil layer. But in many cases this huge water storage capacity is not used efficiently, mainly due to four reasons: „filled bottle effect", „closed bottle effect", „leaking bottle effect". Consequently, the aim of an efficient soil moisture control to help infiltration into, and water storage within the soil in plant available form. For those „actions" adequate information are required on land/soil characteristics. These information are provided by a comprehensive soil/land survey-analysis-categorization-mapping-monitoring system which was developed in Hungary and served as a scientific basis for sustainable land use and soil management including ecosystem management and risk reduction of extreme hydrological events.

Spatial variability of soil properties may appear in yield variation within a single field even in areas considered to be homogeneous from soil survey point of view. Effects of various sources of soil heterogeneity on the annual or long-term average soil water budget appear to differ markedly (Kim, 1995). As individual soil physical properties influence crop yield in different ways and in different magnitudes, we decided to integrate their influence by simulating the soil water balance and to use transpiration as a crop yield indicator. Simulation models are tools for analyzing the moisture regime with respect to physical properties of soils (Majercak and Novak, 1994; Djurhuus et al., 1999). Simulation models, when used in field scale, have to be up-scaled from point validity soil profiles using geostatical methods (Van Meirvenne et al., 1995; Tóth and Kuti, 2002), or effective hydraulic parameters (Smith and Diekkrüger, 1996). The use of effective hydraulic parameter values reduces the number of simulations significantly, but interprets the whole field as an equivalent soil profile. The disadvantage of this approach is that it does not reflect the spatial pattern of the soil water balance elements.

MATERIELS AND METHODS

The aims of our study was to survey the spatial distribution of physical and water management properties of soils in order to evaluate the effect of high precipitation intensity on orchards and to supply complex research evaluation activities for further studies. The main goal is to establish such a precision decision support system, with which the water management properties of soil can be meliorated, and can be reduced the effect of high precipitation intensity on orchards.

The examinations were carried out at an intensive apple orchard in Debrecen-Pallag. The examination site is the part of the Experimental Pomology Site and Study-Farm of the University of Debrecen, Centre of Agricultural Sciences and Engineering, Faculty of

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- physical properties of the soil at the research field in Pallag,
- measuring soil density,
- measuring the water holding capacities,
- measurement of the element content, electric conductivity and the acidity of soil,
- the effect of high precipitation intensity on orchards based on the soil physical and water management properties.

Due to the heterogeneous terrain surface special attention has to be paid to places with different location in order to examine all of the different soil varieties. The coordinates of the sampling points were collected by GPS. *(Figure 1.)*. Systematic sampling strategy was carried out based on the number of the rows and apple trees to collect as much information as possible with possibly the least number of samples. The soil samples were collected by field portable Eijkelkamp soil auger gauge from the surface and 40cm, 70 cm depth. . Samples with the original soil structure were collected from the surface to measure the waterholding capacity. Samples with the original soil structure were collected from the surface to measure the waterholding capacity

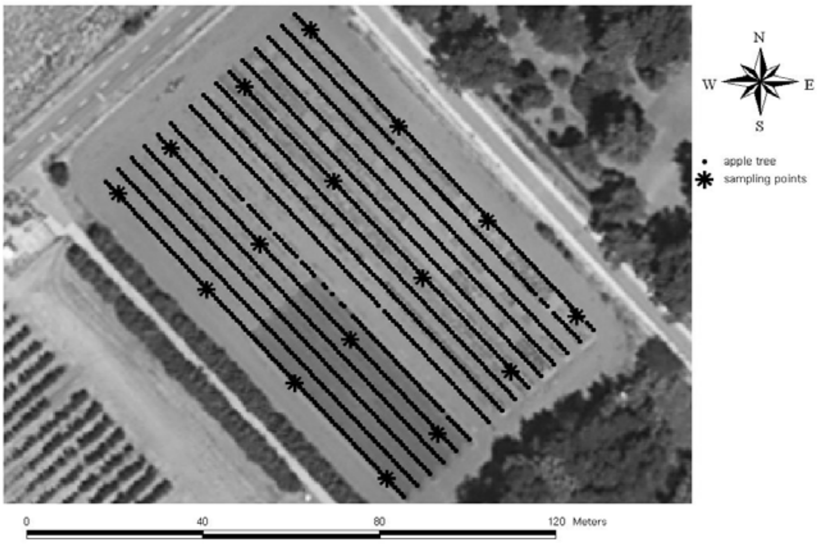

Fig. 1: Research field and the sampling points

First, the weights of the samples were measured and then oven dried at 103 – 105 ^{0}C for 24 hours. The dry samples were homogenized and measured also the weight of them. Based on these results, the actual water content of the soil was determined. After that the dry soil samples were used for further examinations. The sandy grain size fraction were determined by sieving, though 2 mm, 1 mm, 630 µm, 500 µm, 315 µm, 200 µm, és 100 µm sieves. Based on the results the rate of grain size groups were calculated in the percentage of the whole sample weight. The measurement accuracy of the different grain size groups were

0.5 g. The upper limit of soil plasticity (K_A) – according to Arany – was also measured in order to determine the spatial distribution of the physical characteristics of the examined site.

Using the samples with the original soil structure, maximal (pF=0) and minimal (pF=2) waterholding capacities were determined to evaluate water bearing properties of the examined soils.

Based on field experiments the soil permeability and water absorbing capacity were also measured with using infiltration frames. During the experiment two kinds of infiltration frames were used: the internal one with 25*25 cm area and the external one with 50*50 cm area, which surrounds the smaller frame. The larger frame is needed to eliminate the effect of horizontal infiltration error on vertical infiltration. The absorbed water quantities were measured at the 10; 20; 30; 45; 60; 90; 120; 150; 180; 240; 300; 360 second in the internal frame.

Soil density was also measured on field. 3T System penetrometer was used to measure the soil penetration resistance at each centimeters for 60 cm depth and expressed in kPa. It also measures the soil moisture content at each 1-cm-thick layer. The soil moisture content is expressed in volumetric percentage of the field capacity (pF 2.5). Cone angle of the probe, which penetrates to the soil and collects the soil density data, was 60˚.

The pH of the soil samples were measured by EBRO measurement device, according to the MSZ – 08 0206 / 2 – 78 patent, in ionized water – soil sample suspension with 1:2.5 ratios. The electric conductivity was measured by WTW LF 320/SE device, in the same suspension.

The Fe, K and Ca contents of the air dried and sieved (<2mm) soil samples were determined by NITON XL_t 700 field portable X-Ray fluorescent spectrometer.

The spatial heterogeneities of the abovementioned experimental results were evaluated by Surfer 9 geoinformatics software. SPAC Teach program were used to model the initial time of the run-off and surplus water depending on the rainfall intensity. The model was adjusted according to the examined physical mechanical and hydrological features of the soil; soil bulk density: 1.42 g/cm^3, infiltration rate 12 mm/h at 15 V% water deficiency.

RESULTS AND DISCUSSION

Based on soil plasticity, according to Arany, sites with different characteristics could be distinguished in every layer (surface, 40 cm and 70 cm). The spatial variability of soil plasticity, thus the physical features of the soil appeared differently in each layer *(Figure 2.)*.

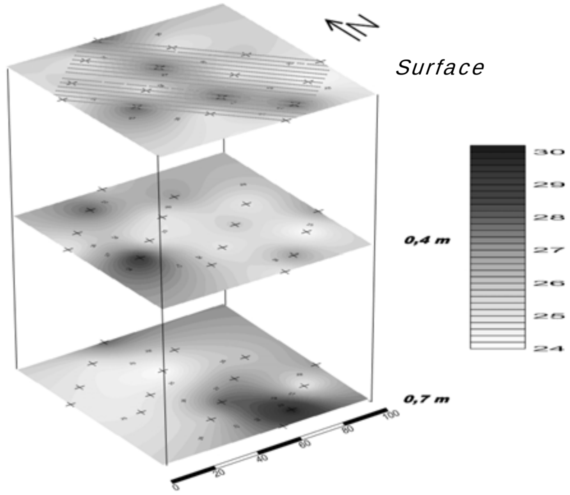

Fig. 2. Spatial distribution of soil plasticity (apple trees illustrated as points on the surface layer)

Since the maximal saturation percentage (K_A=30) measured at the sampling point with the lowest altitude, it was caused by the micro and mezo relief. Significant differences among physical characteristic of the three soil layers can not be found *(Table 1.)*.

Table 1.

Statistics of the saturation percentage (K_A), according to Arany

Depth	*Mean*	*St. Dev.*	*Median*	*Minimum*	*Maximum*
Surface	26	1,41	25	24	29
40cm	26	1,27	26	24	29
70cm	26,25	1,56	26	25	30

Based on the grain size distribution, the rate of the rough-grained sand fractions were high and significant differences among rough-grained sand fractions of the three soil layers can not be found *(Table 2.)*.

Table 2.

Statistics of the rough-grained sand fractions (%)

Depth	*Mean*	*St. Dev.*	*Median*	*Minimum*	*Maximum*
Surface	76,91	2,45	76,74	71,30	80,94
40cm	77,65	2,90	77,16	72,11	82,35
70cm	77,52	3,82	78,16	71,49	84,78

The spatial distributions of the actual volumetric water content were homogeneous in all layers, due the micro-irrigation of the apple orchard *(Table 3.)*.

Table 3.

Actual volumetric water content (%) in the three soil layers

Depth	*Mean*	*St. Dev.*	*Median*	*Minimum*	*Maximum*
Surface	9,44	1,83	9,64	6,21	12,86
40cm	12,83	2,67	12,95	8,3	20,1
70cm	12,85	2,13	12,8	10,1	18,1

The spatial distribution of maximal (WH_{max}) and minimal (WH_{min}) waterholding capacities were heterogeneous. Based on the results, 180-260 mm/m minimal waterholding capacity was measured, which is typical for sandy loam soils *(Table 4.)*. This statement is contradict to the results of the saturation percentage for the first sight, although, this contradiction is fairly caused by the increased soil density.

Table 4.

Maximal (WH_{max}) and minimal (WH_{min}) waterholding capacities of the soils

	Mean	*St. Dev.*	*Median*	*Minimum*	*Maximum*
VH_{max}	42,5	2,56	44,3	40,3	48,4
VH_{min}	24,23	4,74	27	15,2	32,9

Even in the 20-30 cm soil layer the soil density reached and exceeded the 3MPa soil penetration resistance value, which is the threshold for the high soil density, according to Birkás (2002) measurements. The mean penetration resistance values of deeper soil layers were clearly exceeded this threshold. The high soil density changed dramatically the waterholding capacity, infiltration intensity and water saturation properties of the sandy soil. At the Eastern part of the examined site, sandstone layer with extreme high soil density was found at 30-40 cm depth. At this layer penetration resistance values exceeded the upper limit of the measurement range (10000 kPa) of the penetrometer, therefore it was not possible to measure further soil layers *(Figure 3.)*.

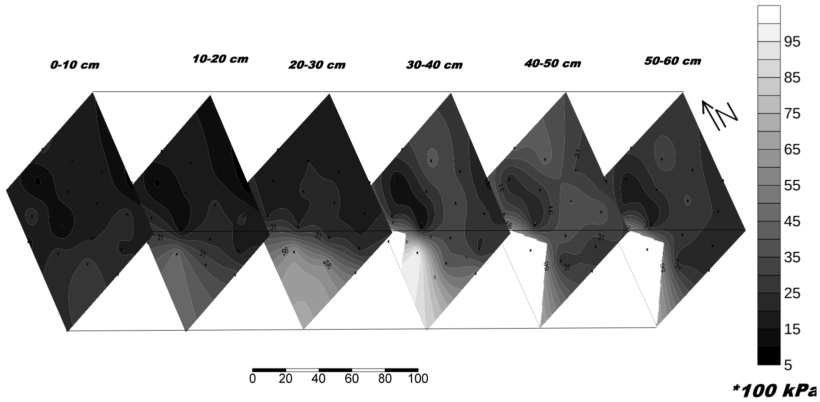

Fig. 3. Spatial distribution of soil density (soil penetration resistance *100kPa)

Based on the electric conductivity (EC) measurements, the slat content of the examined soil layers are very low, so the negative effect of salt will not appear in the future *(Figure 4)*. The pH is ranged between 5.7-6.9, so the soil is moderately acid. Based on the spatial distribution of the pH, those sites were characterized where soil melioration (e.g. liming) is needed.

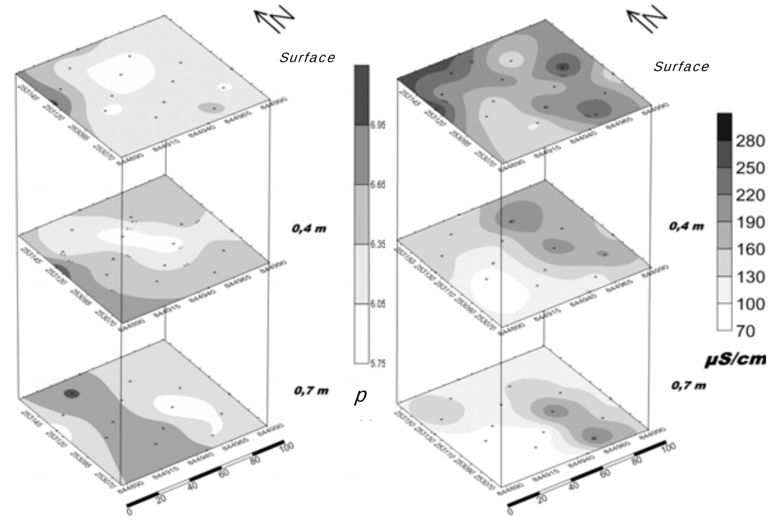

Fig. 4. Spatial distribution of EC and pH

The examined soil contained small amount of calcium, which can be one of the reason for the low acidity. In the case of potassium, the soil layers were well supplied with potassium *(Figure 5.)*, although the K allocation to deeper layers was found, which is a usual process in sandy soils of the Great Plain. Iron content was smaller than 2-8 % Fe_2O_3 rate in an average soil (Filep, 1999).

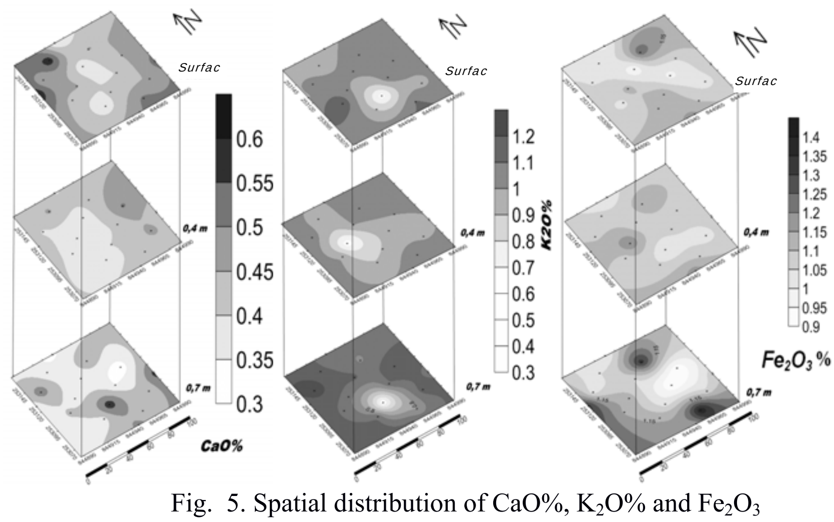

Fig. 5. Spatial distribution of CaO%, K_2O% and Fe_2O_3

The high density had also effect on the infiltration intensity and soil permeability: the infiltration became constant 12 mm/h at the third hour of the field experiment.

SPAC Teach program were used to model the initial time of the run-off and surplus water depending on the rainfall intensity. The model was adjusted based on waterholding capacities and the measured physical and mechanical features of the soil. Based on the results, Hyperbolic relationship was found between rainfall intensity and the initial time of the run-off and surplus water *(Figure 6.)*.

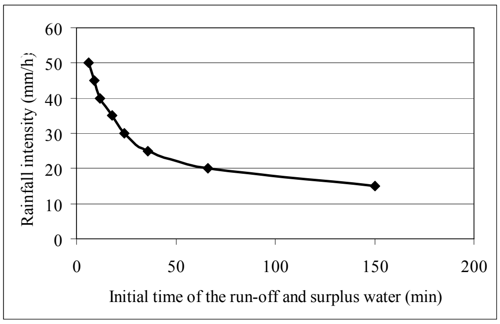

Fig. 6. Hyperbolic relationship between rainfall intensity and the initial time of the run-off

CONCLUSIONS

The examined soil is a sandy soil, with extreme soil density (>3MPa) in 30-50 soil layers. Due to this phenomena, the waterholding capacity is changed, and the infiltration rate became 12 mm/h. Based on the results, the accurate spatial positions of those sites were characterized where soil loosening should be implemented in 30-40 cm depth to eliminate the negative effect of periodic surplus water and run-off. Spatially precise soil physical barriers were determined for micro-irrigation system. Based on the micro-element content and pH, the accurate spatial positions of those sites were characterized where melioration and micro-nutrient fertilization is needed.

REFERENCES

1. Birkás M. (ed.) (2002): Környezetkímélő és energiatakarékos talajművelés. Akaprint Nyomdaipari Kft.
2. Djurhuus J. (1999): Modelling mean nitrate leaching from spatially variable fields using effective hydraulic parameters. Geoderma, 87. 261-279.
3. Filep Gy. (1999): Talajtani ismeretek I. Debreceni Agrártudományi Egyetem, Mezőgazdaságtudományi Kar, Debrecen.
4. Kim R. (1995): The water budget of heterogeneous areas. Doctoral thesis. Wageningen Agricultural University. Wageningen, The Netherlands.
5. Majercak J. - Novák V. (1994): One dimensional variably saturated flow model. GLOBAL. Version 2.1. Institute of Hydrology, Slovak Academy of Sciences. Bratislava, Slovak Republic.
6. Pálfai I. (Ed.) (2000): The role and significant of water in the Hungarian Plain. (In Hungarian) Nagyalföldi Alapítvány. Békéscsaba.
7. Smith R. E. – Diekkrüger B. (1996): Effective soil water characteristics and ensemble soil water profiles in heterogeneous soils. Geophys. Res, 32. 1993-2002.
8. Somlyódy L. (2000): Strategy of Hungarian water management (In Hungarian). MTA Vízgazdálkodási Tudományos Kutatócsoportja, Budapest. 370.
9. Tóth T. – Kuti L. (2002): Testing alternative techniques of numerical simulation versus repeated field instrumental measurements for assessing soil salinity status in a sodic grassland. Agrokémia és Talajtan, 51. 243-252.
10. Van Meirvenne, M. (1995): Spatial extension of a point water balance model. In: Scenario Studies for the Rural Environment. (Eds.: Schoute, J. F. TH. et al.) 293-297. Kluwer. The Netherlands.
11. Várallyay Gy. (1988): Soil, as a factor of drought-sensitivity of biomass production (In Hungarian). Vízügyi Közlemények, LXXX. (3) 46-68.
12. Várallyay Gy. (1989b): Soil water problems in Hungary. Agrokémia és Talajtan, 38. 577-595.
13. Várallyay Gy. (2000b): Soil quality in relation to the concepts of multifunctionality and sustainable development. In: Wilson, M. J., Maliszewska-Kordybach, B.: Soil Quality, Sustainable Agriculture and Environmental Security in Central and Eastern Europe. NATO Sci. Ser. 2. Env. Security. Vol. 69. 17-33. Kluwer Acad. Publishers.
14. Várallyay Gy. (2001): Soil conditions influencing extreme hydrological events. In: Proc. 19th European Regional Conference of ICID, 4-8 June, 2001, Brno. (161) 1-9.
15. Várallyay Gy. (2002): The role of soil and soil management in drought mitigation . In: Proc. Int. Conf. On Drought Mitigation and Prevention of Land Desertification, Bled, Slovenia, April 21-25 2002. ICID-CIIC. (CD)
16. Várallyay Gy.- Szűcs L.- Rajkai K.-Zilahy P.-Murány A. (1980b): Hydrophysical properties of Hungarian soils and the map of their categories in the scales of 1:100 000 (In Hungarian). Agrokémia és Talajtan, 29. 77-112.