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AERATION RELATED PROPERTIES AND THEIR INFLUENCE ON SOIL BIOLOGICAL PARAMETERS

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A b s t r a c t. The paper comprises results of measurements of aeration related soil properties such as: relative oxygen diffusion coefficient (D/Do), air permeability (k): oxygen diffusion rate (ODR), redox potential (Eh), dehydrogenase and catalase activities as well as respiration rates and microbial counts (bacteria, actinomycetes and fungi) of five soil profiles from different countries (Austria, Czech Republic, Hungary, Poland, and Slovakia). The measurements have been performed in the Institute of Agrophysics in Lublin (Poland) in the framework of common multilateral cooperation project.

K e y w o r d s: aeration properties, soils, Central Europe, microbial activity

INTRODUCTION

The aim of the project was to verify the utility of the methods of determination of different aeration related and microbial properties by performing comparative studies using various five soil materials from five different countries. This paper reports the results for five profiles, each representing a different country. They have been selected from the total number of 15 profiles included in the entire research programme [4].

MATERIALS AND METHODS

Soils

The following soil profiles have been selected from each country:

Austria (Fuchsenbigl): chernozem soil developed from alluvial silty/fine sand material, cultivated.

Czech Republic (Tišice): arenic chernozem of carbonate variety, developed on a quaternary fluvial terrace of gravel sand overlain by permeable sand, cultivated.

Hungary (Abádszalók - profile No. 2): Fluvic Gleysol of infusion loess, uncultivated.

Poland (Czesławice - private farm): extensively cultivated Orthic Luvisol developed from loess material.

Slovakia (Zemianska Olča): calcaro-gleyic Phaeozem developed from loam, cultivated.

Their basic properties are presented in Table 1 and full descriptions and characteristics - in the paper of Gliński [4].

Thus the selected profiles are differentiated with respect to soil texture, structure, organic matter content, pH and origin. They are ordered according to increasing clay content.

Measurement methods

The undisturbed soil samples in 100 cm^3 brass cylinders have been collected in late autumn, 1991 and than transported to Lublin in January 92. The measurements of all the

Table 1. Basic characteristic of the soil

Locality	Soil	Horizon cm	Clay %	O.M. %	pH		$CaCO_3$%
					H_2O	KCl	
Czeslawice, Poland	Orthic Luvisol (private farm)	Ap(0-24)	7	1.4	4.9	4.5	-
		E(24-35)	9	0.4	5.9	5.3	-
Tišice, Czech-Republic	Chernozem (cultivated)	Ap(0-30)	14	3.6	8.8	7.9	0.7
		A/Ck(30-50)	-	2.2	8.9	8.0	1.7
Fuchsenbigl, Austria	Chernozem (cultivated)	Ap(0-15)	26.5	2.5	8.5	7.3	21.6
		Ah(15-23)	22.6	2.7	8.5	7.5	20.2
		AC(23-40)	21.9	1.0	8.6	7.7	35.0
Zemianska Olča, Slovakia	Phaeozem	Agkp(0-33)	34.7	4.6	8.4	7.5	10
		A/Cgk(33-47)	24.7	0.7	8.6	7.8	33
		Cgk(47-100)	18.2	-	-	-	-
		Abgrk(100-120)	18.2	-	-	-	-
Abádszalók, Hungary	Fluvic Gleysol (uncultivated)	A(0-20)	52.4	2.5	6.2	5.2	-
		B(21-60)	56.6	1.3	6.4	5.2	-
		BC(61-80)	52.6	1.0	6.7	5.5	-
		C(81-100)	34.4	-	6.9	6.0	-

above mentioned parameters have been done at soil moisture tensions: 0 hPa (capillary saturation for 7 days for the heaviest Hungarian 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 horizon after capillary saturation were equilibrated with particular soil moisture tensions on kaolin tension plates. At each equilibrium D/Do and *k* values were measured. When these measurements were completed the cylinders were resaturated and, after subsequent equilibrations with the tension plates, were used to determine ODR, Eh and the activity of dehydrogenases and catalases.

Microbial counts have been performed on disturbed soil material (taken at the same time with the undisturbed samples) after heaving brought it to the laboratory.

The measurement of relative gas diffusion coefficient (D/Do) was performed according to unsteady - state method of Stępniewski [17] with the modification of the sample holder described by Stępniewski [16] using oxygen as a diffusing agent. The method is also described in Problemy Agrofizyki [5]. The soil core in this method is situated horizontally. Non-shrinking cores in this device are held in the cylinder, but shrinking cores (if they are stabile enough) can also be installed after removing them from the cylinder.

The measurement of air permeability was performed at 10 hPa air pressure with a laboratory permeameter type LPIR-1 produced by the Experimental Department 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.

The oxygen diffusion rate (ODR) method consists of amperometric measurement of electric current intensity corresponding to oxygen reduction on a platinum cathode placed in the soil and negatively polarized with respect to a 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 [14], with an automatic control of the effective reduction voltage was used. Four platinum wire electrodes

(0.5 mm x 4 mm) were placed at a depth of 2 cm and polarized to -0.65 V versus saturated calomel electrode, during 4 min. The principle of the method is described in detail by Gliński and Stępniewski [9] and in Problemy Agrofizyki [5].

Redox potential (Eh) was measured potentiometrically using four Pt electrodes (of the same type as for ODR), saturated calomel electrode as a reference electrode, and a laboratory pH meter (Radiometer, Kopenhagen). The electrodes were placed at a depth of 2 cm. The measurements were taken after stabilization of the readings.

Dehydrogenase activity was measured for triplicate samples by the method of reduction of TTC (2,3,5-triphenylotetrazolium chloride) to formazan during incubation for 20 h at 37 °C, at pH=8.2 according to procedure of Casida *et al.* [1].

Catalase activity was measured (also for triplicate samples) by manganometric titration of surplus H_2O_2 under acidic conditions according to procedure of Johnson and Temple [12].

Respiration rate was determined according to procedure of Maciak and Soechtig [13] based on acidometric titration of the carbon dioxide evolved. The soil sample (100 g) was incubated in a tightly closed glass jar (200 cm^3 in volume) for 48 h at 20 ±2 °C. A small open vessel containing 10 cm^3 of 0.5 M NaOH was placed inside the jar. The amount of CO_2 absorbed was determined by titration of the NaOH solution with HCl using phenolophtalein end point after precipitation of carbonates with $BaCl_2$.

Microbial counts (bacteria, fungi and actinomycetes) have been determined as follows using disturbed soil material:

1. The number and kinetics of bacteria proliferation was determined with the following medium according to Waksman: glucose 1g, K_2HPO_4 - 0.5 g and 100 ml of soil extract per one litre. Observations and counting were carried out on Petrie dishes from the first hours after inoculation of soil solution and then after 1,2,3,5,7 and 14 days of incubation at 28 °C. Hattori [10] proposed the following equation describing the relation between the number of colonies and the incubation time:

$$N(t) = N_\infty\,[1 - \exp -\lambda\,(t - t_r)] \qquad (t \geq t_r)$$

where $N(t)$ and N_∞ are the numbers of colonies observed at a time t, and at a infinite time N_∞, respectively, t_r - parameter reflecting the growth rate, and λ is a parameter indicating the rate of colony formation, which can be interpreted as an index of colony growth dynamics. Since this equation is typical for first-order reaction it is called the first-order reaction (FOR) model. This model enables recognizing the number of cells (or micro-colonies) which are potentially able to grow in the applied culture medium. In comparison to standard methods when microorganisms are counted after a definite time - the FOR model gives much more information. This method was developed later by Ishiguri *et al.* [11].

2. The number of actinomycetes was determined with the above medium after 14 days of incubation.

3. The number of fungi was determined with Martin's medium: $MgSO_4{\cdot}7H_2O$ - 0.5 g, KH_2PO_4 - 1.0 g, peptone 5.0 g, glucose 10.0 g, agar 10.0 g, Bengal Rose-10 ml, streptomycin - 30.0 mg, chlorocycline - 2 mg per 1 litre.

RESULTS AND DISCUSSION

Gas diffusion coefficient versus soil moisture tension is presented in Fig. 1.

In all the horizons the relative gas diffusion coefficient increased with soil moisture tension. Generally D/Do was higher in A horizons as compared to deeper horizons except the profile from Tišice where the relation was opposite, i.e. the deeper A/Ck horizon showed higher D/Do than the plow horizon. The highest diffusion coefficient values in the surface horizon occurred in Z. Olča profile, and the lowest - in Abadszalok profile. The latter profile was characterized by the worst diffusion properties in general, and the diffusion coefficients there did not exceed the value 0.012 even in the top horizon at the highest s.m. tension.

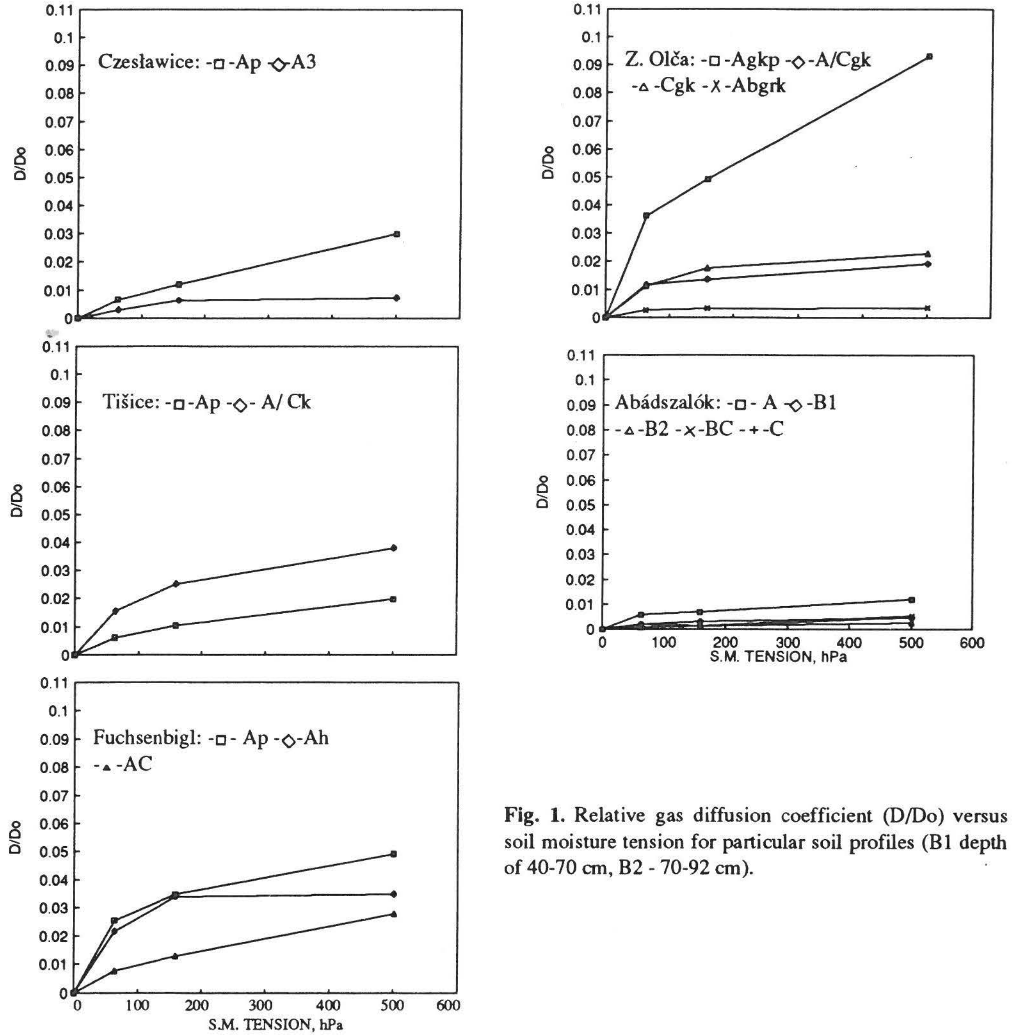


Fig. 1. Relative gas diffusion coefficient (D/Do) versus soil moisture tension for particular soil profiles (B1 depth of 40-70 cm, B2 - 70-92 cm).

There is not a definite D/Do value which is considered critical for aeration of the soil as it depends on soil respiration rate. The literature data quote D/Do=0.005 as a lower critical value corresponding to low respiration activities, and D/Do=0.02 as an upper one for the highest respiration rates [9]. Applying these criteria here we have to state that only in Fuchsenbigl profile the upper critical value was exceeded in all the three horizons studied (s.m. tension range > 100 hPa for the two upper horizons and > 400 hPa for the AC horizon). Other horizons where the value 0.02 was exceeded were as follows: A/Ck horizon in Tišice profile (at. s.m. tension above 100 hPa), Ap horizon of Czesławice profile (s.m. tension above 300 hPa), Agkp and A/Cgk horizons of Z. Olča profile (s.m. tensions > 40 and 400 hPa, respectively).

In turn, gas diffusion coefficients below the lower critical value D/Do=0.005, which seems more realistic for these profiles, occurred in the entire tension range studied for three deeper horizons of Abádszalók profile (B_1, B_2 and BC) and in Abrgk horizon of Z. Olča profile. In the other horizons studied such low values occurred only at s.m. tension range < 50 hPa.

Air permeability versus soil moisture tension is presented in Fig. 2.

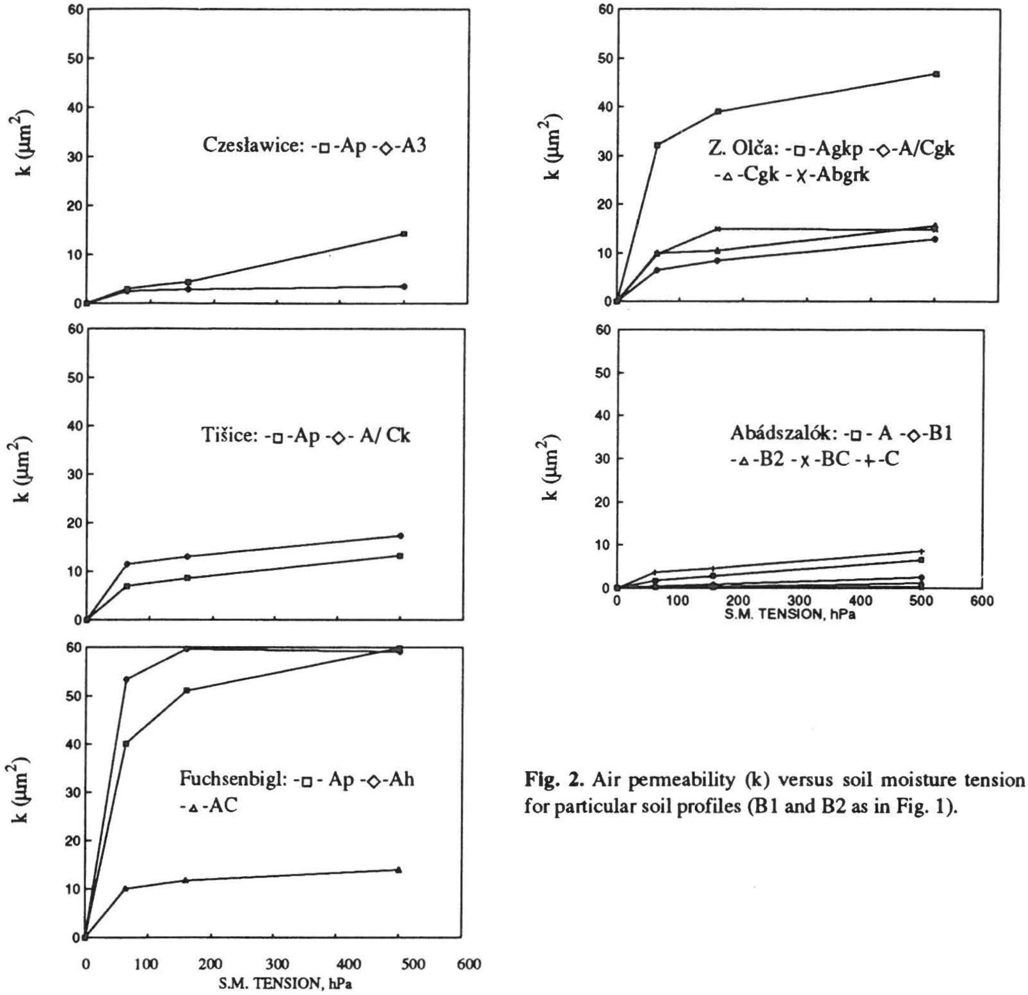
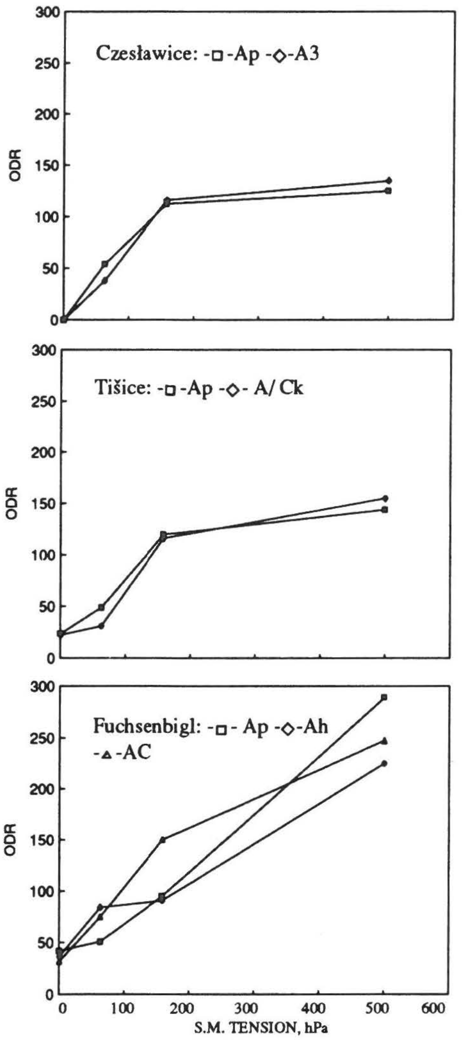


Fig. 2. Air permeability (k) versus soil moisture tension for particular soil profiles (B1 and B2 as in Fig. 1).

The curves presenting *k* values for the profiles studied exhibited monotonic increase with s.m. tension and were rather similar to those for the gas diffusion coefficients. The similarities consist in the fact of highest permeability values in Fuchsenbigl and Z. Olča profiles (up to 50-60 μm^2), and in the smallest - for Abadszalok profile (<10 μm^2). Only in two of the profiles (Czesławice and Z. Olča) the air permeabilities were somewhat higher in the top horizon as compared to the underlying horizons, but in three other profiles one of the deeper horizons showed a bit higher values. It should be noted that in some cases (Z. Olča, BC horizon) it was not possible to measure the k value due to shrinking of the soil cores at the highest soil moisture tension, what caused falling the cores out of the cylinders and made the measurements impossible.

The values of ODR versus soil moisture tension are presented in Fig. 3.

All of the five profiles show an increase of ODR with s.m. tension in the entire range studied. The highest values characterized Fuchsenbigl profile (up to 300 $\mu g\ m^{-2}s^{-1}$) and the smallest (<70 $\mu g\ m^{-2}s^{-1}$) - Abádszalók profile. The critical ODR values which are usually considered to be below 30 $\mu g\ m^{-2}s^{-1}$ [9] occur in all the horizons studied, except the horizons of Fuchsenbigl profile. The range of s.m. tension, characterized by such values is very limited, usually below 50 hPa. Only in Abádszalók profile



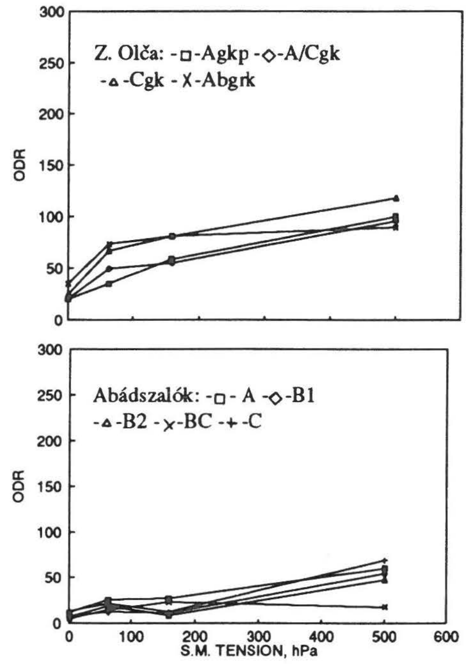


Fig. 3. ODR values ($\mu g\ m^{-2} s^{-1}$) versus soil moisture tension for particular soil profiles (B1 and B2 as in Fig. 1).

it covers for one horizon (BC) the entire tension range studied, and for the others - the range up to 300 hPa.

The values of redox potential versus soil moisture tension are presented in Fig. 4.

The Eh values in all the horizons studied range from 350 to 550 mV. At s.m. tension < 63 hPa the redox potential in most of the profiles shows a tendency to decrease. The decrease is the deepest in Czesławice profile, where at full saturation with water the redox potential reached 350 mV. It should be noted that the Eh values at full saturation are related to 2 days period of keeping the cores saturated, except for Abádszalók where this time was 7 days, and that the Eh drop would decrease with the extension of the saturation period. Relatively small decrease of Eh in the range of low s.m. tensions suggests pretty high redox buffering capacity of the soils. It has been found by Gliński and Stępniewska [6], that saturation time (at 20 °C) needed to decrease soil redox potential to 300 mV (being a measure of the soil redox buffering capacity) varies for mineral soils of Poland from one day (for some loess soils) to more than 15 days (alluvial soils).

Dehydrogenase activity (Fig. 5) was the highest in Fuchsenbigl profile (up to 0.075 nmol formazan $g^{-1}min^{-1}$) and the lowest (below 0.015 nmol

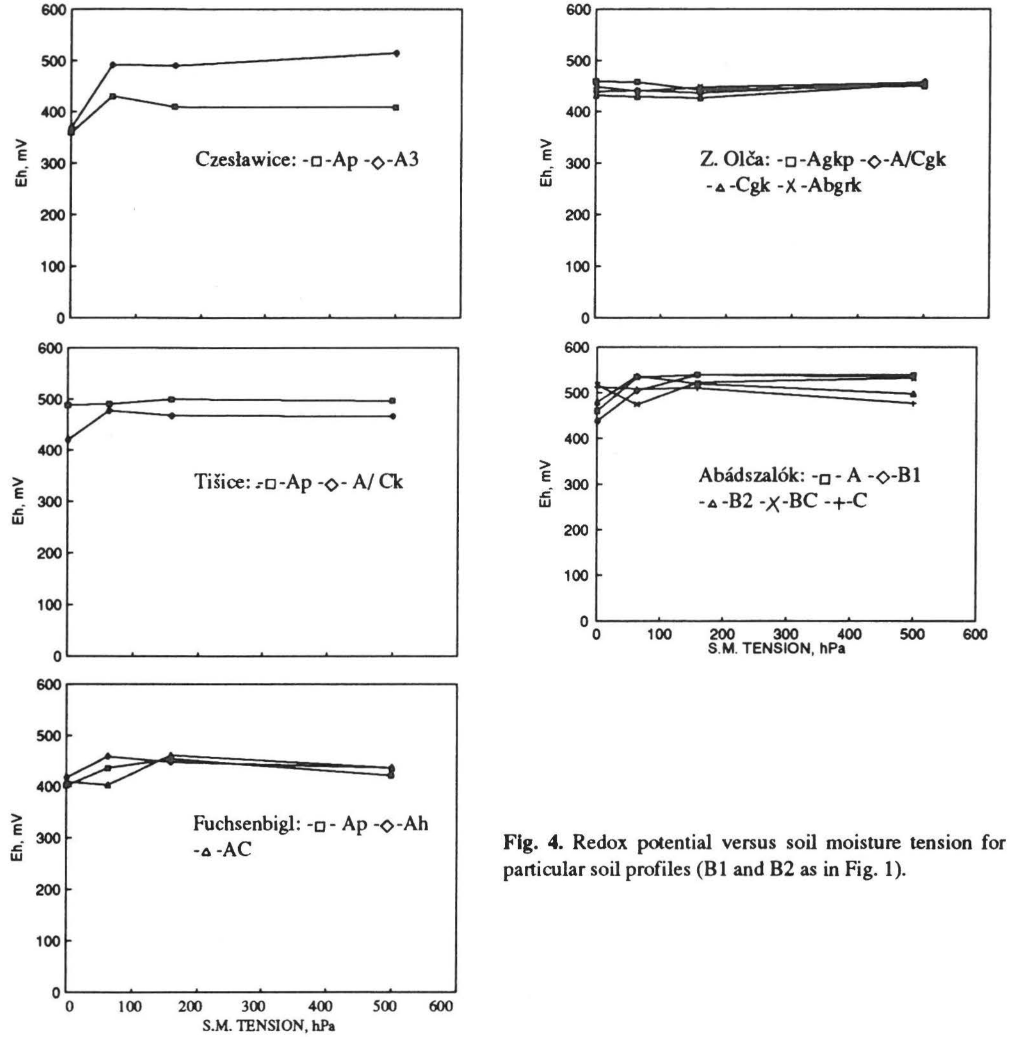


Fig. 4. Redox potential versus soil moisture tension for particular soil profiles (B1 and B2 as in Fig. 1).

formazan $g^{-1}min^{-1}$) in Abádszalók profile. In general the activity in the top horizons was much higher as compared to deeper ones. Most of the horizons studied showed an increase of dehydrogenase activity at saturation with water.

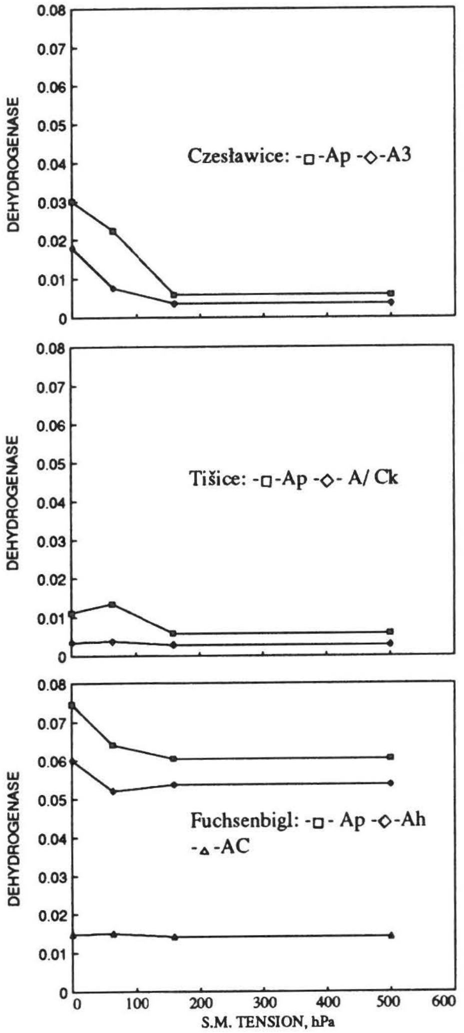
This phenomenon has been noticed earlier [2]. The relatively small increase in such conditions for the horizons studied by us probably is connected with rather short saturation time.

Catalase activities (Fig. 6) were highest for the top horizon of Z. Olča profile (up to 110 μmol $KMnO_4$ g^{-1}) and the lowest for Czesławice E horizon (below 40 μmol $KMnO_4$ g^{-1} in the entire moisture range studied).

The activity did not show a monotonic change with respect to soil moisture tension for all the horizons studied (both increasing and decreasing tendency as well as lack of any tendency was observed in the low moisture tension range).

Earlier data obtained by us [7,8,15] revealed a decrease of catalase activity with an increase of soil water content. It seems that the direction of catalase activity changes depends on soil properties and deserves further attention.

The microbial counts for entire Fuchsenbigl profile and for top horizons of other investigated soils are presented in Table 2.



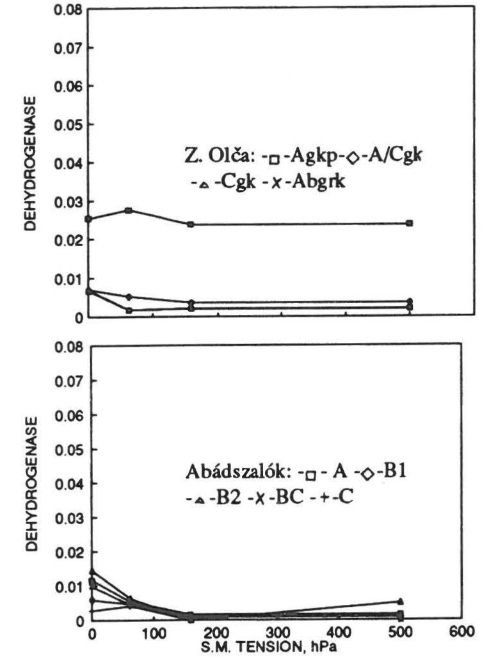


Fig. 5. Dehydrogenase (nmol formazan $g^{-1}min^{-1}$) activity versus soil moisture tension for particular soil profiles (B1 and B2 as in Fig. 1).

Table 2. Number of microorganisms (per g of dry soil) and respiration rate for entire Fuchsenbigl profile and for top horizons of other investigated soils (mean values with standard deviation of the mean).

Soil		Bacteria 10^6 g^{-1}	Actinomycetes 10^6 g^{-1}	Fungi 10^4 g^{-1}	Moisture kg kg^{-1}	Respiration mg CO_2 $kg^{-1}d^{-1}$
Locality	Horizon					
Czesławice	Ap	41.9±2.1	8.32±0.5	19.2±0.5	0.01	21.3
Tišice	Ap	21.5±0.6	10.2±3.7	11.2±1.2	0.18	8.6
Fuchsenbigl	Ap	143±9.7	30.9±4.2	37.7±1.4	0.19	11.7
	Ah	70.0±1.5	21.3±6.3	34.8±2.5	0.20	10.8
	AC	65.2±1.6	5.06±1.2	13.0±0.3	0.21	9.8
Z. Olča	Agkp	114±6.3	28.9±1.3	42.6±4.4	0.33	17.4
Abádszalók	A	82.8±4.2	15.6±3.1	55.2±2.3	0.37	20.6

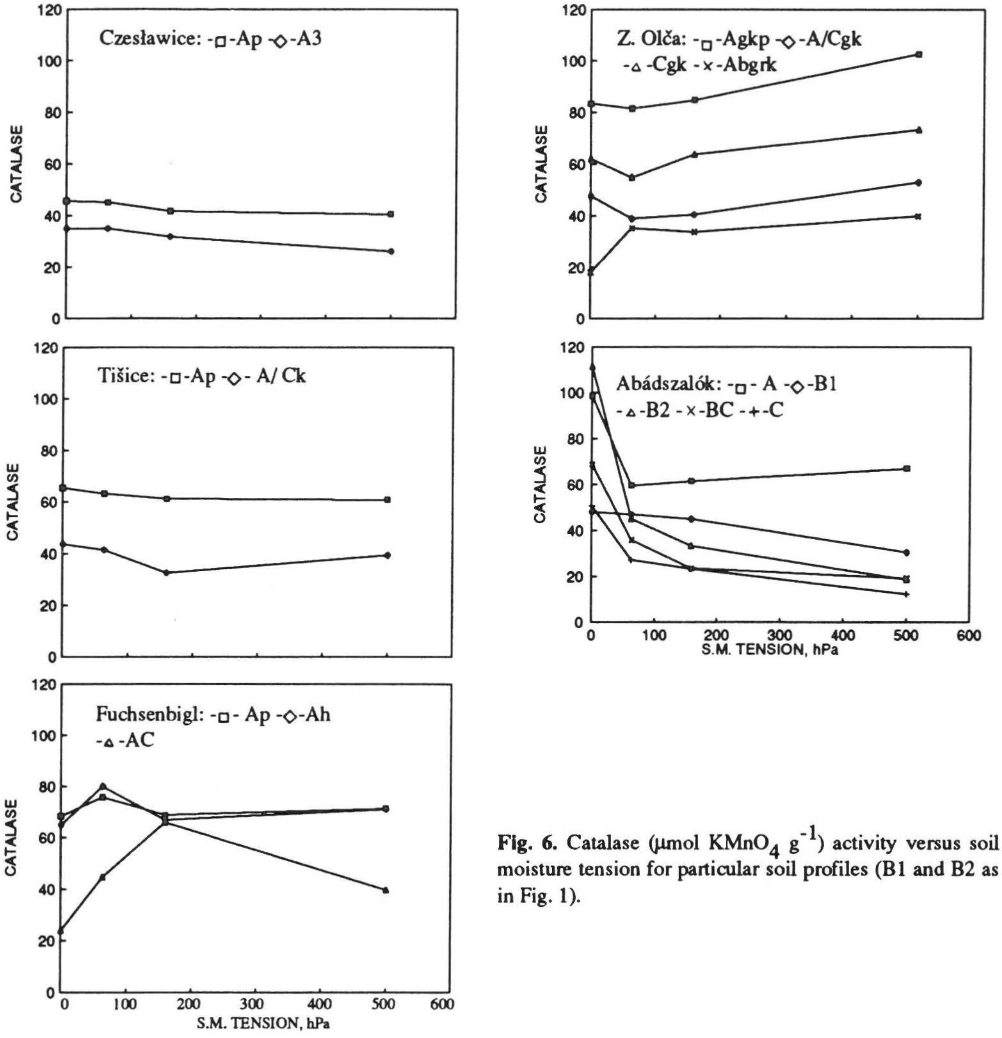


Fig. 6. Catalase (μmol $KMnO_4$ g^{-1}) activity versus soil moisture tension for particular soil profiles (B1 and B2 as in Fig. 1).

In general the number of bacteria was several times higher than that of actinomycetes and by two orders of magnitude higher than that of fungi. The highest number of bacteria was observed in Ap horizon of Fuchsenbigl profile and the lowest - in Tišice profile. The number of actinomycetes was the highest in Ap horizon and the lowest - in AC horizon of Fuchsenbigl profile. As long as only top horizons are concerned the lowest number of actinomycetes occurred in Czesławice profile. The number of fungi was the highest in Ap horizon of Abádszalók profile and the lowest - in Tišice Ap horizon.

The values of soil respiration rates range from 8.6 to 21.3 mg CO_2 $kg^{-1}d^{-1}$ and belong to moderate values found in mineral soils [9]. More detailed discussion of the microbial properties, which are related to numerous external and internal soil factors, e.g. Dąbek-Szreniawska *et al.* [3], will not be performed here.

The correlations between the particular soil parameters were studied by regression analysis using linear [$y = a + bx$], reciprocal [$1/y = a + bx$], multiplicative [$y = ax^b$], and exponential [$y = \exp(a + bx)$] models. The results of the regressions analysis for the model with best fit to the experimental data are presented in Table 3.

Table 3. Correlations between particular parameters studied calculated for all the soil moisture tensions and all the horizons of the investigated soil profiles (N = 65).

Dependent variable y	Independent variable x	Equation	Correlation coefficient r	a	b
Air permeability	D/Do	$y=ax^b$	0.99***	1528	1.17
ODR	D/Do	$y=a+bx$	0.59***	39.2	2112
	k	$y=a+bx$	0.58***	41.2	2.09
Eh	ODR	$y=ax^b$	0.26*	444	0.0116
Dehydrogenase	D/Do	$y=a+bx$	0.36**	9.3×10^{-3}	0.406
	ODR	$y=a+bx$	0.25*	9.04×10^{-3}	7.94×10^{-5}
	k	$y=a+bx$	0.63***	6.13×10^{-3}	7.19×10^{-4}
	catalase	$y=ax^b$	0.61***	2.06×10^{-10}	4.31
Catalase	D/Do	$y=a+bx$	0.43***	44.7	557
	ODR	-	n.s.	-	-
	k	$y=a+bx$	0.43***	45.1	0.562

* - significant at p=0.05 *** - significant at p=0.001
** - significant at p=0.01 n.s. - not significant

These results show that the aeration indicators used in the study are interrelated although the data concerned different soil types, developed from different parent materials and subjected to diverse agricultural management systems. The highest correlation was found between air permeability and gas diffusion coefficient (r=0.99), intermediate - for the dependence of oxygen diffusion rate on D/Do and on air permeability, and the weakest - between redox potential and ODR. Best correlations were usually obtained for the linear models and only in two cases (dependence of air permeability on D/Do, and that of redox potential on ODR) - for the multiplicative model.

SUMMARY

The activity of dehydrogenases was linearly and positively correlated with all the three aeration indicators used, and that of catalases - only with D/Do and *k*.

The activity of dehydrogenases was also correlated with that of catalases and the multiplicative model was the most suitable here.

Gas diffusion coefficient was the highest in Z. Olča (up to 0.09) profiles and the lowest - in Abádszalók profile, where it did not exceed the value of 0.012 in the moisture range studied. It increased with soil moisture tension and usually decreased with depth.

Air permeability was the highest in Fuchsenbigl and Z. Olča profiles and the lowest in Abádszalók profile. It usually increased with s.m. tension and decreased with depth.

The values of ODR showed a monotonic increase with s.m. tension and were the highest in Fuchsenbigl profile and the lowest - in Abádszalók profile. In the latter profile ODR values below 30 μg $m^{-2}s^{-1}$ occur at tension range up to 300 hPa, and in other profiles studied - only at soil moisture tensions <50 hPa.

The values of redox potential were above 350 mV for all the horizons studied and only under conditions close to saturation a slight decrease for most of the horizons was observed.

Dehydrogenase activity was the highest in surface horizon of Fuchsenbigl profile, and the lowest - in Abádszalók profile. It generally decreased with depth and with s.m. tension.

Catalase activity did not show a monotonic change with s.m. tension but usually it decreased with depth. It was the highest in the surface horizon of Z. Olča profile and the lowest - in the E horizon of Czesławice profile.

Of the top horizons studied Fuchsenbigl soil was the most abundant in bacteria and actinomycetes, and Abadszalok soil - in fungi, while Tišice soil appeared to be the most poor in bacteria and fungi, and Czesławice - the most poor in actinomycetes.

Respiration rates of the soils investigated range from 8.5 to 21.3 mg CO_2 $kg^{-1}d^{-1}$.

High correlation was found between the aeration indicators measured.

Dehydrogenase activity was correlated linearly positively with ODR, redox potential and air permeability and curvilinearly with the activity of catalases (multiplicative model).

Catalase activity appeared to be correlated linearly with the gas diffusion coefficient (D/Do) and with air permeability (*k*).

CONCLUSIONS

1. It has been shown that the application of the methods used in this study allowed us to characterize satisfactorily the aeration related and microbial properties of particular soil layers of the profiles investigated demonstrating their differentiation with depth and soil moisture tension.

2. For shrinking soils which created slits between the cylinder walls and the core, and later fell out of it, it was not possible to measure the air permeability.

3. The measurement of D/Do in the case of such slits was affected at the beginning of slit formation i.e. as long as it was not possible to remove the soil from the cylinder and to install it separately.

4. The results obtained suggest existence of general relationships between biological parameters and aeration indicators in different soils.

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