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RELATIONS BETWEEN AERATION STATUS AND PHYSICAL PARAMETERS OF SOME SELECTED HUNGARIAN SOILS

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A b s t r a c t. The present studies were performed with the use of soil cores representing three Hungarian soil units characterized as Fluvic Gleysol, Vertic Gleysol and Ortic Solonetz under diversified land use practice. Relative gas diffusion coefficient (D/D_0), air permeability (k), air-filled porosity (Eg) and water content (W) of the soil were correlated with its aeration indices such as ODR and Eh. Threshold values of soil physical conditions ensuring appropriate aeration conditions in the soil were determined.

K e y w o r d s: relative gas diffusion coefficient, air-filled porosity, air permeability, water content

INTRODUCTION

Soil is defined as an unconsolidated natural material on the surface of the earth that has been subjected to various environmental factors. The main aspect of the soil physics is preserving appropriate proportions between the soil solid, liquid and gaseous phases. Soil physical properties and processes are closely interconnected to a higher or lower degree. Disturbance in the equilibrium oxygen concentration of the soil often resulted in the lack of beneficial conditions for plant development and growth. The above condtions are affected by the soil texture, structure, bulk density, aggregation, pore size distribution, air composition, profile characteristics, etc. Soil characteristics are the most important input parameters for the oxygenation model.

The amount of air in the soil determines not only the reserve of oxygen present, but primarily, the value of the oxygen diffusion coefficient. Therefore, it affects the rate of gas exchange in the soil which, together with the rate of soil respiration, determines composition of the soil air.

While considering the process of gas diffusion in the soil, it is necessary to distinguish macrodiffusion, i.e., diffusion in the whole soil profile disregarding soil heterogenity in the microscale, and microdiffusion through water films surrounding plant roots. Principles and the theory of gas diffusion in a porous body are widely discused by Gliński and Stępniewski [5].

Linn and Doran [7], observed that bulk density, volumetric water content and water-filled pore space were similarly greater for the surface no-till soils than for the conventionally tilled soils. Differences in the soil aeration between different tillage-management systems may influence the number and activity of microorganisms. Doran [1] observed that the number of anaerobic microorganisms decreased only a little with the depth in the no-till soils, and were generally greater at a depth of 75 to 150 mm as compared to the ploughed soils. This led Doran and Power [2] to the conclusion that greater soil water contents and bulk densities often associated with no-tillage, limited oxygen diffusion into the soils, thus establishing a less-aerobic environment as compared to the ploughed soils.

A relative gas diffusion coefficient, air-filled porosity, air permeability and moisture content are very important parameters, decisive for the course of several processes significant from the point of view of plant production for which soil aeration is particularly important.

In the present paper laboratory studies of the relative gas diffusion coefficient (D/D_0), air permeability (k), air-filled porosity (Eg), and moisture content by mass (W) of the soil extended by studies of oxygen diffusion rate (ODR) and redox conditions (Eh) were performed in order to characterize the investigated soils and to establish relations among these parameters.

Undisturbed soil cores from six Hungarian profiles representing three soil types, and two types of cultivation (four horizons of each of the investigated profiles) after preincubation under controlled air - water conditions on suction plates were used in the studies.

MATERIALS

The experiments were carried out with soils from the middle region of the Great Hungarian Plain in the Transtisza Region of Hungary. The investigated area is one of the lowlands of the Carpathian Basin [9].

The investigated sites are situated within the natural geographical region of Nagykunsag (Great Kunsag). The profiles selected for the investigation represent three soil units characterized as Fluvic Gleysol, Vertic Gleysol and Orthic Solonetz. Each soil unit was represented by two profiles: one taken from a natural uncultivated site and the other from a cultivated site in its vicinity:

A-1 Abadszalok: alluvial meadow soil (Fluvic Gleysol), cultivated, ploughed yearly to the depth of 25-30 cm and deep-loosened to the depth of 80 cm every 4th year. Last loosening before sampling was performed in 1983.

A-2 Abadszalok: alluvial meadow soil (Fluvic Gleysol), the same as A-1 but non-cultivated during the 10 last years. Both sampling sites are drained by a subsurface drainage system of 90 cm depth and 25 m spacing.

K-1 Kisujszallas: meadow soil (Vertic Gleysol), subjected to 25-30 cm normal ploughing yearly and 80 cm deep loosening every 4th year. Last deep loosening in 1987.

K-2 Kisujszallas: meadow soil (Vertic Gleysol), with 25-30 cm normal ploughing and deep loosening every 4th years. Last deep loosening before sampling was performed in 1990.

P-1: Karcagpuszta: Shallow meadow solonetz (Orthic Solonetz), non-cultivated.

P-2: Karcagpuszta: ameliorated meadow solonetz (ameliorated Orthic Solonetz), 15-20 cm chiseling/discing yearly, 60 cm deep-loosening every 4th year. Subsurface drainage at the depth of 100 cm with 25 cm spacing. Gypsum application to the A + B horizon according to the gypsum requirement calculated on the basis of exchangeable sodium percentage [9]. Last deep loosening before the sampling procedure was performed in 1987.

METHODS

Undisturbed soil samples in 100 cm^3 brass cylinders (51 mm in diameter and 49 mm heigh) were collected in the late autumn of 1991 and than transported to Lublin in January 92. The measurements of all the above mentioned parameters were taken at the soil moisture tensions of 0 hPa (capillary saturation for 7 days for the heaviest profile from Abadszalok, and for 2 days for the other profiles), 63 hPa (pF 1.8), 159 hPa (pF 2.2), and 500 hPa (pF 2.7). Three undisturbed soil cores representing each of the horizons after capillary saturation were equilibrated with particular soil moisture tensions on kaolin tension plates. At each equilibrium D/D_0 and k values were measured. When these measurements were completed the cylinders were resaturated and, after subsequent equilibrations with the tension plates, used to determine ODR and Eh.

Their basic soil properties are presented in Table 1 and descriptions and characteristics in the paper of Gliński [3].

T a b l e 1. Basic soil characteristics

Profile	Horizon (cm)	Particle size distribution			Bulk density (Mg m^{-3})	pH		O.M. (%)
		Sand (2000-50 μm)	Silt (50-2 μm)	Clay (<2 μm)		H_2O	KCl	
Abádszalók-plough cultivated and deep-loosened (A-1)	A (0-20)	15.6	36.6	47.8	1.2	5.9	4.8	3.3
	B (21-60)	13.9	32.3	53.8	1.3	6.3	5.1	1.6
	BC (61-80)	17.6	29.8	52.6	1.4	6.7	5.4	0.8
	C (81-120)	43.6	24.6	31.8	1.5	7.2	6.1	n.t.
Abádszalók-uncultivated (A-2)	A (0-20)	13.7	33.9	52.4	1.2	6.2	5.2	2.5
	B (21-60)	11.7	31.7	56.6	1.3	6.4	5.2	1.3
	BC (61-80)	19.2	28.2	52.6	1.5	6.7	5.5	1.0
	C (81-120)	41.9	23.7	34.4	1.4	6.9	6.0	n.t.
Kisújszállás-plough cultivated (K-1)	A (0-30)	18.6	35.4	46.0	1.3	6.4	5.8	3.2
	B (31-50)	15.8	32.6	51.6	1.4	6.6	5.8	1.9
	BC (51-110)	13.2	30.8	56.0	1.5	7.3	6.3	0.07
	C (91-110)	11.2	45.4	43.4	1.5	7.4	7.0	n.t.
Kisújszállás- plough cultivated and deep-loosened (K-2)	A (0-30)	20.2	35.2	44.6	1.3	6.4	5.8	3.2
	B (31-50)	12.2	42.8	45.0	1.4	7.5	6.7	0.3
	BC (51-80)	10.6	47.6	41.8	1.5	7.7	7.1	0.5
	C (81-130)	28.2	25.8	46.0	1.5	6.7	5.7	n.t.
Karcagpuszta-unculti-vated with natural vegetation (P-1)	A (0-20)	24.2	34.0	41.8	1.4	7.4	6.9	1.5
	B (21-40)	13.4	35.2	51.4	1.6	9.0	7.4	0.6
	BC (41-70)	16.0	32.2	51.8	1.6	8.1	6.9	1.2
	C (71-85)	5.4	52.4	42.2	1.6	9.0	7.8	n.t.
Karcagpuszta-culti-vated, deep-loosened, chiseling/discing (P-2)	A (0-20)	20.8	34.0	45.2	1.4	7.8	6.9	1.4
	B (21-50)	14.0	29.2	56.8	1.5	8.4	7.1	0.5
	BC (51-70)	12.4	33.2	54.4	1.5	8.7	7.5	0.4
	C (71-95)	11.4	49.2	39.4	1.6	9.0	8.0	n.t.

O.M. organic matter, n.t. - not tested.

The measurements of relative gas diffusion coefficient (D/D_o) were performed according to unstedy - state method of Stêpniewski [11], with the modification of the sample holder described by Stêpniewski [10], using oxygen as a diffusing agent. The soil core in this method is situated horizontally. Nonshrinking cores in this device are held in the cylinder, but shrinking cores (if they are stabile enough) can also be installed after they are removed from the cylinder.

The measurements of air permeability (k) was performed at 10 hPa air pressure with a laboratory permeameter type LPIR-1 produced by the Experimental Departament of Metallurgy in Cracow. The soil core (in the cylinder) in this device is placed vertically and the air is blown through it from the bottom.

Soil air fills the part of the soil volume that is not occupied by water. The air content in the soil (Eg), often called the air-filled porosity of the soil, is therefore equal to the difference between the total porosity of the soil (Eo) and its current water content by volume (ΘΔμ

$$Eg = Eo - \Theta = Eo - d\,W$$

where d is soil bulk density and W is water content by mass.

The method of oxygen diffusion rate consists in the amperometric measurement of electric current intensity corresponding to oxygen reduction on a platinum cathode placed in the soil and negatively polarized with respect to the reference electrode. The indicator is a measure of potential oxygen availability for plant roots. For the ODR measurement a device described by Malicki and Walczak [8], with an automatic control of the effective reduction voltage was used. Platinum electrodes, 4 mm long and 0,5 mm in diameter, were used for ODR measurements. The electrode polarization time was 4 min, and the polarization voltage was - 0,65 V versus a saturated calomel electrode. Four platinum wire electrodes were placed at the depth of 2 cm.

Redox potential was measured potentiometrically using platinum electrodes (of the same type as for the ODR), and a laboratory pH meter (Radiometer pH M 64). The measurements were taken after stabilization of the readings (2-5 min).

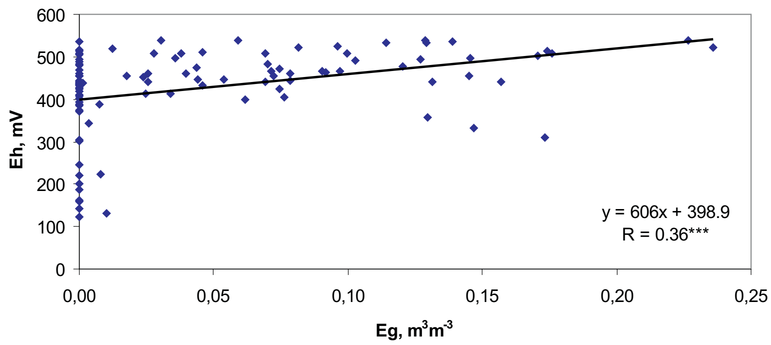
The analysis of variance and regression analysis were used in the statistical processing of data concerning all soil profiles without differentiations into soil units and their usage. The linear (y=ax+b) and logarythmical y=a lnx +b models were used for the description of the analyzed relationships. The models were chosen according to the highest correlation coefficient. All the statistical analyses of particular soil parameters were carried out along the entire range of soil water tension levels.

RESULTS AND DISCUSSION

The obtained results allowed to present a number of relationships between the examined soil physical parameters and soil oxygenation characteristics. In this study, changes of the redox potential and oxygen diffusion rate in relation to air-filled porosity, relative gas diffusion coefficient, air permeability and water content were confirmed by the statistical analyses of all the data.

Air-filled porosity is one of the main factors influencing aeration conditions. The values of redox potential and oxygen diffusion rate versus soil air-filled porosity are presented in Fig. 1. The Eh values in all the soil units studied ranged from 100 to 550 mV and were linearly related to Eg. Substantial decrease of Eh below 300 mV, occurred only at $Eg < 0.02$. Gliñski and Stêpniewska, [4] defined the index t_{300} as the time needed to lower soil redox potential under flood conditions at a fixed temperature to the level of 300 mV. The above authors found out that some alluvial soils needed more than 15 days of flooding conditions at room temperature to lower soil Eh below 300 mV. In our experiment, however, Abadszalok alluvial profiles were saturated only for 7 days and that time was not always sufficient to lower Eh below 300 mV. Due to the above, the Eh values at Eg=0.60 were scattered in the range from 100 mV to 550 mV.

Oxygen diffusion rate ranged from almost 0 to 70 μg $m^{-2}s^{-1.}$ and linearly increased with



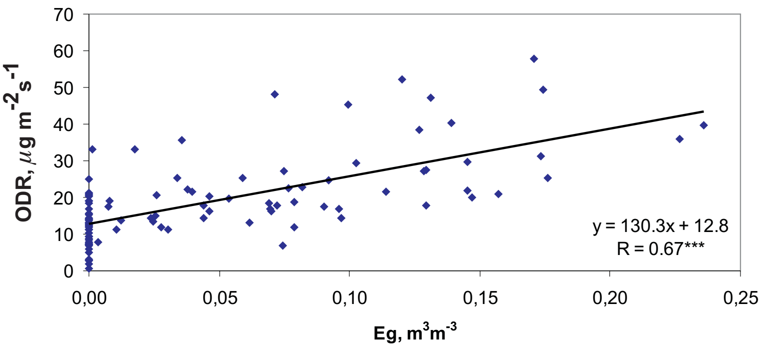


Fig. 1. Redox potential (*Eh*) and oxygen diffusion rate (ODR) versus air-filled porosity (*Eg*) of the soils.

Eg. The value of 35 µg $m^{-2}s^{-1}$ considered in literature as the limiting one for most cultivated plants [4], occurred at $Eg < 0.17$. At air-filled porosity below 0.10 m^3m^{-3} (deficient aeration) oxygen diffusion rate was < 25 μg $m^{-2}s^{-1}$. ODR values in soils vary, most frequently, within a range from 0 to 200 µg m^{-2} s^{-1}. They decrease with an increase in the soil moisture content and therefore increase with an increase in the matric potential and air-filled porosity of the soil.

Figure 2 shows a positive correlation of relative gas diffusion coefficient and air permeability with air-filled porosity. Determination of air filled porosity is the oldest and the easties method of estimation of soil aeration status. D/D_o= 0.005 considered as critical for gas exchange in the soil occurred at air-filled porosity of about 0.12-0.14 m^3m^{-3}. The corresponding *k* values was 2.5 µm ^{2}. Both these parameters are in the range of low values, i.e., D/D_o below of 1.2% of the gas diffusion coefficient in free atmosphere, and the *k* values below 10 µm^2.

Stêpniewski *et al.* [13], noted the highest diffusion coefficient in Slovakia Phaeozem profiles (up to D/D_o=0.1), and this value D/D_o for the Orthic Luvisol from Poland, chernozem from Czech Republic and for chernozem from Austria was up to 0.03, 0.04, 0.05, respectively. These values of gas diffusion coefficient occurred in the investigated profiles at the highest soil moisture tension (500 hPa).

The same authors [13] observed the highest air permeability values for the chernozem from Austria (up to 60 µm^2), and for the phaeozem from Slovakia (up to 50 µm^2). For the Orthic Luvisol from Poland and for the chernozem from Czech Republic the highest *k* values oscillated between 15 and 18 µm^2. These highest *k*

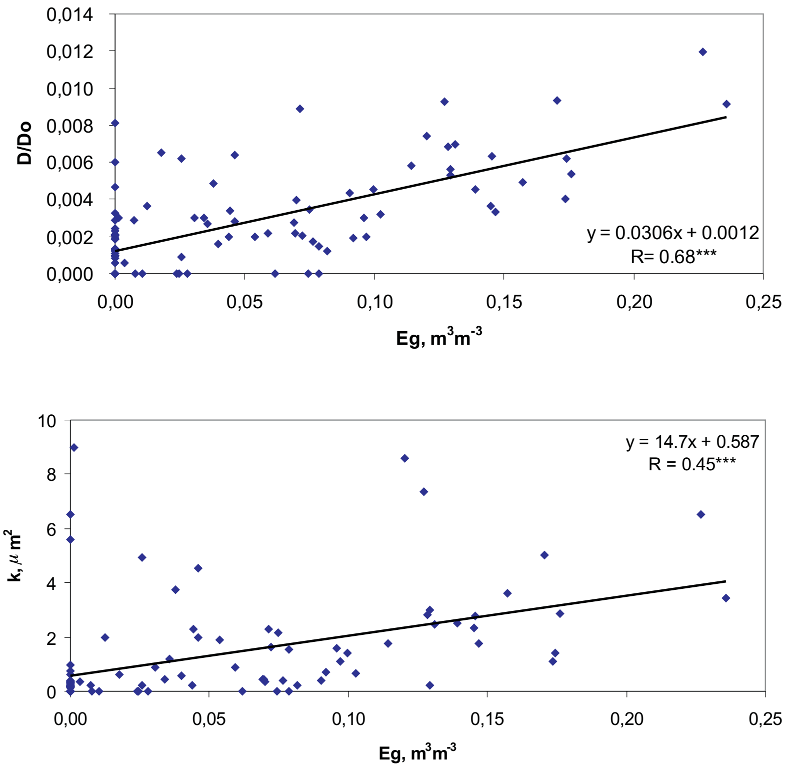


Fig. 2. Relative gas diffusion coefficient (D/D_o) and air - permeability (k) versus air-filled porosity (Eg) of the soils.

values were observed for the investigated profiles at the highest moisture tension (500 hPa), except for the soil from Austria, where the highest air permeability occurred at 159 to 500 hPa.

Figure 3 shows values of *Eh* and ODR as a function of relative gas diffusion coefficient (D/D_o). Both of the parameters were positively correlated with D/D_o. The average values of *Eh* were 450, 520 and 570 mV at D/D_o: 0.004, 0.008 and 0.012, respectively. The average values of ODR were 25, 40 and 55 μg $m^{-2}s^{-1}$ at D/D_o: 0.004, 0.008 and 0.012, respectively. Data from literature call D/D_o = 0.02 as the upper, and D/D_o = 0,005 as the lower critical value. For this lower value, the average *Eh* values were about 450 mV and ODR values about 25 μg $m^{-2}s^{-1}$.

Almost all the Hungarian soils under investigation showed very low *k* values between 0.2 and 6.5 μm^2. The values of ODR were positively correlated with air permeability (Fig. 4). The average values of ODR were 20, 30 and 45 μg $m^{-2}s^{-1}$ at *k* values equal to 2, 4 and 8 μm^2, respectively. Redox potential showed an increasing tendency with an increasing air permeability, but was not si- gnificantly correlated with this parameter.

Soil water status is one of the most important parameters affecting root growth and functions. Development of a plant is affected by the water content directly and indirectly by other physical factors, such as mechanical impedance, temperature, and transport of nutrients towards the root in the soil. The values of ODR (Fig. 4) were negatively correlated with moisture content (*W*). The average values of ODR were 33, 22 and 13 μg m^{-2} s^{-1} at 20, 30 and 40 % moisture content, respectively. The critical ODR values of 35 μg $m^{-2}s^{-1}$ occurred at *W* values of about 0.20 kg kg^{-1}. It should be

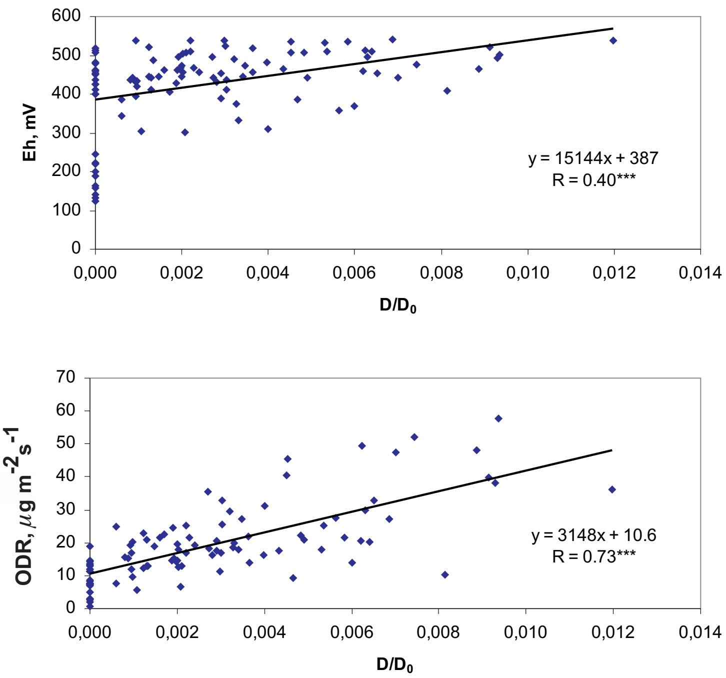


Fig. 3. Redox potential (*Eh*) and oxygen diffusion rate (ODR) versus relative gas diffusion coefficient (*D*/*Do*) of the soils.

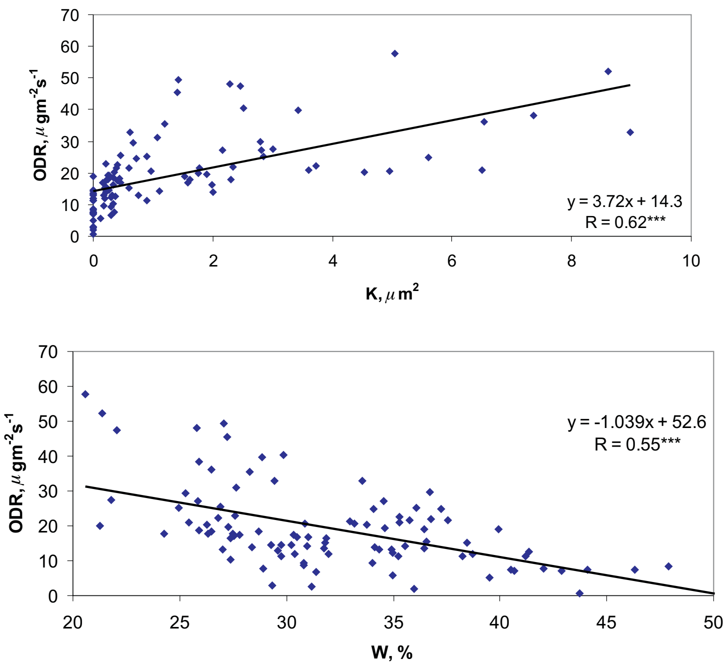


Fig. 4. Oxygen diffusion rate (ODR) versus air permeability (*k*) and water content (*W*) of the soils.

emphasized, that the scattering of ODR values was very heigh at the lower moisture content range and decreased with an increase of *W* values. The redox potential showed a decreasing tendency with an increasing water content, but was not significantly correlated with this parameter.

All the Hungarian soils showed an increase of ODR with the soil water tension from 0 to 500 hPa. The highest value (64 $\mu g\ m^{-2}s^{-1}$) was found in the C horizon of A-1 and the lowest (0.5 $\mu g\ m^{-2}s^{-1}$) in the A horizon of P-2 profile [12].

Redox potential values (Fig. 5) were correlated with oxygen diffusion rate. Redox potential of about 490 mV was found at the ODR of 35 $\mu gm^{-2}s^{-1}$. A distinct decrease of *Eh* was observed at the ODR below 15 $\mu g\ m^{-2}\ s^{-1}$. A similar relationship was found by Gliñski *et al.* [6] for Orthic Luvisol, but an important decrease of *Eh* was observed at ODR < 10 $\mu g\ m^{-2}\ s^{-1}$. Figure 5 shows a positive correlation of air permeability (*k*) and relative gas diffusion coefficient. The values of *k* about 2 μm^2 was found at a lower critical value of the *D*/*Do* coefficient (0.005).

Properties affecting the oxygen status in the soil may be satisfactorily expressed by the investigated soil parameters.

Stêpniewski *et al.* [13] found out a close relationship between oxygenation indicators ODR, *Eh* and Fe^{+2} and dehydrogenase activity. ODR appeared to be the most sensitive oxygenation parameter for describing also the relationship between enzyme activity and soil aeration status. Our investigations confirmed applicability of ODR as an indicator of soil oxygen status and made it possible to determine and compare the limiting values of air-filled porosity,

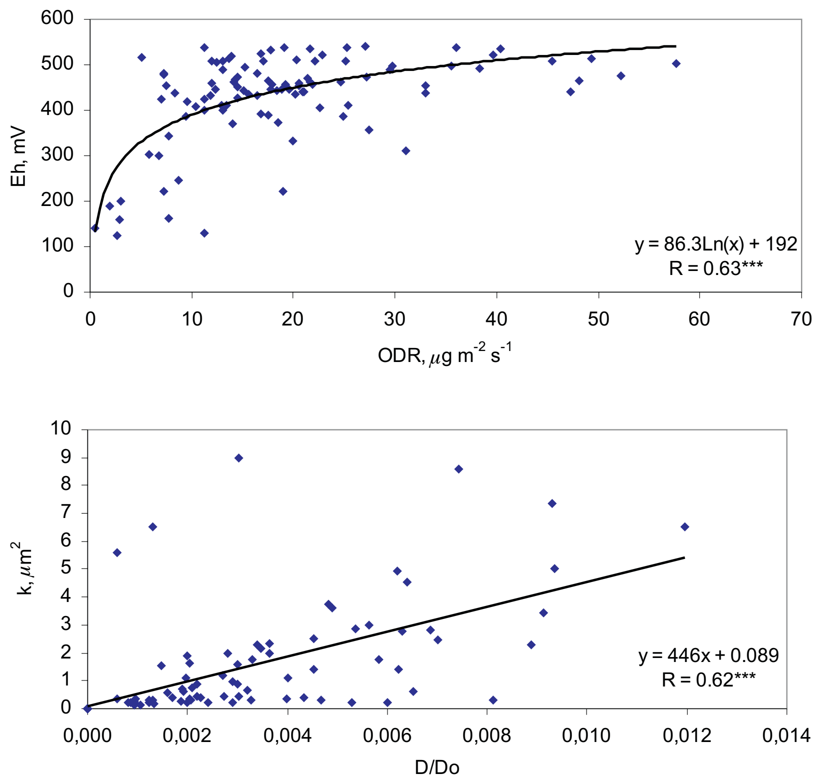


Fig. 5. Redox potential (*Eh*) versus oxygen diffusion rate (ODR) and air-permeability (*k*) versus relative gas diffusion coefficient of the soils.

soil moisture, relative gas diffusion coefficient, air permeability and also the values of redox potential.

CONCLUSIONS

Statistical analysis of all the results concerning relations between aeration status and physical parameters of various Hungarian soils led to the following conclusions:

1. ODR values ranged from 0 to 60 μg $m^{-2}s^{-1}$ and were linearly correlated with air-filled porosity, air permeability, gas diffusion coefficient (positive correlation) and with the water content (negative correlation) .

2. The limiting ODR value $< 35\,\mu g\ m^{-2}s^{-1}$ occurred at $Eg < 0.17\ m^3m^{-3}$; $D/D_o < 0.008$; $k < 5\ \mu m^2$.

3. Redox potential values ranged from 100 to 550 mV and were linearly correlated with air-filled porosity and gas diffusion coefficient.

4. Relative gas diffusion coefficient and air permeability were linearly correlated with air filled porosity. Relative gas diffusion coefficient of 0.005 occurred at Eg=0.13 m^3m^{-3} and air permeability of 2.5 μm^2 .

5. Redox potential values were correlated with oxygen diffusion rate. A distinct decrease occurred at the ODR < 15 μg $m^{-2}s^{-1}$.

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