# Monitoring and modelling the properties of soil as porous medium: the role of soil use

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Abstracts

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# MONITORING AND MODELLING THE PROPERTIES OF SOIL AS POROUS MEDIUM: THE ROLE OF SOIL USE

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***BOOK OF ABSTRACTS***

EDITORS: Wojciech Skierucha
Ryszard T. Walczak

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# ORAL PRESENTATIONS

## EXAMINATION OF SWAP SUITABILITY TO PREDICT SOIL WATER CONDITIONS IN A FIELD PEAT-MOORSH SOIL

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Numerical models based on the solution of Richards' equation are used as a tool to predict and analyse soil water fluxes in the vadose zone. Such models require specifying initial and boundary conditions as well as functional parameters such as soil moisture retention characteristics, unsaturated hydraulic conductivity and water uptake by plant roots. Also the soil profile needs to be schematised by dividing into the number of characteristic layers according to similarity of the soil properties.

One of the well known numerical models based on the solution of Richards equation is SWAP (Soil – Water – Atmosphere - Plant). In recent years SWAP has been validated using laboratory and field experimental data for a number of mineral soils. The purpose of this paper is examining the possibility of SWAP applications for prediction of soil water conditions in a field peat-moors soil.

The shallow peat - moorsh soil used as a meadow, located in the Biebrza river valley, was selected for the present study. In the top layer (0-25 cm) the soil is highly influenced by so-called moorshing process. The moorsh layer is underlying by highly decomposed peat moss layer (25-35 cm), medium decomposed sedge peat (35-50 cm) and highly decomposed alder peat (50-120 cm). The water level in the soil profile is regulated by ditch drainage and subirrigation system and soil is used as grassland. For the characteristic layers in the soil profile the soil moisture retention and unsaturated hydraulic conductivity functions were determined using "one-step" method.

The simulations of soil water conditions were performed for vegetation periods in 1996 and 1997. The flux type upper boundary condition calculated from meteorological data measured at Biebrza meteorological station was used in the simulation procedure. The lower boundary condition was formulated as measured values of the groundwater level. The initial condition was assumed as soil moisture pressure head distribution at equilibrium with measured groundwater level. The crop coefficients were applied to calculate grassland potential evapotranspiration, which then was used to calculate potential transpiration and to formulate the sink term representing water uptake by plant roots.

For validation of SWAP model the comparison of the calculated data of moisture content and soil moisture pressure head against the measured data was performed. From the comparison it can be seen that the agreement between measured and calculated moisture content values is relatively closer than for the values of soil moisture pressure head. The performed validation shows the applicability of SWAP model for prediction of soil water conditions in shallow peat – moorsh soils.

## PORE-SHAPE COMPONENT OF SOIL WETTABILITY

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Matric potential of soil water is a result of wettability of solid phase by soil solution. It is a common opinion that the wettability or repellency of soils depends on surface properties of soil particles, type of organic matter and associated contact angle. There is no direct method of its measurement in porous media. One way of porous media- water reppelency/wettability quantification are indices like a water drop penetration time (WDPT) or the ethanol probe (EP) which are applied in soil science. In the first method a soil –water interaction is characterized via time of water drop percolation, in second one –the lowest ethanol content of water – ethanol solution which wets the soil

Among the indirect methods the wetting front displacement following a horizontal infiltration and a capillary rise experiments are applied to determine the contact angle. Their theoretical background is described by Washburn equation. In principle these methods are valid under assumption that the pore shape can be modelled by cylindrical tube, while the real pores in soils have at least three different features: they are either cylindrical or straight and they are interconnected. The consequences of non-cylindrical shape of pores on capillary rise are examined in this paper.

# ON SOME THERMAL CHARACTERISTICS OF THREE COMMON SOILS IN BULGARIA

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The general heat properties of the soil, characterizing it from the viewpoint of its ability to conduct and accumulate heat, are the thermal conductivity, $\lambda$ and the heat capacity of the soil, $C$. A secondary parameter is the thermal diffusivity, $a$, of the soil.

Heat capacity per unit of soil volume depends on the heat capacity of the individual components of the soil and is equal to the sum of such components capacities, while thermal conductivity of the soil is not directly related to the values of thermal conductivity of the individual soil components, but depends also on the distribution of soil particles in space.

The thermal diffusivity of the soil, $a$, is the quotient of the thermal conductivity and the heat capacity per unit volume of the soil: $a = \lambda / C$ . It determines the capability of the soil to equalize the temperature at all the points of the object under study, and in terms of numbers equals the rate of temperature change at a given point in the soil, caused by a unit change in the temperature gradient. The thermal diffusivity and temperature regime of three common soils in Bulgaria were investigated in this study.

Soil thermal diffusivity was determined by indirect method on the basis of data from standard soil temperature measurements. For that purpose theoretical model based on the heat conduction equation was used. The calculations were made by the formula

$$a = \frac{\omega (z_{i+1} - z_i)^2}{2 \ln^2 \frac{A(z_{i+1})}{A(z_i)}}$$

where $z$ is the vertical coordinate, $A(z_i)$ and $A(z_{i+1})$ – the amplitudes of annual soil temperature variations at two consecutive depths in soil, $\omega = 2\pi / \tau$ – the cyclic frequency of temperature variations, $\tau$ – the period of variations.

Mean long-term daily soil temperature data from 3 meteorological stations (Sofia–CMS, General Toshevo and Ivailo) of the National Institute of Meteorology and Hydrology for the period 1993 – 2002 was used to determine mean long-term amplitudes of annual soil temperature variations at depths of 0.02 and 0.20 m for every station. In this way, by using the above formula, mean values of thermal diffusivity of the soil layer 0.02 – 0.20 m were calculated. It was found that the soil thermal diffusivity was highest at General Toshevo ($3.86\times10^{-7}$ m$^2$s$^{-1}$) and its values were $2.25\times10^{-7}$ m$^2$s$^{-1}$ and $2.13\times10^{-7}$ m$^2$s$^{-1}$ respectively for Ivailo and Sofia–CMS.

The annual course of mean long-term daily soil temperatures is graphically presented for depths of 0.02 and 0.20 m for every station. Our results show that the lowest soil temperatures are during winter, in January. The minimum temperatures at a depth of 0.02 m are lower than at 0.20 m. The lowest minimum temperature –0.4°C is at a depth of 0.02 m in station Sofia–CMS. The highest temperatures are during summer, in July. The maximum temperatures are higher at a depth of 0.02 in comparison with those at 0.20 m depth. The highest maximum temperature 28.5°C is at a depth of 0.02 m in station Ivailo.

Soil samples were taken close to the soil thermometers on the grassed ground in each of the indicated meteorological stations. The type of the soils (Sofia–CMS – Eutric Vertisol, General Toshevo – Luvic Chernozem and Ivailo – Calcaric Fluvisol), their mechanical and chemical composition, $pH_{(H_2O)}$, $pH_{(KCl)}$ were determined in the Institute of Soil Science “N. Poushkarov”.

## GEOMETRICAL FACTORS AFFECTING THE BULK ELECTRICAL PROPERTIES OF SOILS AND ROCKS: MEASUREMENTS AND CONTINUUM MEAN FIELD COMPUTATIONS

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Understanding the relationship between the effective electrical conductivity and dielectric permittivity of soils and rocks and their porosity and volumetric water content is important because measurements of electrical properties are used to determine porosity and water content. In this lecture we are going to report experimental and theoretical studies aimed at improving our understanding of the way the geometrical attributes of granular materials determine their effective conductivity and permittivity [2-5]. In order to avoid interfacial surface conductivity and bound water effects we have used coarse granular materials of low surface area such as glass beads, quartz sand grains, tuff and mica particles. Accurate measurements of the effective electrical conductivity [4,5] and permittivity [2-5] of anisotropic packings of mica particles [2] and isotropic packings of glass beads, sand grains and tuff particles [3-5] have demonstrated: 1, an alteration of the directional effective conductivities and permittivities of anisotropic packings attributed to particle shape and orientation; 2, a reduction in the permittivity of isotropic packings due to deviation from a spherical particle shape and an increased broadness of particle size distribution. The measured effective conductivities and permittivities are predicted reasonably well by modified classical mixing formulas [2-4], reviewed in e.g. [1]. Particle shape effects were modeled using the depolarization factors of equivalent oblate particles [2,4] and those of particle size distribution using a finite number of inclusion-intermediate background mixing [3]. For dense granular packings of various particle shapes and size fractions, of a background/inclusion conductivity ratio of 1/8 to 80 the effects of the neighboring particles can be accounted for with a single value, $a = 0.2$, of a heuristic parameter $a$ defined in the range of 0 (Maxwell/Clausius-Mossotti mixing law) to 1 (coherent potential approximation).

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# EFFECTS OF MANAGEMENT ON SOME PHYSICAL PROPERTIES OF SOIL

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The study was conducted on a silty loam soil (Orthic Luvisol) under conventional tillage (CT) and under 35y orchard (OR) with a permanent sward. Soil samples were taken from four layers up to 40 cm. Soil organic C (SOC) and pH were higher and bulk density lower under OR than under CT in all layers. The acidification of tilled soil can be associated with greater nitrification and the leaching of Ca2+ from the soil surface layer without protective sward.

Pore size distribution for pores >50 to 0.1 μm was calculated from water retention. Pores 7.5 to 0.4 um were determined using mercury porosimeter (Carlo Erba) with mercury intrusion at pressure of 0-2 MPa into soil samples after degassing (Hajnos, 1998). Nitrogen adsorption/desorption isotherms were used to determine volume of pores <0.008 nm (Dubinin, 1979). The effect of soil management on the pore size distribution was related to soil depth. Contribution of large pores (>50 μm) in the top 0-10 cm depth was higher under CT and in deeper soil it was higher under OR. Porosity for pores with radius of 15 μm to 0.1 μm retaining plant available water was higher and that of small pores (radius < 0.1 μm) was lower under orchard soil with higher SOC content. The differences between the treatments were most pronounced in large pores. Variability of pore size distribution with depth was less under orchard than conventionally tilled soil. Altogether the data confirm negative correlation between the contribution of large and small pores. Water infiltration into the orchard soil was several times greater than into annually tilled soil due to likely high contribution of surface open earthworm channels in the former.

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# COMPACTION INFLUENCE ON SOME PHYSICAL PROPERTIES OF SOIL /LUVISOL/

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The mechanical compressibility of soil, considered as a media for plants and trees growth, is affected by both internal (=soil) and external factors. Therefore, the determination of the compressibility requires the use of multi-functional methods in order to deal adequately with the complex relation, existing between the needs of the growing plants and trees and the physical characteristics of soil, as affected by the loads, which the soil has to support.

As a result of the development of heavier agro-forest machines and of the intensification of soil, plants and trees treatments within the last three decades the question concerning the maximum acceptable mechanical compressibility of arable and forest land is more often asked nowadays.

Actually, this question is more complex and involves the soil feature. It has significant interrelationship with most of the recognized physical, chemical and biological properties of soils, as well as, with the environmental factors, such as climate, weather, tillage, agricultural and forestry treatments and crop use.

Further, the state of compaction of a soil largely determines the physical and the related chemical soil conditions. They control the responses of crop plants, required for the effective farming and forestry, and the conservation of soil and water needed for a permanent agriculture and forestry. The state of compaction of soil largely establishes the air, water and temperature relationships and largely influences the seed germination, seedling emergence, root growth and in fact all phases of crop and forest growth and production.

A change in the state of compaction of soil can be caused by forces, which may originate from mechanical sources such as heavy machines. This kind of forces are external factors.

The following internal parameters influence the ability of the soil to withstand mechanical loading:

- the kind of clay minerals, sort and amount of absorbed cations
- the content of organic substances
- the structures and their strengths induced by swelling and shrinkage
- the bulk density and pores size distribution
- the water content , as well as the water suction

The soil strength induced by the internal forces must be equilibrated with the external forces:

- kind of loading
- load intensity
- time dependence and number of compaction events

Both dynamic and static loadings induce a load-dependent increase in the internal stress of the soil. The experimental investigation of the effect of external and internal stresses of soil requires the control of both mechanical stresses, applied externally and internally, as well as the response in dilatation.

In the present work the influence of the heavy tilling machines on a brown forest soil (Luvisol) is considered and the following properties of this soil are examined in laboratory: bulk density, moisture content (volumetric and weight water content), and the pores size distribution, water potential and pF-curves.

## HYDRAULIC FUNCTIONS IN BI-MODAL SOILS WITH LOGNORMAL PORE SIZE DISTRIBUTION

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Soil water retention curve together with saturated and unsaturated hydraulic conductivity are basic soil hydraulic functions used in the solution of transport processes in soils. We modified the relevant equations based on lognormal pore size distribution to bi-modal soils. We used the measured data from A and B horizons of four soil profiles to test the proposed theory. Bi-modal soils are characterized by the existence of matrix and structural domains of capillary pores. The pressure head separating them is not constant and it varies in a broad range of values. The classification of soil pores into various categories with fixed boundaries of pore radii lacks therefore objectivity. The structural porosity is lower than the matrix porosity and their ratio decreases in the B horizon. Parameters of the pore size distribution obtained by optimisation differ in the two domains. They were used for plotting the separate soil water retention curves of matrix and structural domains. Parameters characterizing the unsaturated conductivity function differ substantially when the matrix and structural domains are compared. Our assumption on different configuration of soil porous systems in matrix and structural domains was proved. We obtained a good agreement between computed and measured data when the optimised parameters entered into equations of soil water

retention and the unsaturated conductivity function. The proposed equations and restrictive conditions are therefore well applicable to bi-modal soils.

Keywords: Pore size distribution; hydraulic functions; unsaturated conductivity; soil water retention curve

## WHAT CAN WE MEASURE USING ION-SELECTIVE ELECTRODES?

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It can be envisioned that the combination of recent achievements at the area of chemical sensors (especially that related to the chemical recognition of analytes with appropriate polymeric ion-selective membranes) with breakthroughs in electronics and miniaturization can lead to developments of reliable and selective devices that allow for real-time measurements, in-soil monitoring of electrolytes in time as well as the mapping of soil nutrients in the form of pH, $K^+$, $Ca^{2+}$, $NH_4^+$, $NO_3^-$ or $Cl^-$ ions. The systematic control of these nutrients in soil will allow for an optimisation of the overall production process of the crop as well as reducing the environmental impact caused by excess of nutrients in the soils.

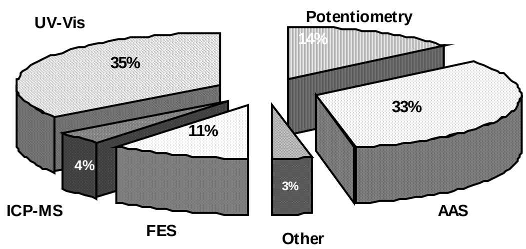


***Fig. 1.*** *The contribution (in %) of various methods used to measure electrolytes content in soil.*

Among standard methods used to measure nutrient levels in soil the atomic absorption spectroscopy (AAS), flame emission spectroscopy (FES), inductively coupled plasma-mass spectroscopy (ICP-MS), UV-Vis spectrometry (UV-Vis) can be listed. They are rather complex and time consuming due to the extraction and pre-treatment processes involved. Moreover, the instrumentation required for these measurements is also expensive. In contrary, the use of ion-selective electrodes (ISEs) would be of an advantage.

ISEs are one of the biggest groups of chemical sensors, used widely for clinical, environmental, industrial and recently also agricultural analysis. They have been the subjects of widespread interest of analytical chemists for more than 30 years. This is due to the fact that ISEs can provide accurate, rapid and low cost method of analysis. The very important advantage of potentiometric methods employing ISEs is their selectivity and possibility of determination of certain analytes in mixtures without separation of other sample components. In contrast to many other analytical methods, ISEs are capable of determining ion activities, rather than total concentrations. Moreover, the analyte is not consumed in the course of the measurements.

In this work, beyond the principles of the functioning of ion-selective potentiometric sensors, the overview of their application for the determination of soil electrolytes will be presented.

## HEAT FLUX MEASUREMENTS IN SOIL WITH THE THERMAL PROBE OF 16 SENSORS

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The study describes the thermal probe with 16 sensors predicted for the measurements of the temperature profile under surface. The temperature profile may be employed for assessing the incoming or outgoing heat flux in the ground if thermal conductivity of the medium under test is known from other research methods. In this paper the soil was characterized by results of a complex research with analysis of compounds combined into the statistical model of thermal conductivity. The model was broadly verified on many kinds of soils and will be described. The joint use of the model with the temperature profile brought heat flux values which are non consistent to the heat flux values taken from the heat flux plates employed in parallel to the experiments. The heat flux plates work reasonably well in conditions of high insolation but poorly under low insolation or in conditions of low temperature gradient values. Proper comparison will be provided in the paper. The thermal probe is capable to provide good determination of the thermal profile under low temperature gradient and seems to be a valu-

able alternative to the plates. The method of temperature measurement will be discussed electrically in some general constrains.

## REACTION OF MANGO TREE STEM WATER CONTENT TO IRRIGATION WITH SALINE WATER

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Close, direct, and accurate monitoring of the plant water status may serve as a practical (irrigation scheduling) and a research (climate-environmental induced physiologic changes) tool. Methods for high-frequency capacitance measurement (e.g., TDR) possess the potential for high resolution dielectric measurements with minimal dependence on properties of the measured matrix. The present study tested the accuracy, response time, and sensitivity of the TDR methodology in measuring changes in water status in a mango tree stem exposed to saline irrigation waters. Under induced stress conditions, stem and root zone water content and electrical conductivity were simultaneously measured. Our study is distinct in its detailed and frequent measurements of $\theta_{stem}$ using short (28 to 70 mm) TDR probes in trees growing in a detached medium. We have found that stem WC response to root zone applied salinity and water stress were negative and positive, respectively. Stem EC was primarily dependent on WC and only negligibly on stem cells salinity. Stem WC response time between to water application was ~4 hours.

# CHARACTERIZATION OF SEAM MATERIAL OF PAVED URBAN SOILS

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Increasing rainwater infiltration by re-opening sealed areas is among the main ideas of recent urban planning. Pavements seam to be good technical measures to reach that goal. But there is no definite knowledge about the consequences of such strategies for the groundwater quality. Rainwater runoff in sealed and partial sealed urban areas contains heavy metals, from different industrial sources, at least from traffic. In our own investigations we found above-threshold heavy metal concentrations in the seam material. Concurrently the resulting concentration of the equilibrium soil solution was very low for the seam material but increased in underlying layers. Because the original seam material and the underlying material were identically at the construction date, any input must have lead to this higher retention capability. In paved urban soils, the seam substrate is influenced by inputs of various organic substances, like foliage, hairs, dog faeces etc. as natural sources and carbon black and rubber from tires, soot from domestic firing/heating and from car engines, oil and fuel as artificial sources lead to total carbon contents of up to 6 %, depending on the age and the location. Because organic material of paved soils differs not only in composition but also in temperature and humidity regime, the characteristics should be different from those of non-urban soils.

We want to give an overview about physical and chemical characteristics of this material, like pore characteristics and surface properties. We investigated water vapour adsorption isotherms, specific surface, surface charge, water retention functions and general characteristics like CEC in order to compare the seam material's retention capability with non-urban soils.

# NITROUS OXIDE PRODUCTION IN AN ORGANIC SOIL PROFILE IRRIGATED WITH MUNICIPAL WASTEWATER

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Nitrous oxide ($N_2O$) is greenhouse gases playing important role in destroying the ozone layer. Nitrous oxide is 300 (mass basis) times more radiatively active than $CO_2$ at absorbing infrared radiation.

Atmospheric concentrations of $N_2O$ have been increasing at a rate of 0.2-0.3% per year during the last century. Agricultural soils are among the largest sources of anthropogenic $N_2O$ emission. Increasing atmospheric content of $N_2O$ gives cause for serious environmental concern.

Artificially drained organic soils contribute to an important degree to the atmospheric load of $N_2O$. Irrigation of soils with substantial doses of the wastewater can induce anoxic conditions in which nitrate ($NO_3^-$) and nitrite ($NO_2^-$) are converted to dinitrogen gas ($N_2$). Intermediate in the process of denitrification is nitrous oxide which most is emitted from wastewater treatment systems. $N_2O$ can also be produced from nitrification in aerobic conditions.

The aim of the study was to measure $N_2O$ production in an organic soil (*Eutric Histosol*) irrigated with municipal wastewater.

The measurements were made during vegetation season on experimental fields situated near Lublin (Poland) in the valley of Bystrzyca river.

The fields of a surface about 1 ha each were prepared in order to obtain three treatments with different plant covers with: willow (*Salix americana*, *Salix viminalis*) and meadow (with *Alopecurus pratensis, Phalaris arundinacea, Festuca pratensis* as dominating grass species). Each field was divided in the plots: A – control soil, wetting only by precipitation and ground water; B – soil irrigation with single dose of wastewater (60 mm); C - soil irrigation with double dose of wastewater (120 mm). The basic characteristics of soil *Eutric Histosol* material: 32.9 % organic C, pH 7.37 in KCl and particle size fraction: 4% (0-0.1 mm), 55% (0.1-0.02 mm) and 41% (<0.02 mm). The fields were flooded 10 times during vegetation season with 600 mm and 120 mm of wastewater per year. The irrigation wastewater contained in average 25 mg $NO_3$-N $dm^{-3}$, and 30 mg of total N $dm^{-3}$, while the average content of total phosphorus was 5 mg $dm^{-3}$ of which 4.8 mg $dm^{-3}$ constituted phosphate P.

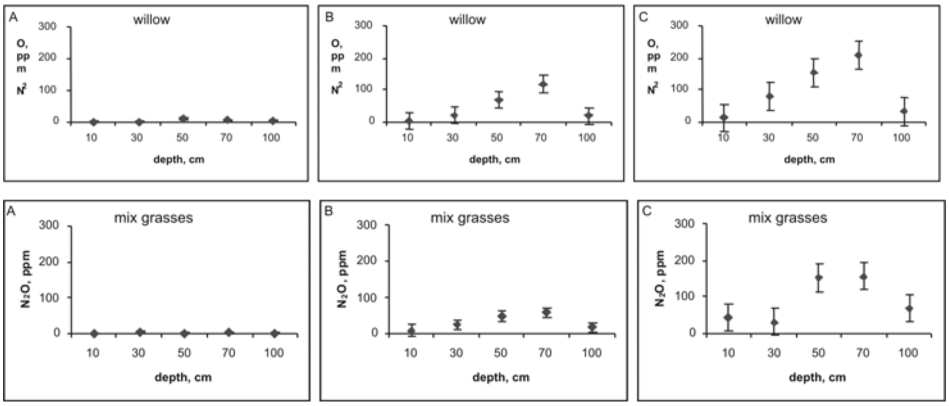


***Fig. 1.*** *N2O concentration at different depths of soil profile irrigated with wastewater. A-control soil; B-single irrigation dose; C-double irrigation dose of the wastewater. Standard error in bars.*

Soil air was sampled from depths of 10, 30, 50, 70 and 100 cm and analysed for $O_2$, $CO_2$ and $N_2O$ content. Simultaneously redox potential (Eh) at the same depths was measured with permanently installed Pt electrodes.

Presented results of research are an average from three years study (1998-2000).

Irrigation caused a decrease of oxygen content in soil air, which was related to the irrigation wastewater dose and the depth within the soil profile. The observed decreases in the content of oxygen were accompanied by decreases of soil redox potential and increases in the content of carbon dioxide and nitrous oxide.

Nitrous oxide concentration usually showed a maximum at 70 cm depth between first and third flooding day for every treatment. The highest concentration about 208 ppm $N_2O$ was observed at a depth of 70 cm in the field irrigated with the double wastewater dose while the highest for the single dose was about 118 ppm on the field planted with willow.

The concentration of $N_2O$ decreased to initial values after eighth day for both of the treatments. Nitrous oxide in the soil air reached value up to about 19 ppm at a depth of 50 cm of the control fields (Fig. 1.).

Intensive production of $N_2O$ was observed for values of the redox potential from 0 to -200 mV during the flooding cycle.

Increase of $CO_2$ concentration to 5% and simultaneously decrease of $O_2$ concentration down to 10,5% as result irrigation was observed in soil air.

# DETERMINATION OF MOISTURE DIFFUSIVITY AND SALT DIFFUSION COEFFICIENT OF BUILDING MATERIALS USING TRANSIENT METHODS

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Coupled water and salt transport in cement mortar was investigated in the conditions of one-sided sodium chloride-in-water solution uptake. The organization of the experiments was the same as in common water sorption experiments. The 40 x 40 x 160 mm samples were exposed by their 40 x 40 mm face to the NaCl solution with the concentration of 18.195 g Cl- in one liter of the solution. Duration of the experiment was 1 hour, 24 hours and 7 days for three different groups of samples. After this time, the samples were cut into 8 pieces and in each piece water content and chloride concentration were measured.

In the computational inverse analysis of the coupled water and chloride transport in cement mortar we assumed for simplicity just the diffusion mode of both water and salt transport without the cross effects. Therefore, the result of our analysis was the identification of apparent water and salt transport parameters instead of the basic parameters of the coupled water and salt transport defined exactly in the sense of irreversible thermodynamics.

Under these simplifying assumptions, we had formally the same parabolic differential equations and the same boundary and initial conditions for both water transport and chloride transport, namely

$$\frac{\partial C}{\partial t} = div(D(C)\, grad\, C) \quad (1)$$

$$C(0,t) = C_1 \quad (2)$$

$$C(\infty,t) = C_2 \quad (3)$$

$$C(x,0) = C_2 \quad (4)$$

where $C$ is either water concentration in kg of water per kg of the dry porous body or chloride concentration in kg of $Cl^-$ per kg of the dry porous body, $D$ is either the apparent moisture diffusivity or the apparent chloride diffusion coefficient.

In the solution of the inverse problem to the system of equations (1)-(4), we assumed that the water or concentration field *C(x,t)* is known from the experimental measurements as well as the initial and boundary conditions of the experiment. Solving an inverse problem meant in this particular case the determination of the *D(C)* function using the above data.

On the basis of the previous experience with the solution of inverse problems of moisture diffusion and heat conduction (for a detailed analysis see [1]) we employed two methods for determination of the *D(C)* function in this paper, namely the Matano method (for the application in moisture diffusion see e.g. [2]), which is most frequently used in the inverse analysis of moisture profiles, and the double integration method (see [2]), which was in the previous work shown as the most reliable (see the error analysis in [3]).

It should be noted that the methods of solution of the inverse problem of water or chloride transport applied in this paper were not based on an exact mathematical solution (see [1] for a more detailed analysis). The solution was rather a physical one, consisting in choosing some very simple boundary and initial conditions and relaying on the validity of the assumption that under these conditions the solution existed and that there did not appear any singularities in the solution. In a reality, from the mathematical point of view we did not know anything about the existence and uniqueness of the solution. In addition, the most principal input parameters of the inverse problem, namely water or concentration fields *C(x,t),* were not given in the form of continuous functions but rather in the form of pointwise defined functions. This required data approximation including smoothing of the originally measured data sets that could introduce significant errors to the analysis. Therefore, the verification of results obtained by the above solution of the inverse problem at least in the physical or technical sense and some optimization of the calculation procedure was necessary.

In the optimization procedure we have chosen first a smoothing factor of the data approximation function in more or less random way, mostly based on the experience with previous similar cases. In our case we applied for data approximation the linear filtration method with Gaussian weights (see [3] for details). Then, we performed the backward analysis, i.e., determined the *D(C)* function using the methods of the solution of the inverse problem mentioned above. The calculated *D(C)* function was used afterwards as the input parameter in a forward analysis when the problem (1)-(4) was solved numerically. In our particular case we used the computer code Delphin 4 [4] for the computations. Finally, the agreement between the calculated water or concentration fields *C(x,t)* and the original measured data was evaluated using a common least-square procedure. If the least-square difference between the measured and calculated data fell within the given limits, the process of optimization was stopped. Otherwise, another value of the smoothing factor was chosen and the whole procedure was repeated until a good closeness-of fit was achieved. It should be noted, however, that a situation could occur when a good closeness-of fit was not accompanied by a reasonable smoothness-of-fit of the original data. This was also not a desired result because the random fluctuations might become too important. Therefore, always a compromise between closeness-of-fit and smoothness-of-fit had to be found.

ACKNOWLEDGEMENT

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## A COMPARISON OF CAPACITANCE AND TDR TECHNIQUES FOR DETERMINATION OF MOISTURE PROFILES IN BUILDING MATERIALS

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Dielectric methods for the determination of moisture content are based on an analysis of the behaviour of dielectrics in a time-varying electric field and consist in the measurement of permittivity of moist porous media [1]. The determination of moisture content using the permittivity measurements is based on the fact that the static relative permittivity of pure water is equal to approximately 80 at $20^0$C, while for most dry building materials it ranges from 2 to 6. The permittivity of materials is strongly affected by the orientability of molecules in the electric field. This characteristic is high for water in gaseous and liquid phase, but is significantly lower for water bound to a material by various sorption forces, which makes the orientation of water molecules more difficult. This feature makes it possible to distinguish between the particular types of bond of water to the material using the permittivity but on the other hand, it results in the dependence of the sensitivity of moisture measurements on the amount of water in the material. The relative permittivity of water bonded in a monomolecular layer is approximately 2.5, but for further layers it increases relatively fast. Therefore, the dependence of relative permittivity on the moisture content is generally characterized by an abrupt change at the transition from a monomolecular to a polymolecular layer. Consequently, the methods of moisture measurements based on the determination of changes of relative permittivity have low sensitivity in the range of low moistures and their application is rather limited.

Based on the frequency of the applied electric field, the dielectric methods can be divided into two groups: capacitance methods and microwave methods. Capacitance methods are employed in the range of lower frequencies, typically from 100 kHz to 100 MHz. The permittivity is determined using a capacitor, usually with the measured material as its dielectric. The measuring capacitor usually has either a simple plate form (for measuring solid materials) or consists of two coaxial cylinders (for measuring loose materials). Microwave methods differ from the capacitance methods principally only in the applied frequency of the power supply. In the spectrum of electromagnetic waves microwaves occupy the frequency range of 1 GHz to 100 GHz, i.e. the range of dm to mm waves. Their wavelength is comparable with the dimensions of the electric elements such as capacitors or resistors, and so capacitance methods cannot be employed. Also, for the signal transmission coaxial cables or wave guides are employed instead of the usual wires. Moisture measurements are performed in a relatively narrow range of microwaves between 2 GHz and 12 GHz. The main reason is that in this range the microwave technology is most advanced, as most common radars work in this frequency range. The microwave techniques are generally believed to be more precise and more reliable than capacitance methods, mainly because they much less affected by the presence of salts in water. However, they use more sophisticated technology for the detection of either reflected or transmitted waves and their calibration is usually more difficult.

In this paper, a comparison of two dielectric methods for measuring moisture content in building materials was performed. The first of them was a typical capacitance method. The capacitance moisture meter used in the measurements (see [2]) was equipped with electrodes in the shape of two parallel plates with dimensions 20 x 40 mm. The device was built on the basis of the determination of impedance change and worked in the frequency range of 250 - 350 kHz. The moisture meter reading was proportional to the capacity of the measuring capacitor (its dielectric was the investigated material). The calibration curve was determined for each sample. The final moisture profile was used for that purpose, which was determined by the gravimetric method as well. The sample was cut to 1 cm wide pieces, and the data on the measuring device were assigned to the moisture content of the particular 1 cm segments determined by the gravimetric method.

The second method used for moisture measurements was the time-domain reflectometry (TDR) technique belonging to the class of microwave methods. The TDR measuring equipment developed by Easy Test was employed in this case (see e.g. [3]). The TDR sensors were individually calibrated to obtain their particular reference travel times and characteristic probe lengths [4]. In this calibration, the travel times for water and benzene experimentally determined for each sensor were used.

In the experimental work, rod-shaped AAC samples with the dimensions of 20 x 40 x 290 mm were used for the capacitance method and 70 x 50 x 330 mm for the TDR method. PVC thermal shrink-wrap was employed for water and vapor proof insulation on the lateral sides to assure 1-D water transport and perfectly plain surface. The initially dry specimens were put in contact with water and moisture profiles were determined in 10 chosen time intervals. The experimental results have shown that both methods gave very similar results. The differences were within the error range of both methods.

## ACKNOWLEDGEMENT

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# CALIBRATION OF STRAIN GAGE TRANSDUCERS FOR SOIL STRESS MEASUREMENTS

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## INTRODUCTION

Stress measurements in granular materials like soils, grains or powders require the use of special transducers. In most applications, strain gage type or piezzoresistive transducers are used. The advantage of strain gage is their simplicity and low costs, while they suffer from time effects. It is very important to apply proper installation procedures in strain gage transducers production. Piezzoresistive transducers have time stable output but are more expensive and require more space for their greater size. In the present paper, experiences with strain gage pressure transducers are presented. These transducers are used for soil stress determination under vehicles wheels as well as for grain pressure distribution in silos. Before use transducers require calibration. Normally, pressure transducers are calibrated in air or fluid, but in case of transducers intended to use in granular materials, the calibration procedure have to respect transducer – material interactions. In the present paper there is presented and discussed such a method, introduced in The Institute of Agrophysics.

## STRAIN GAGE TRANSDUCERS

The transducers are produced with circular pattern full bridge strain gages. There are two different transducers sizes: 20 and 30 mm (outline diameter). The strain gages are bonded to elastic membranes, which are fabricated from an aluminum alloy. The dimensions of the membranes are set by means of experimental methods. The transducers are integrated with miniature signal amplifiers, so the output is 0..5V. it is very important in field experiments, the integrated transducers are easy to use and maintain. The transducer is shown in Fig.1.

## CALIBRATION METHOD

In order to respect membrane – soil interactions and their influence on output signal, an in-soil calibration method was applied. In this method, the pressure acts on the transducer throughout a thin layer of soil or other investigated material.

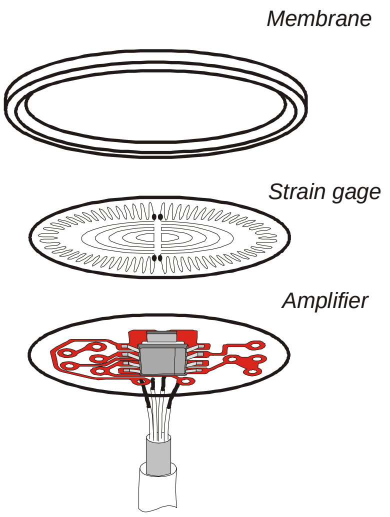


***Fig.1.*** *Strain gage pressure transducer*

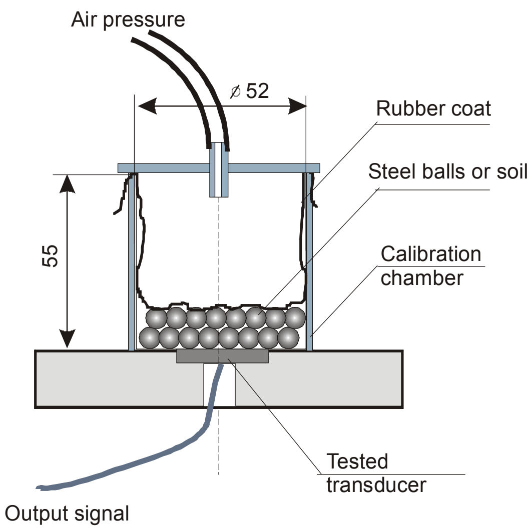


***Fig.2***. *Calibration test stand*

As the soil water content has also an effect on output signal, the soils were prepared by adding water to obtain WC from 0 to 15% with 2,5 % step. In order to respect the interaction between the membrane and soil aggregates, steel balls of different diameters (2.5, 3,4 and 5 mm) were used as a model calibration material. External air pressure was applied in 10 kPa steps up to 190 kPa. The calibration stand in shown in Fig.2.

## RESULTS

The effect of the type of soil and steel balls size is shown in Fig. 3. It was assumed, soil water content has a significant effect on the output signal, for both 20 and 30 mm size transducers. The type and kind of calibration materials: soils (loess, sand or turf) and steel balls have also an effect on readings.

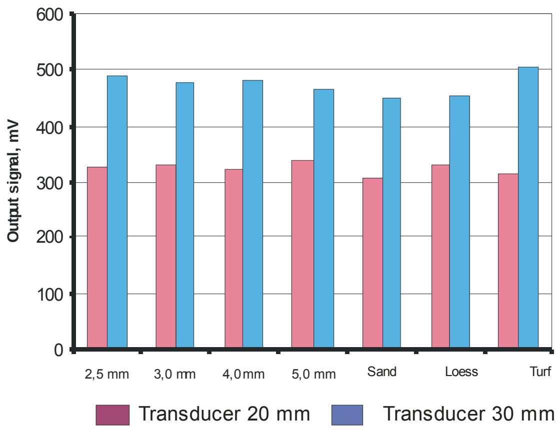


***Fig.3.*** *The effect of soil type and steel balls size on outgoing signal for two transducers*

CONCLUSIONS

It is important to respect the type and the state of the material to be investigated with pressure transducer. Specific soil-membrane interactions may influence the outgoing measure signals, even more at various soil water content.

## SPATIAL VARIATION OF BASIC SOIL PROPERTIES IN SMALL LOESS CATCHMENT

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Primary catchment is an elementary landscape unit that reflects response of all processes taking place inside its borders. Even in such geologically homogenous area as loess deposits, soils and its properties are differentiated due to process of pedogenesis, time of agricultural use, changes in land use and management practices, and intensity of erosion. In the effect, inside the loess catchment, upper soil layer is developed from different soil horizons, and soils form a complex mosaic pattern. Up to now, information about variation of soil properties is generally limited to the field scale. It is difficult to judge if such analysis are suitable for proper characterization of soils of the whole catchment. Conducted studies aimed to evaluate a spatial variation of soil properties inside small loess catchment, typical for short wave landscape of northern part of the Lublin Upland.

Studies were conducted in loess catchment of the area 5.7 ha, located in the Lublin Upland (51020' N; 22046'). Majority of the catchment is covered by slopes from 0-30 (52%), slopes from 3-60 cover 35%, 6-100 - 12.4%, and above 100 - 0.6%. Predominant expositions are western, northern and south-western (75%). Inside the catchment borders, there is one parcel (0.5 ha) located in the valley and parts of ten other parcels. Majority of parcels is occupied by annual crops, and grasslands occupied only about 6% of the area. According to historical evidences, the catchment is under agricultural use not longer than about 170 years.

Samples to characterize soil properties were taken from plow (5-15cm) and subsoil (30-40cm) layer from 143 sampling points located in a regular grid of 20x 20 m. In each point, soil texture, humus content, pH (KCl), and content of water-stable aggregates was analyzed. Samples were collected after harvest in the summer 2002. Non-eroded soils were represented by 41 samples (29,7%), slightly eroded by 40 (29%), moderately by 12 (8,7%), severely by 9 (6.5%), very severely by 2 (1,4%) and colluvial soil by 34 (24.6%). Five sampling points represented disturbed soils with increased sand content (location inside former household area) were excluded from the calculation. Results showed that to most variable classes of texture in plow layer belonged content of coarse sand (1-0,1mm) with coefficient of variation 37%, clay (<0.002mm) - 30%, and very fine silt (0.005-0.002mm) – 23%. The same classes were also most variable in subsoil layer with coefficients of variation 25, 14.1 and 13%, respectively. Absolute values for upper soil layer ranged from 0,3-1,9% for coarse sand, 6-18% for clay and 2-9% for very fine silt. Respectively, for subsoil, the ranges were 0-1%, 5-24%, and 0-10%. Humus content ranged from 1.05-2.47% in upper layer and from 0.2-2.3% in subsoil with coefficients of variation 15 and 59%, respectively. Range of soil pH was similar for both layers (3.7-7.2), although its variation was a little higher in plow layer (18%). Contrary to the above properties, content of water stable aggregates (WSA) was highly differentiated according to land use. For grassland (6 samples), the average value of WSA>1mm was 53.5 and 24.5%, whilst for annual crops – 13.6 and 4.3% for upper layer and subsoil, respectively. Coefficients of variation for water stable aggregates were above 42%.

## IMPROVEMENT OF THE EVAPORATION METHOD FOR QUANTIFYING THE UNSATURATED HYDRAULIC CONDUCTIVITY AND WATER RETENTION FUNCTION

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The evaporation method is an internationally accepted approach for the quantification of soil hydraulic properties. The potential of this method for improvements of the quality and reduction of costs has been analysed.

From a database of more than 1500 soil samples, 104 samples were selected and evaporation as well tension dynamics were analysed. The samples cover a wide range of texture classes, dry bulk densities and evaporation rates. Beside German soils, soil samples of Ohio (USA) and China (Shaanxi province) were analysed. The tension distribution in the measuring layer stays approximately linear during the measuring time. However, for clay and sand soils a reduction of evaporation rate of < 2mmd$^{-1}$ is recommended. With exception of sand, the evaporation is constant in all other soils during the measuring time. In sand soils, the evaporation dynamics can be described by a square function with high accuracy (B>0.99). Resulting from that, only two in sand soils four weightings are necessary. Other advantages are time and cost reduction with perpetuation of same high quality of unsaturated hydraulic conductivity and water retention function. The measuring range could be extended over 100 kPa by applying special tensiometers.

Keywords: Evaporation method, evaporation dynamics, tension, unsaturated hydraulic conductivity, water retention function

## VERIFICATION OF DIELECTRIC MIXING MODELS ON THE BASE OF TDR MEASUREMENTS

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The popular dielectric mixing models of soils: 3-phase model $\alpha$, 4-phase model $\alpha$, 4-phase model $\alpha$ with the bound water dielectric constant, $\varepsilon_b$, dependent

on soil water content, $\theta$, 4-phase de Loor model and regression model were verified on mineral soils. The material used consisted of sixteen mineral soils of different texture, volumetric water content, bulk density and particle density. Apparent dielectric constant of the soils, $\varepsilon$, was determined by TDR technique with use of instrumentation developed by the authors. The remaining variables were measured with the application of standard methods.

It was assumed that for each tested soil there is a transition moisture value, $\theta_{WP}$, which make the distinction between soil water as bound or free. This moisture can be determined from the empirical formula as:

$$\theta_{WP} = 0{,}0674 - 0{,}00064 \cdot SAND + 0{,}00478 \cdot CLAY$$

where SAND and CLAY are percentages of sand and clay in the tested soils. The index *WP* stands for the soil wilting point.

Further assumptions concerning 4-phase models were as follows:

– if $\theta > \theta_{WP}$, the soil dielectric constant was represented by the 3-phase representation of $\alpha$ and *de Loor* models,
– if $\theta \le \theta_{WP}$, the soil dielectric constant was represented by the respective 4-phase models, and the dielectric constant of bound water changed linearly from the value for solids (dry soil) to the value for water (when $\theta = \theta_{WP}$)

It was found that for mineral soils the 4-phase model $\alpha$ with the bound water dielectric constant, $\varepsilon_b$, dependent on soil moisture, $\theta$, works equally well as the regression model, which allows the TDR equipment user to correct the $\varepsilon(\theta)$ relation for the bound water influence using clay content in the modified a model. This correction gives similar results as using soil bulk density with the regression $\varepsilon(\theta)$ model.

## NEW DEVELOPMENTS IN MONITORING INSTRUMENTATION OF SOIL PROPERTIES FROM IAPAS, LUBLIN, POLAND

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The study presents two electronic devices developed in the Institute of Agrophysics: an upgraded version of a portable moisture meter of porous media, working on the Time Domain Reflectometry principle of operation and a data logger intended to monitor physical and chemical parameters of soil, equipped with the wireless communication and internet access.

The new TDR soil moisture meter is a light, handheld device equipped with a clock, a large amount of memory capable to store thousands of measured values while powered from a single charging of a small battery. A graphical display unit is used for presenting the signals reflected from a TDR sensor, displaying the measured values of moisture, electrical conductivity and temperature. The operation of the device is controlled by software user interface by means of a keyboard. A user can select the variable to measure (moisture, temperature or electrical conductivity in all combinations), give names to each collected data point for identification in the memory, connect the meter to PC compatible computer by a standard USB connection and monitor the state of battery. Also the meter is equipped with the GPS unit for geographical localization with the accuracy of ±5m.

The MIDL (Multi Interface Data Logger) is a functional device for controlling the operation of various measurement devices and store the collected data in a memory, which is in the form of a standard Multi Media Card (MMC). The access to data collected from the connected sensors and the configuration data is possible by the radio interface, serial interface or Internet by means of the Internet browser. The device executes the commands in cyclic way controlling the measurement process by means of serial interface. It has very low power consumption and one of the executable commands sets a sleep mode of the device and then, after the programmed delay the device wakes up to continue operation. Each MIDL data logger has a unique number to identify in the Internet and for the construction of widespread measurement networks with global access.

## ERROR ANALYSIS OF THE WATER CONDUCTIVITY COEFFICIENT MEASUREMENT BY INSTANTANEOUS PROFILES METHOD

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Knowledge of the soil hydrophysical characteristics is essential for the description, interpretation and prediction of the progress of practically all physical, chemical and biological processes in the soil-plant-atmosphere system. Modelling of these processes requires also representative data of the soil hydrophysical properties. Generally, the majority of the simulation-prognostic models describing the hydrophysical processes taking place in the soil-plant-atmosphere system are more efficient when the accuracy of the data describing the water characteristics of the soil are more accurate. Due to the large variability range of the water conductivity coefficient in the whole range of soil water potential values, the correct determination of its value is essential to acquire sufficient accuracy of the applied models.

The studies about the about the determination of water conductivity coefficients in the unsaturated zone by instantaneous profiles method began in the 60-ies of the former age, and continued in 70-ies. This method requires simultaneous measurements of water potential and moisture of the soil, therefore it was recognized as time consuming and demanding expensive and specialized measurement equipment, especially for moisture measurement. With the development of the measurement techniques of capillary-porous media moisture, including TDR technique, the instantaneous profiles method is now being applied as a standard for the determination of the water conductivity coefficient in unsaturated zone in a number of scientific centres, including the Institute of Agrophysics PAS.

The objective of the study is to discuss the sources of errors and calculate the maximum absolute measurement error of the water conductivity coefficient determined by the instantaneous profiles method in the soil water potential range from 0 to 900 hPa.

## DEVELOPMENT OF SIMPLE AND ROBUST REDOX AND PH ELECTRODES FOR USE IN SOILS

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### INTRODUCTION

The main focus of archaeologists in Europe is changing. Following the "Treaty of Valetta" archaeological sites are no longer being excavated as a rule. Instead, measures should be taken wherever possible to preserve archaeological sites *in situ*. This means that archaeological materials will stay in the soil in most cases. The main idea behind this new policy is that archaeological sites form a non-renewable, rare, archive of human past. It is thought that future generations must have a chance to excavate sites as we are doing nowadays. Because excavation techniques will become more sophisticated in the future, and because the questions we want to answer from the "soil archive" will change, we should preserve as much archaeological heritage as possible.

While we want to preserve archaeological sites, we influence the soil environment at the same time. Many of the changes we make to the soil (lowering of the groundwater table, ploughing, construction, etc. etc.) do not enhance the preservation of archaeological sites. Although we still do not know exactly how most archaeological materials degrade, we know that oxidation (following dessication) and acidification act negatively on most materials. So, when aiming for the preservation of archaeological sites, while at the same time making changes to the soil environment, the need for monitoring the oxidation status and pH of the soil arises.

## DEMANDS ON MONITORING EQUIPMENT

Many archaeological sites to be monitored lie in "remote" areas in often privately owned land. This means that monitoring equipment can neither rely on electricity from a power network nor make use of heavy equipment. It must be possible to carry the equipment in e.g. a backpack. Other restrictions are imposed by the continued agricultural use of many areas. Also, the nature of the work (monitoring archaeological sites) sets demands on the monitoring equipment: the physical disturbance of the soil must be minimized, while measurements should be possible until at least 2 meters depth. Last but not least is the wish to monitor the redox potential of the soil on a daily basis, making the need for a data logger evident.

## SOLUTIONS

To meet the demands above, three steps had to be taken. First, a probe had to be designed together with an aid to push the probe into the soil. Secondly, sensor had to be selected that are robust enough to be used in very different types of soil. Fortunately, the demands on accuracy were not very high. The redox potential should be measured within 50 mV accuracy, the pH within 0.5 units. Thirdly, a suitable data logger had to be found, which is difficult because of the demand to operate stand-alone for at least one year.

The final probes are based on the well-known glass-fiber poles of dome tents. With some adaptations it is possible to construct a moderately flexible but strong enough probe that can house the redox or pH sensors. The probes can be made to any length desired.

The redox sensor is easy enough: a standard platinum wire sensor fits the demands. The platinum is mounted in the probe in such a way that it stays clean as it is pushed through the soil. Contact with "fresh" soil particles at any depth is made sure by mounting the platinum under a small angle relative to the probe. As a reference any reference electrode can be used that is suitable to use in soils (e.g. a double junction Ag|AgCl electrode). As pH sensor different types were tested: miniaturized glass, metal-oxide and ISFET. Both the glass and ISFET electrodes soon showed too vulnerable to use in soils other than peats or unripened clays. Moreover, the design of ISFET electrodes is such that the measuring point soon gets filled with soil that is difficult to remove. Therefore, a metal-oxide pH sensor is used, in spite of its sensitivity to e.g. redox species. This sensitivity is minimised by coating the sensor with NAFION.

At the time of writing this abstract, field tests are carried out with a newly designed datalogger by the Vrije Universiteit, Amsterdam. This datalogger should be able to store thousands of readings from 8 redox probes over at least one year without any maintenance necessary at all.

## ASSESSMENT OF THE EFFECT OF GROUNDWATER LOWERING ON THE CAPILLARY RISE IN A SANDY SOIL

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Importance of capillary conductivity in assessing the amount of water supply of a meadow by capillary rise is demonstrated by applying the model SIMWASER using data on soil water regime and grass growth from field experiments in the Drau valley in Carinthia/Austria.

There in dry summers capillary rise from groundwater substantially is contributing to meet the water demand of the grass sward. Lowering the river bed downstream of some hydropower plants was accompanied by declining grass yields and field experiments were started to test, if and to what amount this measure could have been the reason for the yield depressions. These experiments were run from 1991 till 1995 on two sites with comparable soil conditions but different ground water depths and covered systematic measurements of soil water tension to 150 cm depth by using calibrated gypsum blocks, while water content measurements were confined to the main rooting depth of 50 cm using the hand operated EASY TEST FOM moisture meter. Some water content measurements were done down to the groundwater level by a neutron moisture meter at times with different ground water levels.

An automatic weather station was run at one of the experimental grass fields which were managed by a farmer according to the usual scheme, which consisted in up to four cuttings a year. Grass yields were measured by hand harvesting three replicates of each one square meter, weighing, taking sub samples to be dried and analysed for water content and dry matter.

Results show, that at the site with higher ground water level the grass yields were substantially higher than those at the site with deeper ground water. Simulation showed, that grass yields at both sites are directly depending on the ground water level during June and July: a draw down of the ground water during this period by 70 – 100 cm will effect a yield depression up to 30- 35 % .

In the present paper the influence of the capillary conductivity upon the simulated grass yields will be investigated by running the model using different sets of this important hydraulic soil parameter. The main features of the model SIMWASER will be briefly explained and a more detailed description of the soil physical parameters and the methods used for their measurement will be given. Capillary conductivity data either from measurements in the laboratory as well as derived from measured saturated conductivity or estimated from standard tables based on the texture of the respective soil class will be used to run the model. Simulated grass yields will be compared and results will be discussed focussing on the requirements concerning the determination of capillary conductivity.

## EFFECT OF ALUMINUM ON MICROSTRUCTURE OF PLANT ROOTS; A STUDY USING THE WATER VAPOR ADSORPTION-DESORPTION TECHNIQUE

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Recent increase of soil acidification due to atmospheric deposition and improper soil nutrition increases the actual needs for process studies to evaluate both mechanisms and parameters controlling plant response on acid toxic environments. Aluminum is a major component of acid toxicity in soils. Number of studies suggests that the pore system of the root tissue undergo marked alteration under aluminum stress.

Water vapor and nitrogen desorption isotherms were used for estimation of micropore parameters (nanometer range) for roots of barley Ars and wheat Henika grown in a nutrient solution and stressed with various concentrations of aluminum at the shooting stage. Water vapor adsorbed in a high relative vapor pressure range was assumed to be due to capillary condensation process. The pore radius was associated with the relative water vapor pressure using Kelvin equation. The total pore volume was taken as the difference between the volume of the condensed (adsorbed) vapor at maximal relative pressure and the amount of adsorbed vapor at the relative pressure equal to 0.32 (below this pressure surface adsorption processes dominate). Average pore radii were calculated from pore size distribution functions evaluated from pore volume vs. pore radius dependencies.

The desorption isotherms of roots grown in the presence of Al differed from these of Al-free roots: the amount of condensed water for both plant roots decreased after aluminum stress.

For both plants, the amount of micropores in the roots measured from water vapor desorption isotherms decreased after aluminum treatment, however the average pore radii exhibited no defined tendencies. Nitrogen desorption isotherms data appeared to change less than these for water vapor.

Changes in root tissue porosity indicate the damage of the root tissue by cracking throughout the pores.

## VARIABILITY OF SOIL MOISTURE IN FEN PEAT-MOORSH SOIL

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Soil moisture is very important variable, which integrates all components of water and the surface energy balances. Furthermore, it is highly variable in space and time. An understanding of the soil moisture content and its variability is very important for hydrological studies in organic soils which actual condition and preservation depends on water related processes.

The solid phase of organic soils is made of plant fibres, humus and mineral matter as well as amorphous substances. Organic matter is one of the main constituents of soil affecting the soil's hydrophilicity or hyrophobicity, and thus it affects the soil's behaviour during drying or wetting. The soil hydrophobicity (water repellence) can influence on actual soil moisture patterns and its variability.

The objectives of this study were to characterise the variability of soil moisture content over short distance in peat-moorsh soil and to evaluate of soil water repellency.

The variation in soil water content was studied at Otoczne experimental site located within Kuwasy drainage-subirrigation system in the Biebrza River Valley. The soil of experimental site is classified as peat-moorsh soil. The moorsh layer is underlying by medium decomposed sedge and sedge-reed peat layers. The site is used as an extensive meadow. Volumetric water content was determined by sampling the soil profile at different depths using steel cylinders (volume 100 $cm^3$ and height 5 cm). Fifty-one samples were taken from each of the following depths: 5-10, 15-20, 25-30, 35-40 and 45-50 cm, at close intervals along transects of 300 cm length. The wet soil samples were weighted, dried for 24 hours at 105$^{\circ}$C, and weighted again in order to determine soil water content and dry bulk density. The soil was sampled at six different dates during the vegetation period in 2004. The severity of water repellency was determined using the water drop penetration time test. The measurements were done immediately after the taking of wet weight of the samples. Three drops of distilled water from a standard medicine dropper were placed on the surface of soil sample, and the time required to penetrate into soil was recorded.

The analysis of the soil moisture measurements shows that the coefficient of variation (CV) of the soil water content for five depths in the six trenches varied between 1.75% and 9.44%. Water repellency measured by water drop penetration time test in considered peat-moorsh soil is extremely depended on soil water content.

## SOLUTE TRANSPORT IN SUBSURFACE DRAINED SOIL: NUMERICAL MODELLING AND EXPERIMENTAL APPROACH COMPARISON

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Subsurface drained soils represent about 10% of French agricultural land (3 millions of ha). Tile drain pipe network in waterlogged soils strongly modifies water flow during winter by reducing runoff and restoring infiltration. Thus shallow water table dynamic in superficial soil noticeably influences the transport of agricultural pollutants.

The present work aims to describe and understand the processes of bi-dimensional solute transfer in subsurface drained soil, using tracer monitoring in a metric size experimental laboratory model (MASHYNS: Model of Hydraulic Simulation in Shallow water table). Preliminary experiments have been conducted to characterize the soil hydrodynamic parameters. The hydraulic functioning of the system has been monitored by 46 tensiometers, and is assumed to reach a steady state. Chloride tracer has been injected as a pulse or as an initial uniform resident concentration in the system. The spatial repartition of chemical tracer in the whole system has been possible by designing and installing 26 four-electrode EC probes. Chemical analyses of output-drained water supplement the experiment and validate the EC monitoring.

In the pulse experiment, elution curves show an earlier peak and an asymmetric shape. Compared to a classical mono-dimensional lysimeter experiment, those results confirm that leachate in subsurface drained soil is accelerated at the beginning of the experiment and prolonged at the end by long tailing phenomena. Earlier peak phenomena have often been attributed in literature to preferential flows. In the field, preferential flows are linked to macropores and cracks. Nevertheless in the experimental context (homogeneous porous media), those preferential flows are essentially controlled by the heterogeneity of velocity field, due to tile pipe (considered as a seepage boundary condition). Darcy velocities and gradients are higher near the tile pipe, increasing leachate. They are lower at mid drain spacing, increasing the tail effect.

Resident solute experiments allow determining the residential time of pollutant in the whole system (from surface to bottom, and from mid-drain spacing to above drain pipe). This residential time exponentially varies as a function of distance to the pipe: from a few mm of cumulative drained water (equivalent to few hours in field conditions) to several hundreds mm of cumulative drained water (equivalent to several winter seasons in field conditions).

Those experimental results were used in the modelling part. The classical CDE approach and a simple "particle tracking" method were evaluated.

Experiments and simulations highlight the particular consequences of the bi-dimensional character of water flow and the hydrodynamic influence of the saturated/unsaturated zone. Distribution of the pollutant in the soil profile at the beginning of the leaching period and cumulative drained water are the two major parameters for the understanding and quantification of leachate processes.

# CENTRE OF EXCELLENCE FOR APPLIED PHYSICS IN SUSTAINABLE AGRICULTURE "AGROPHYSICS"

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Research in the idea of sustainable agriculture cover different areas of science including physics, economy, social science, engineering and also politics. Implementation of sustainability in agriculture as the capability of maintaining agricultural productivity and usefulness to society indefinitely requires the cooperation of multidisciplinary specialists. The European Community has recognized the researchers from the Institute of Agrophysics Polish Academy of Sciences as specialists in applied physics and agriculture. The Institute has been honoured as an European "Centre of Excellence for Applied Physics in Sustainable Agriculture: with the acronym "AGROPHYSICS".

The Centre started in March 2003 and it will work in the period of three years. Centres of Excellence are units conducting scientific research, developing modern technologies in accordance with international standards and using the research facilities of cooperating institutions for joint projects. The status of the Centre of Excellence allows the Institute to receive funds from European Union and the Polish State Committee for Scientific Research to support the innovative activities of the Institute, promotion of its research aimed to further development of technologies and products both domestically and abroad.

The overall objectives of the Centre involve:

1) research activities financed from the budget of the Institute of Agrophysics: studies on various aspects of sustainable development of agricultural areas and the effective use of agricultural-food,
2) support activities financed by European Community:
   a) organization of research workgroups, conferences, summer schools, lectures,
   b) international cooperation: scientific exchange with other research Centres (trips, lectures), participation and creation of international research projects under 6$^{th}$ Framework Programme of EC,
   c) development of Agrophysics as a scientific discipline: exchange of experience, unification of research methods and terminology.

The research program of the Centre is focused on the:

1) physical, physico-chemical and biological processes of mass and energy transportation in the "soil-plant-atmosphere" system,

2) physical properties of agricultural materials and the processes influencing plant production,
3) processes related to the harvesting, transportation and storage of agricultural products.

All scientists, young researchers and students interested in the research cooperation, exchange of experience, application of research work in practice, education in the fields presented above are invited to contact with the person responsible for the particular WP for information about the planned schedule of activities. Apart from lectures, workshops, training there are also possibilities to visit the Lublin, the agriculture as well as university centre in Poland.

We hope that the activity of "AGROPHYSICS" Centre Excellence for Applied Physics in Sustainable Agriculture will result in bilateral cooperation between IAPAS and other scientific organizations in the form of short and long-term visits and trainings as well as multilateral research cooperation finalized in generation the research projects of 6th FP of European Union.

Information about the AGROPHYSICS Centre of Excellence is available in Internet at www.6pr.pl/coe/mini/data/5.html and on the IAPAS site www.ipan.lublin.pl .

## DETERMINATION OF PHYSICAL PROPERTIES OF AGRICULTURAL POROUS BODIES WITH THE USE OF THERMOGRAPHY

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This presentation concerns the studies performed in the Institute of Agrophysics Polish Academy of Sciences on application of thermography for determination of physical properties of agricultural porous bodies. The radiation temperature of plant cover was found as an important agrophysical parameter which enables to evaluate the energetic soil water status and the conditions of plant growth. The laboratory and field experiments were the base to evaluate plant water stress and actual evapotranspiration of agricultural areas. A model of actual evapotranspiration is described, basing on the energy balance equation in which radiation temperature of plant cover is a component of sensible heat flux, expressing the transport of heat energy from evaporating surface to the atmosphere. The measurements of radiation temperature dynamic distributions on the surface of bare soil are used to model the processes of heat transport in the soil and to detect the intrusions in the soil profile, e.g. buried mines.

The evaporation from the soil and actual evapotranspiration were modelled for the investigated sites with standard methods, which use basic meteorological parameters as inputs data. The whole day registration of meteorological data was performed with the use of the automatic data acquisition system. It was found that different soil water content distribution in the soil profile strongly influences the radiation temperature of the plants and daily actual evapotranspiration courses.

It was stated that including soil water potential as independent variable of multiple regression into the models of plant cover radiation temperature improves their predictive accuracy in the case when dependent variable is the difference of crop temperature in the conditions of water stress and under unlimited availability of soil water.

## BASIC PHYSICAL CHARACTERISTICS OF POROUS MEDIA AND THEIR DETERMINATION

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Agrophysics is an integral part of environmental physics and it deals with the processes in agricultural used land and processes connected with food production.

Multiphase agrophysical system is complex, therefore:

– it is necessary to adapt measurement methods and models used in other fields of research and apply them to agrophysical media,
– agrophysical measurement methods and instrumentation can be applied in less complex porous media, like building materials, food products, etc.

The majority of physical and chemical processes occur in soil, as a porous body, in the interfaces between the phases with the continuous exchange of mass and energy and water is the main medium generating this exchange. Depending on physical conditions (temperature and pressure) water porous bodies can be in three phases at the same instant. The change of water phases is associated with mass and energy (heat) movement. The processes of heat, water and salt transport in the soil can be described by 3-dimensional non-linear differential equations with coefficients that can be determined experimentally.

The scientists need quantitative information describing the effect of climatic conditions and tillage on the soil. The minimal number of parameters describing the state of soil that are necessary for modeling and consequently prediction are: water status (water content and water potential), temperature, mechanical properties, diffusion of gases and salt concentration. The soil water status (water content and potential) influences the other parameters in the crucial way and its determination seem to be the basic objective.

Fast and accurate measurements of water content of porous media in field conditions are based on the dielectrical properties of water molecules. Their polar nature, expressed by high dielectric constant of water, as compared to other materials of typical porous bodies enables to perform indirect measurement of porous bodies water content. TDR technique seems to be the most promising because of its advantages: simplicity of operation, accuracy and fast response, universal calibration for the majority of soils, non-destructive mode of use, portable systems available and ability to automatize and multiplex probes. TDR technique has also disadvantages: the probes require excellent contact with the soil, probe installation may disturb the soil and the price of TDR meters is still too high. The advantages and popularity of TDR technique are the reasons to make it a standard for soil moisture determination.

The research on the state of soil as a porous material and especially its water content should be developed in the fields:

- measurement methods,
- modeling of water related parameters,
- measurement instrumentation (sensors, portable and not expensive moisture meters),
- standardization of moisture measurement of soil, food and industrial materials.

## INFLUENCE OF PHYSICAL AND CHEMICAL PARAMETERS ON SOIL HYDROPHYSICAL CHARACTERISTICS

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The measurements of the water retention curve and the water conductivity coefficient in saturated and unsaturated zones are time and labor consuming and require a specific instrumentation. Therefore, a general tendency exists to evaluate those characteristics with acceptable accuracy with the use of elaborated physical, mathematical and statistical models and algorithms. The investigations, performed in this direction have resulted in creation of numerous models and algorithms, which enable to evaluate the water retention curve and the values of the coefficient of water conductivity. A large group of these models are pedotransfer functions. In this study the pedotransfer functions elaborated and developed in Poland are presented.

## BULK SOIL REDOX POTENTIAL AND ARSENIC SPECIATION IN THE PORE WATER OF FEN SOILS

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### INTRODUCTION

Field survey data have indicated elevated geogenic arsenic levels in some fen soils developed on Quaternary floodplains of Southern Germany. Current hypotheses relate the areas with maximum arsenic topsoil levels to hydrogeological situations which favour (i) exchange between Tertiary (arsenic-rich sediments) and Quaternary aquifers and (ii) capillary rise of contaminated ground water to surface or subsurface horizons.

In soils, arsenic exists in two redox states differing in both mobility and toxicity. Under oxidising conditions the less toxic and less mobile pentavalent arsenic prevails while under reducing conditions mobile trivalent arsenic predominates. In fen soils, due to high organic matter levels and fluctuating groundwater tables, redox potential ($E_H$) can be expected to be highly variable. To study implications for toxicity and mobility of arsenic, we focussed on the dynamics of soil moisture status, $E_H$, and arsenic speciation in a series of parallel lab-scale column experiments.

### MATERIALS AND METHODS

*Soil and experimental set-up.*

Samples were collected at a degraded fen site, air-dried and passed through a 2 mm sieve. Total arsenic concentrations were up to 1.5 g/(kg soil) and soil pH was neutral. Cylindrical polymethylmethacrylate containers with a length of 28 cm and a void volume of 2 L were filled with soil material from four discrete horizons differing in their proximity to the ground water table. The soil materials were manually compacted to match the bulk densities measured in the field. The columns were instrumented with tensiometers, platinum electrodes, a reference electrode, and nylon suction cups (two depths each). Porous plates equipped with nylon membranes served as the bearing for the packed beds and allowed to apply increasing pressure heads during the experiment.

*Soil moisture dynamics, sampling, and analysis*

The columns were saturated from bottom to top with degassed tap water and successively exposed to lower boundary pressure heads of –10, –25, –50, –100, and –350 hPa to simulate a falling ground water table. During every suction step (3 to 7 days) pore water was collected by suction cup sampling. To minimise system disturbance sample volumes were between 5 and 10 mL. The arsenic species distribution in pore water was determined by an integrated sampling/ion chromatographic separation scheme. Chromatographic fractions were analysed offline by ICP-MS. In addition, the water drained from the columns after each pressure head increment was collected for analyses of pH, EC, major anions, and arsenic. Drainage water samples were analysed by directly coupled ion chromatography/ICP-MS.

*Monitoring of soil redox potential*

The platinum electrodes used for $E_H$ monitoring consist of a Pt wire (1 mm diameter, 20 mm length) connected to a coax-cable. The connector is sealed with two layers of different synthetics to avoid water intrusion under long-term saturated conditions. The sensor and junction are coated with a small carbon fiber shaft 6 mm in diameter, leaving 10 mm of Pt wire uncovered. As a reference an Ag/AgCl electrode was used. $E_H$ values were recorded with a data logger with an electric input resistance sufficient to avoid polarisation of the electrodes. Logger-internal signal multiplexing allowed the use of two Pt-electrodes combined with a common reference electrode. Pt-electrodes were installed at depths of 7 and 21 cm from the column surface (upper/lower half), whereas the common reference electrode was inserted between. Thus, $E_H$ values could be monitored with both a temporal and a spatial resolution. Redox signals were corrected to the standard hydrogen electrode and verified by measuring commercial $E_H$ standard solutions. No pH correction was used since the soil pH was circumneutral throughout.

## RESULTS AND DISCUSSION

All four columns reached a stable redox potential within 10 days of saturated conditions. In the upper half of the columns $E_H$ values were around +150 mV, while values between –150 and –200 mV were observed in the lower half. Differences may be attributed to diffusion of atmospheric oxygen during the experiment. Averaged over depth, the individual columns showed a horizon-specific development of reducing conditions. Apparent redox buffer capacities decreased with proximity to the water table. This is in agreement with longer times of water logging of (mineral) subsoil horizons and the concomitant development of hydromorphic features.

After 10 days of saturation the soil columns were drained by a stepwise increase of the pressure head. In the upper half of the columns, an immediate response of $E_H$ was observed with a fast shift towards oxidising conditions ($E_H$ values between +500 and +600 mV). Averaged over depth the times needed to re-establish oxidising conditions increased with proximity to the water table, corroborating the depletion of redox buffer capacity.

Arsenic speciation was found to strongly respond to redox potential. This holds for both the development of the ratio arsenic (III)/(V) over time within individual soil horizons and its behaviour between horizons at a distinct time. Results are in agreement with the predominance of mobile trivalent arsenic species during water logging. Capillary rise of arsenic-rich ground water as well as contaminant transport driven by redox gradients within the profile may thus explain arsenic enrichment in the surface horizon of the fen soil.

Comparison between pore water samples and drainage water collected during the pressure head steps indicates superiority of the integrated sampling/speciation procedure over the offline approach. The main advantage of the integrated scheme rests with a conservation of the species distribution at the time of sampling. This is particularly important as speciation showed a high sensitivity towards aging of samples, i.e., even when stored under light protection at 4°C the ratio of As(III)/(V) was unstable in a couple of days.

## CONCLUSION

Monitoring of bulk soil redox potential in combination with an integrated sampling/speciation scheme allows insight into the dynamics of arsenic in fen soils and a better understanding of arsenic redistribution within the soil profile. The corresponding equipment should thus be integrated in studies of critical times of water logging or the test of mitigation strategies of geogenic arsenic on a field scale.

## SEASONAL PREFERENTIAL FLOW OCCURRENCE

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Preferential flow is one of the main impacts of water repellency.

The water infiltrates in flow fingers bypassing parts of the soil matrix. The pattern of flow paths and water repellent areas has typical ranges of decimeters. The degree of water repellent areas has a seasonal dynamic and a huge impact on solute transport and ground water recharge.

To study the dynamics a 1.2m wide trench was equipped with TDR probes with 10 cm spacing up to 0.6 m depth. The readings of the 64 TDR probes were stored hourly. These moisture distribution data were processed to sequences, which illustrate the water flow in the topsoil. The degree of preferential flow was analyzed with the beta function for a horizontal cross section in 20 - 30 cm depth. This is the horizon were repellency has the greatest impact on the water flow at this site. The 'effective cross section', which carries 90% of water content change, was determined using the TDR measurements for different precipitation events over the year.

The results show a high degree of preferential flow in summer with an effective cross section of 0.3 - 0.4 $m^2/m^2$ and a more or less evenly infiltration in spring and beginning of winter with a cross section of about 0.7 $m^2/m^2$. In wintertime again a high degree of preferential flow was found. But this time due to frost. The results confirm field observation data and tracer studies on that site.

## THE ABILITY OF CALCARIC REGOSOLS TO NITROUS OXIDE RELEASE AND SINK UNDER FLOODING CONDITIONS – MODEL EXPERIMENT

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Nitrous oxide ($N_2O$) is one of the most important greenhouse gas emitted mainly from biotic sources Soil can remove atmospheric $N_2O$ under conditions favorable for $N_2O$ reduction.

**Table 1.** Main characteristic of the soils.

| Soil type | Texture | O.M. [%] | $NO_3$-N [mg kg$^{-1}$] | pH |
|---|---|---|---|---|
| Calcaric Regosols (No 543) | Sandy loam | 0.88 | 9.78 | 5.99 |
| Calcaric Regosols (No 922) | Silty loam | 1.89 | 5.37 | 3.83 |

**Table 2.** Maximum and daily $N_2O$ release and consumption.

| Treatment | $N_2O$-N mg kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sandy loam (No 543) | | | | Silty loam (No 922) | | | |
| | Release | | Consumption | | Release | | Consumption | |
| | max | daily | max | % | max | daily | max | % |
| Soil + $H_2O$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soil + $NO_3^-$ | **32.19** | 5.37 | 3.44 | 10.7 | **93.23** | 10.36 | 93.23 | 100 |
| Soil + $NO_2^-$ | 42.96 | 1.65 | 0 | 0 | 28.66 | 1.43 | 0.95 | 3.3 |
| Soil + $NH_4^+$ | 1.99 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soil + $N_2O$ | 0 | 0 | **70.58**# | 45.3 | 0 | 0 | **167.32**## | 100 |
| Soil + $N_2O$ + $NO_3^-$ | 19.11 | 6.37 | 13.13 | 7.2 | 70.39 | 7.82 | 231.57 | 99.3 |
| Soil + $N_2O$ + $NO_2^-$ | 24.25 | 3.46 | 5.093 | 2.7 | 18.68 | 4.67 | 26.9 | 15.2 |
| Soil + $N_2O$ + $NH_4^+$ | 2.45 | 0.61 | 77.06 | 47.5 | 1.46 | 0.24 | 162.0 | 100 |

# - 70.58 mg kg$^{-1}$ /26 days = 2.72 mg kg$^{-1}$ d$^{-1}$

## - 167.32 mg kg$^{-1}$/13 days =12.9 mg kg$^{-1}$ d$^{-1}$

$N_2O$ evolution and consumption in Calcaric Regosols developed from loam (No 543 and 922) depending on nitrogen addition and kind of soil were studied. Soil samples (5 g dry soil with 4.5 ml distilled water and 0.5ml of solution of nitrogen like a $KNO_3$, $NaNO_2$ and $(NH_4)_2SO_4$ in concentration 100 mg/kg) were incubated with addition of $N_2O$ (1% v/v) in tightly closed 60 cm$^3$-glass flasks at 20$^o$C for 26 days. Soils without $N_2O$ amendment were control variants. Gas concentrations ($N_2O$, $CO_2$, $O_2$ by gas chromatograph) were measured during incubation in three replications.

# SORPTION OF NITROUS OXIDE ($N_2O$) AND DEHYDROGENASE ACTIVITY – MODEL EXPERIMENT

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Biological denitrification is a respiratory process in which N-oxides (electron acceptors) are enzymatically reduced under anaerobic conditions to nitrous oxide and dinitrogen for ATP production by organisms that normally use $O_2$ for respiration. Soil can produce and remove atmospheric $N_2O$ under conditions favorable for $N_2O$ reduction. Soil dehydrogenase activity is related to microbial populations, respiration activity and soil organic matter. It has been shown close relation between dehydrogenase activity and soil denitrification process.

$N_2O$ consumption and dehydrogenase activity in Calcaric Regosols developed from sand and loam (No 543 and 922) depending on nitrogen addition and kind of soil were studied. Soil samples (5 g dry soil with 4.5 ml distilled water and 0.5ml of solution of nitrogen like a $KNO_3$, $NaNO_2$ and $(NH_4)_2SO_4$ in concentration 100 mg/kg) were incubated with addition of $N_2O$ (1% v/v) in tightly closed 60 $cm^3$-glass flasks at $20^oC$ for 26 days. Soils without $N_2O$ amendment were control variants. Gas concentrations ($N_2O$, $CO_2$, $O_2$ by gas chromatograph), soil dehydrogenase activity were measured during incubation in three replications.

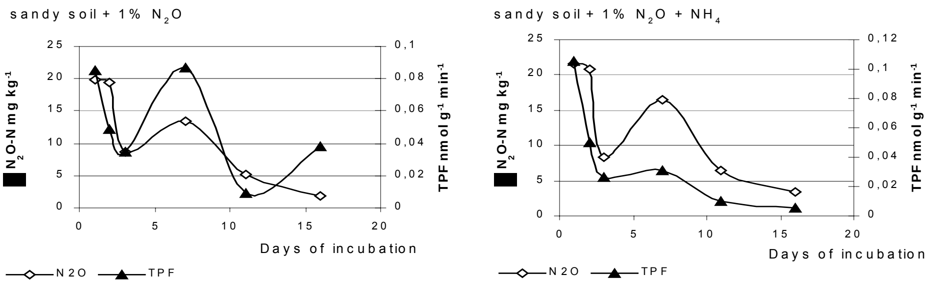


***Fig.1.*** *Nitrous oxide sorption and dehydrogenase activity in soil developed from sand with $N_2O$ and NH4+addition.*

Completely different relationship between dehydrogenase activity and $N_2O$ sink was observed in the soil developed from loam (Fig. 2)

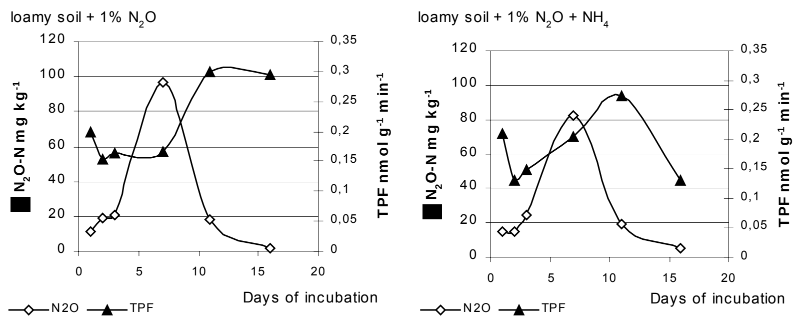


***Fig.2.*** *Nitrous oxide sorption and dehydrogenase activity in soil developed from loam with $N_2O$ and NH4+addition*

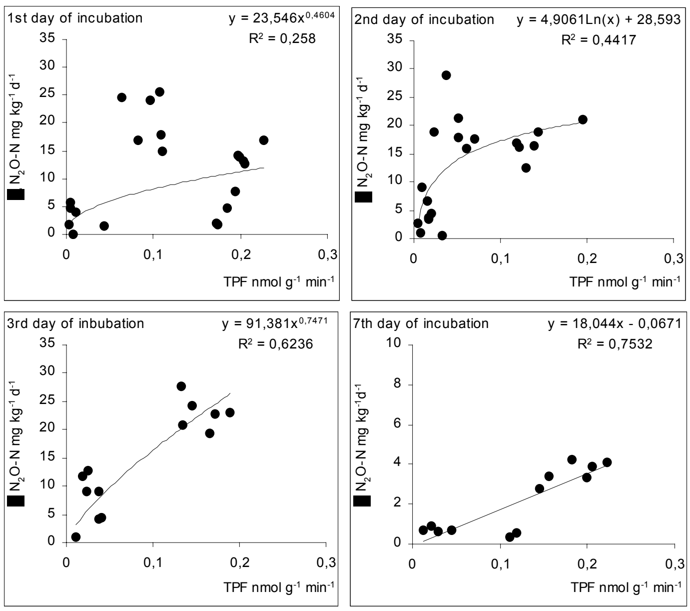


***Fig. 3.*** *$N_2O$ sink versus dehydrogenase activity*

$N_2O$ sorption ability showed high significant positive correlation with dehydrogenase activity (Fig. 3).

# POSTER PRESENTATIONS

## APPLICATION OF THERMOGRAPHY FOR EVALUATION OF PARAMETERS CHARACTERIZING SEED AND FRUIT QUALITY

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In the Institute of Agrophysics Polish Academy of Sciences the investigations have been performed to apply thermography for determination of quality of plant materials. This paper presents the methodology of the radiation temperature measurement of the chosen fruit and seed material. The results of the studies of germination capacity of leguminous plant seeds and the impact of the firmness of the fruit tissue and the extract content on thermal response of the fruit surface in the heating process are presented. Furthermore the application of thermal imaging for detection of apple bruises is described.

The extensive research on finding new methods of investigation of the seed germination capacity is awaited because germination tests used these days require long time of waiting for the result and in case of rare species cannot be used at all because a representative number of seeds has to be at disposal. The proposed in this paper use of the thermographic method for the evaluation of germination capacity of leguminous plant seeds enables to shorten the time of the selection process and can be performed on individual seeds.

The mechanism of water uptake in the process of swelling is different in case of healthy, dead and sick seeds. This fact has its representation in the energy balance of the seed surface. The created method is based on monitoring the heat conversion in the early stages of water absorption in the seed, which has its representation in the changes of radiation temperature of seed surface during the swelling process.

Thermal properties of fruits (thermal diffusivity) are strongly influenced by the composition of its tissue and in case of any disturbance caused by mechanical or physiological factors they are considerably modified in some parts of fruit. These changes of thermal properties have impact on the rate of temperature changes under temperature gradient occurring between the surrounding and the fruit. It was confirmed that thermography is a good tool for detecting apple bruises as well as translucence (glassiness) of the fruit flesh.

The seed material included some varieties of soya bean, vetch, pea, navy bean, snap bean and broad bean coming from different years of harvest, so that the seed material was characteristic for different storage periods, including the time after which seeds lose their germination capacity. During the experiment a standard method of testing the germination capacity was applied for the seeds of the investigated varieties, to be compared with the new method based on thermography measurement. Three varieties of apple were acquired: “Gloster”, “Jonagold” and “Ligol”, differing with density, skin colour and size.

The measurements were performed in settled and controlled external conditions. This required thermo stabilisation of laboratory and installation of the sensors of air temperature humidity and pressure. The system of registration and processing of infrared and visible range images consisted of AGEMA 880 LWB and two CCD cameras. It enabled to measure the radiation temperature with the accuracy of 0.1ºC.

The rapid development of infrared technology and its increasing availability for users, let us think, that methodical and practical results of the initialised studies in the form of ready measurement procedures and determination of the relation between radiation temperature of seed or fruit material and the parameters of their quality evaluation, will find use in plant material storage and breeding.

This paper is prepared in frame of Project No. 3P06R 092 22 financed by Polish State Committee for Scientific Research.

## VOLTAMMETRIC ESTIMATION OF POTENTIAL OXYGEN FLUX DENSITY IN THE SOIL

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Oxygen conditions in the soil are, among the water content and the availability of nutrients, one of the most important factors stimulating the growth of roots and respectively the development of the whole plants. From many quantities, characterizing the soil aeration, the most important are the oxygen concentration and the oxygen flux that can flow in specific conditions in a given soil. Especially the latter parameter seems to be important, because it enables to evaluate simultaneously the availability and the speed of replenishment of the used oxygen in the plant roots.

Determination of the potential oxygen flux in the soil is possible, between others, with the use of voltammetric method. It consists in registration of the current-voltage curve, i.e. the dependence between the current and the potential on the cathode, *I(U)*. When the oxygen flux magnitude is limited by the diffusivity of the medium, what manifests itself in the occurrence of the plateau area in *I(U)* dependence (in fact the plateau never occurs because the nearly always there is a slope in this dependence and it is accepted to use the term of quasiplateau), the calculated integer of the function *I(U* in the quasiplateau area is recalculated into the oxygen flux in the soil. The quantity, determined this way is called OFD (oxygen flux density).

The application of the voltammetric method was an improvement of previously realized amperometric measurements of the potential oxygen flux in the soil proposed by Lemon and Erickson and called ODR (oxygen diffusion rate).

## PROBLEM OF A QUALITY OF AGROPHYSICAL RESEARCH

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Agrophysics is rather new interdisciplinary branch of science that was originated from agronomy in late fifties of 20th century. The etymology of the word “agrophysics” indicates the subject of the investigation (soils, plants, plant and animal materials) as well as the scientific methods, specific for physics and all the natural and technical sciences (precise defining of the studied values, measurement, monitoring, analysis, interpretation and modelling).

Despite the definition of agrophysics still undergoes changes and is being improved in many discussions, one considers the agrophysics as an interdisciplinary science that applies physical methods for research of properties of agricultural materials and products, sustainable plant and animal production, modern food processing technology, especially concentrating on the quality of substrates and food products, as well as for studying processes in the soil-plant-atmosphere, and plant-machine-crop systems.

As this holds for other natural sciences, the activity of agrophysicists can be divided into two general groups. The first is connected with the development of new and the adaptation of the existing methods for agrophysical purposes. The second group is connected with application of these methods. The present article is addressed to researchers working in both the above groups. Its aim is to begin a discussion on the quality of agrophysical research.

Agrophysical methods have their own specific character that is not always met in the other branches of science. As one of the important aspect of this specific character one can regard the enormous diversity of the studied objects. Examples are two of them, being classified by the agrophysics as granular-porous media: soil clay fraction of micrometer dimensions where microscale transport, diffusion and adsorption processes are studied and a grain silo of hundreds tons capacity for which much effort is directed on its macroscale properties as a way of filling and emptying to minimize lost of quantity and quality of the stored material.

The second, even more important aspect of the specific character of agrophysical research, is a space and time variability of the studied objects. Agrophysics studies properties of the objects themselves, as well as the processes taking place within and among the objects. Main groups of objects under the interest of agro-physics are presented in Fig. 1. Majority of these objects can be treated as living organisms or their residues. So the space and time variety of agrophysical objects may be very high and dynamic.

To characterize the quality of the measurements one should define a client i.e. the recipient of the results. Three main groups of the clients of the agrophysical studies can be listed as follows:

- government – in case of research realized in the frame of the statutory activity of agrophysics-related institutions and/or for state-financed projects
- other institutions (because of not buying the results, according to the regulations these are better defined as consumers) by studying the literature and conference presentations
- industry – both by studying the literature and conference presentations and by financing research projects

As a rule, various clients receive the same results.

The quality of all research results (including agrophysical) lies on three „pillars": validation of measuring methods, estimation of the result uncertainty and traceability. This is worth noting that all the above elements are closely interrelated.

# MECHANICAL PROPERTIES OF AGRICULTURAL GRANULAR MATERIALS

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## GRANULAR MATERIALS

In recent decades increases in the number of processes and operations involving granular materials have resulted in a growing need for new theory and technology. This was accompanied with growing interest in investigations of physical properties of granular materials. Elaboration of effective design methods of technological processes requires detailed knowledge of physical properties of the processed material as well as proper understanding of their interrelations with construction materials. Development and refinement of methods for determination of physical properties of granular materials is becoming particularly important. Despite unquestionable progress in development of measurement methods mechanical properties of granular materials measured in various laboratories can vary greatly. A significant source of the wide range of results is due to the large number of measurement methods and a lack of standard experimental procedures. Moreover some influencing factors such as moisture content, bulk density, packing structure and load history remain out of control that contribute to observed variability.

Granular materials of biological origin constitute a coherent group of materials distinguished by large deformability of particles and strong dependence of their mechanical properties on moisture content. Contrary to materials of mineral origin, moisture penetrates inside grain, leading in some cases to qualitative changes in physical properties.

## POROSITY AND PACKING

Porosity strongly influences properties of granular material. Method of filling test apparatus with wheat that resulted in a decrease in porosity increased the airflow resistance by an order of magnitude. The effect of grain orientation that would be typical in storage bins was negligible, less than 10% in airflow resistance.

A great deal of work has been done to develop a usable theory o gravity flow of granular materials. The most widely accepted approach was developed by Jenike (1961). The author further refined the approach, but his original testing method and interpretation is still the basis of many codes of practice and later investigations by other researchers. Jenike method (also termed as direct shear test) give as a result of determination the parameters of internal friction (also termed strength parameters) – cohesion (c), angle of internal friction (φc) and effective angle of internal friction (φc). In our testing the method of sample deposition was found to have significant influence on both force-displacement characteristics and coefficient of internal friction. Stress history had considerable influence on the rate of friction force increase. The angle of internal friction of cereals was found to be influenced by the initial orientation of non-spherical grain in the test specimen. The maximum change in the angle of internal friction for wheat was found of approximately 4 degrees.

AGRICULTURAL GRANULAR MATERIALS

Granular materials of plant origin differ from mineral materials in strong susceptibility to moisture changes as well as in deformability of particles. With the moisture content increase of cereals the angle of internal friction increased in a range from 22° in the case of 10% m.c. oats up to 35° for 20% in m.c. wheat. The lateral to vertical pressure ratio decreased with an increase in moisture content and was found in the range from 0.30 in the case of 20% in m.c. corn up to 0.49 for 10% in m.c. oats. Effect of deformability of grain brings difficulties in testing of strength of cereal grain of increased moisture content. For such a material stress-strain curve did not level until relatively high displacement. For direct shear test on wet grain (up to 20% of m.c.) the shear path had to be elongated up to 0.1 displacement-to-sample diameter ratio (as compared to 0.05 – Eurocode 1 recommended).

FLOWABILITY AND PARTICLE SIZE DISTRIBUTION

Flowability is a measure of the quality of granular product that influences its end-use value for some materials used in the chemical, mineral, pharmaceutical and food industries. Variation in flowability of ingredients is a significant source of errors during the weighing and proportioning, resulting in non-uniformity in the finished product. A number of food powders were tested for flowability with maximum consolidation pressure of 100 kPa. The flow functions of all tested materials took values characteristic for free flowing and easy flowing materials. Flowability of wheat meal was tested with increasing content of fines (particles of size from 0.1 to 0.2 mm). Addition of 25% of fines resulted in a higher than two-fold increase in flow function. Content of fines was also found to influence significantly compressibility of the meal. In uniaxial test basic material reached maximum vertical pressure at strain of 0.05, while the material containing 25% of fines reached maximum stress at a strain of 0.07.

## MEASUREMENT AND MODELLING OF THE TDR SIGNAL PROPAGATION THROUGH LAYERED DIELECTRIC MEDIA AND OF THE EFFECTIVE PERMITTIVITY OF SANDY SOILS

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Layered dielectric materials are often encountered in the natural environment due to differences in water content caused either by a wetting or drying front. This is especially true for coarse-grained materials such as sandy soils, sediments and some rocks that have very distinctive layers of water content. This poster examines the issue of how the permittivity along a TDR probe is averaged as a function of layer thickness and probe orientation. Measurements of apparent permittivity, $K_a$, using TDR are presented for two, three and multi layer materials. TDR waveforms are modeled for multiple layers of varying thickness and show a change in the averaging of the apparent permittivity from refractive index to arithmetic when more thin layers are present. Analysis of the modeled results shows that the averaging regime is frequency-dependent. However, broadband techniques applied to materials with a few layers will generally produce refractive averaging. A transition to arithmetic averaging is found for systems having many (>4 layers). Narrow-band methods may be very sensitive to layering and may perform in a highly non-refractive way when layering with a strong permittivity contrast is present.

Many empirical formulas relating TDR-measured permittivity, $K_a$, to volumetric water content (θ) have been proposed owing to the lack of a robust and accurate physically-based model describing this relationship across a range of soils. Soil-specific calibrations are often infeasible due to the time-consuming gravimetric sampling required for adequate calibration where limited resources often prevail. In this poster we propose a physically-based sample scale model for the permittivity - water content relationship in coarse-grained media using physically-based particle- scale or calibrated two-point anchoring. Materials tested include mono-size glass spheres and quartz sand grains in addition to two sandy soils. The physically-based model accounts for particle shape and bulk density using a two-phase, particle scale mixing model and refers to a wetting or draining profile with a sharp wetting or drying front. Our measurements indicate the absence of dielectric hysteresis for the materials studied. An alternate calibration approach only requires the measured soil effective permittivities for dry and saturated conditions (i.e., two-phase mixtures) and knowledge of the bulk density. For the effective permittivity of dry sandy soils we recommend to use a common value of $\varepsilon_{dry} = 3$. The results provide insight into the appropriate "refractive index" modeling of layered (wetting/drying) soil profiles with the grain-scale modeled two-phase permittivity providing bounds for the sample-scale three-phase porous medium.

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## MONITORING OF SOIL WATER STATUS AS AN IMPORTANT ISSUE OF AGROPHYSICS

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Soil physical parameters change continuously for climatic reasons and human activity as well. Mineral composition, grain distribution and humus content are practically not affected by spatial and temporal change. Human activity: organic and chemical fertilization, as well as mechanical influence modify the variable parameters of the soil solid phase including: organic matter content, aggregate distribution and soil compaction. The basic quantities describing the soil physical status in the quantitative way are: soil water content and potential, soil temperature, mechanical properties: texture and porosity, gas diffusion, salt concentration and ions activity.

The most important soil physical property for the monitoring, directly influencing the others is soil water content, therefore the majority of agrophysical measurements should be done with parallel determination of soil moisture.

The progress in soil water content monitoring is connected with the development of:

- sensors (selective, accurate, not disturbing the measured property, equipped with intelligence – "smart sensors"),
- measurement instrumentation (field, portable, with high data storage capacity, not expensive and reliable),
- global exchange of information using radio connections, Internet access and Global Positioning System facilities.

Recent advances in the implementation of TDR technique in soil moisture measurements and the growing offer of measurement instrumentation give a chance to replace laborious and time consuming gravimetric method with a new standard. The physical principle of moisture measurement of porous bodies including soil is, although simple to understand but difficult to implement because of technical complexity. There is still a lot to do in the field of calibration of various soils, validation the soil dielectric mixing models, sensor construction and decreasing the price of TDR meters. The development of high frequency mobile telecommunication greatly supports new instrumentation designs in TDR soil moisture metrology giving the chance for price decrease.

Soil water content measurements in real time with the application of monitoring networks can be applied in precision agriculture to optimize the use of fertilizers, simplify irrigation scheduling and increase environmental security.

## CALIBRATION OF TDR INSTRUMENTS FOR MOISTURE MEASUREMENTS OF AERATED CONCRETE

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Moisture condensation in the building barrier is a normal phenomenon and practically inevitable in our climatic zone. Large amount of water occurring in barriers is disadvantageous from as well construction as hygienic-sanitary point of view. Water penetrating the pores of building material is one of the biggest problems during winter. When moisture content is high, numerous freezing and thawing causes material disintegration and decrease of its bearing parameters.

Too much water in building structure during wintertime causes also decrease of its insulating parameters, which leads to indoor temperature decreases and generates extra expenses for heating. All disadvantages mentioned above indicate the need to elaborate an easy and possibly low-invasive method for measurements of moisture in porous building material.

For measurements of building materials moisture levels we apply TDR method. TDR (Time Domain Reflectometry) is a well-developed and commonly used method for measuring of moisture level in soils.

There are some factors causing difficulties with precise measurements of water content in the materials. The most important problem seems to be the fact that dielectric constant of mineral material may vary depending on kinds of material, which may lead to need to calibrate measuring instruments to obtain accurate results for specific material.

The major aim of this article is to present TDR measuring method as a tool to measure changes of water content in building materials, propose a way of calibration for measurement needs and present data and calibration curves for aerated concrete block as a commonly used building material.

The formulas and curves are established on a base of gravimetrical experiments with constant measurements of TDR signal propagation in blocks of aerated concrete.

We prepared calibration curves for most popular densities of aerated concrete in Polish building market: 400 kg/m$^3$, 500 kg/m$^3$, 600 kg/m$^3$, 700 kg/m$^3$. It is possible to use calibration curves in measurements of moisture profiles in the buildings.

Application of other probe construction may enable adoption of this method for building materials – much harder and aerated concrete, but it is necessary to find a proper installation and calibration method that will make it possible to measure most of common materials in Polish building market. This paper seems to be a step to this extensive topic.

## INFLUENCE OF PREPARATION OF MUCKS SAMPLES ON THEIR POROSITY

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One of the important features needed to characterize porous materials is their porous texture. The structure of single-grained soils can be considered quantitatively in terms of the total porosity and of the pore size distribution. Pore size distribution is one of the most important characteristics of the soil material. Many of the fundamental chemical and physical properties of soil are strictly related to the size, shape and orientation of colloid particles. Soil pores affect transport of gases, water and nutrient ions needed for plant growth and ease of root penetration. Investigations of the variation of pore size upon wetting are useful for understanding of moisture characteristic and freezing behavior of soil water.

Several classifications of pores according to shape and size have been proposed. The classification recommended by IUPAC divides pores roughly into the following groups: (i) micropores with dimensions <2.0 nm, (ii) mesopores in the range of 2.0-50 nm and (iii) macropores with dimensions >50 nm. This classification is somewhat arbitrary and has been developed mainly in relation to the adsorption of nitrogen at its boiling point.

Pore size distribution measurements can be made in coarse-grained soils by means of the pressure-intrusion method, in which a non-wetting liquid (generally mercury) is forced into the pores of a pre-dried sample. In the case of fine-grained soils, capillary condensation method (desorption method) is applied. Gas adsorption measurements are widely used for determining the surface area and pore size distribution of a variety of different solid materials.

Most methods for the determination of structure require the soil to be freed of water and yet to retain its original character. Prior to the determination of an isotherm, it is usually to remove all physisorbed material. The exact conditions required to attain a clean surface depend on the nature of the system. For the determination of the surface area and mesopore size distribution by nitrogen adsorption, outgassing to a residual pressure of about 10-4 Torr is considered acceptable. Inorganic oxides are usually outgassed at about 150 ºC while microporous carbons and zeolites require higher temperatures (about 300 ºC). Shrinkage is usually the evidence of changes in pore size distribution of soil sample during drying, but it is not be sufficient evidence of changes in the pore volume of a particular range of equivalent radii. On the other hand, the absence of any shrinkage is not equivalent to the lack of any changes in soil structure. In the case of skeletal arrangement, in spite of little shrinkage during drying, clay particles coat the grains and drying increases the average pore size.

The evidence of lack of sample destruction during drying and/or mercury intrusion could be the agreement between the results of this method and the results of other, which do not constitute essential limitations in this context.

The study was conduced on muck taken from upper layer of peat-muck profile located on grassland in Lublin Polesie region. The pore size characteristics of muck samples were calculated from adsorption isotherm of nitrogen and from the mercury intrusion curves. Before the measurement the muck samples were pre-dried at different temperature.

Carlo Erba mercury Porosimeter Series 2000 was used to determine the pore size and pore volume distributions in range from 3.7 to 7500 nm radius by mercury intrusion. The samples were dried by owen-drying at 105C and then outgassed before mercury intrusion. Using the computer program Milestone 100 and cylindrical pore model the bulk density, pore surface area, average pore radius and total porosity were calculated.

The adsorption-desorption isotherms of nitrogen gas at liquid nitrogen were obtained with Sorptomatic 1990 (Fisons) apparatus. Before adsorption measurements one soil sample was dried at 105 ºC and outgassed under vacuum, the next one was only outgassed overnight at the room temperature. The pore parameters of investigated soil samples were evaluated by computer program Milestone 200. The micropore volume was calculated from Dubinin-Radushkevich equation (DR), applied to desorption isotherm data over a limited range of relative pressure (below the onset capillary condensation).

The pore size distribution calculated for given muck samples pre-dried at different temperature from both measuring methods differs markedly. It has been found that drying temperature influenced the obtained values. The variations in pore size characteristics seem to due to complicated geometry of organic matter or by heterogeneous character of samples.

## SPATIAL DISTRIBUTION OF SOME PHYSICAL PROPERTIES IN RELATION TO SOIL COMPACTION

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Spatial variability of soil environment is a resultant of physical, chemical and biological processes, including geological and pedological ones and anthropogenic activity. Effects of natural and anthropogenic processes on the spatial variability are not well understood. Anthropogenic effects are associated with significant effects of excessive topsoil and subsoil compaction by agricultural machinery traffic on hydrological, thermal and air relations of soil.

Disregarding the spatial variability of the soil environment can lead to physical and chemical degradation of soil and reduced efficiency of cultural practices that lead to limited plant growth and reduced crop yield. In addition, these increase costs of chemical application and enhance adverse impact on soil and atmosphere environments. Understanding spatial variability of soil will allow more detailed description of physical phenomena and minimize their adverse effects on soil environment. The aim of this study was to assess spatial distribution of thermal properties of sloping soil under grass covered and conventionally cultivated vineyard.

The experiment was carried on at a Piedmont's hillside viticulture (N-W Italy), 450 m elevation with average slope of 20% and south/south-west aspect. The climate is characterized by rainfall averaging 840 mm and cold and snow winter and dry summer with rainstorms. The vineyard, with rows following the contour lines, lies on silt loam soil containing on average 33% sand, 58% silt, 9% clay. Two treatments that is permanent grass cover and cultivation treatment were applied in the vineyard inter-row of 2.7 m width. Organic matter content was 4.7% and 3.4% on grass covered and cultivated soil, respectively. Corresponding values for particle density were 2.60 and 2.62 Mg m-3. In both treatments the crawler tractor (Fiat 55 CV) of 2.82 Mg weight and 1.31 m width was used for tillage and chemical operations along the inter-rows across the slope at the same locations. The width and length in contact with the ground of each track were 0.3 m and 1.4 m, respectively.

The measurements of soil water content and bulk density in each treatment were done in autumn 2001 in places corresponding to upper rut, inter-rut and lower rut areas along the slope and vine-rows on 30-m long four transects. Mean daily topsoil temperature was about 20°C while sampling. Soil cores of 100 cm3 were taken from the depths of 1-8, 9-16 and 17-25 cm. It was observed that in cultivated soil rut depth under the lower vs. upper track was more than twice higher due to greater ground contact pressure in the former as a result of tractor's tilt on the slope. Similar effect was observed in grass covered soil but the differences between the tracks were smaller.

The thermal properties were determined with statistical-physical model of thermal conductivity and empirical formulae for heat capacity and thermal diffusivity. The determination was performed at 4 soil wetness corresponding to: dry state, current soil moisture content, field water capacity and saturated with water.

It was found that bulk density and its range and standard deviation of soil under grass cover were greater than under conventionally cultivated vineyard. The variability was highest for current soil water content and it was lower and similar at field water capacity and water saturated soil under both treatments. Thermal conductivity and heat capacity tended to increase with increasing soil wetness. Thermal diffusivity reached maximum in the range of soil wetness between current soil moisture content and that at field water capacity. The highest variability of all thermal properties occurred at current soil moisture content and it was much lower in dry soil. In water saturated soil the least variable were thermal conductivity and heat capacity and at field water capacity – thermal diffusivity.

Distributions of the thermal properties in the grass covered and cultivated inter-rows were dependent not only on distribution of soil compactness but also on distribution of soil water content along the slope. Relative effect of bulk density and soil water content was associated with method of vineyard management and kind of the thermal property.

## PARTICLE SIZE DISTRIBUTION IN SOILS FROM LASER DIFFRACTION AND SEDIMENTATION METHODS AND THEIR INITIAL COMPARISON

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Particle size distribution is one of the most fundamental soil characteristics, which directly affects many physical and chemical soil properties. On the base of particle size distribution one can estimate other soil properties such as: water retention and water conductivity coefficients in saturated and unsaturated zones.

For over 100 years particle size distribution has been used to describe similarities and differences between soils. Nowadays, about 400 methods are known, used for measuring particle size distribution. The most frequently used are sieve, pipette and areometer methods. Pipette and areometer methods are also known as sedimentation methods. All the above mentioned methods are imperfect and time consuming. An alternative method for measuring the particle size is laser diffraction method. The angle at which the light is scattered by a particle is inversely proportional to the size of the particle. The theory of Mie, which describes an interaction between laser light and particles, is used to convert data from laser light diffraction to particle size distribution.

Institute of Agrophysics PAS disposes Malvern Mastersizer 2000 which measures particle size in a large range: 0.02–2000 mm (in liquid dispersion) on the base of laser diffraction method. This method does not yield identical particle size distribution with sieve and sedimentation methods, which were used before. Each of these methods is based on different principles and assumptions, and uses different approximations. Results from laser diffraction method and the sieve and sedimentation methods cannot be directly compared because the laser diffraction method underestimates sand and clay fractions and overestimate the silt fraction.

The objective of our study is to determine the equations of regression, which make possible to compare particle size distribution from sedimentation and laser diffraction methods.

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