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CHARACTERISTICS OF AERATION PROPERTIES OF ORTHIC LUVISOL FROM POLAND UNDER DIFFERENT LAND USE

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A b s t r a c t. The present publication comprises results of measurements of aeration status related to soil properties such as: oxygen diffusion coefficient (D/D_0), oxygen diffusion rate (ODR), redox potential (*Eh*), dehydrogenase and catalase activities as well as Fe^{+2} content at the soil moisture tensions of 63, 159 and 500 hPa in the (Ap) surface and (E) subsurface horizons of 3 soil profiles of an Orthic Luvisol under different land use (forest, farm and experimental field). Results of the investigations showed differentiation in the aeration properties related to land use, soil horizons, water tension and reciprocal dependencies of aeration parameters.

K e y w o r d s: soil aeration, ODR, *Eh*, catalase activity, dehydrogenase activity, gas diffusion coefficient (D/D_0), Fe^{+2} concentration

INTRODUCTION

Soil air-water conditions are very important for the regulation of aeration status and they are decisive for the physical parameters and type of soil metabolism.

Soil is defined as the unconsolidated natural material on the surface of the earth that has been subjected to various environmental factors. One of the aims of soil physics is to provide appropriate proportions between solid, liquid and gaseous phases. Any disturbances of the equilibrium oxygen concentration in the soil make beneficial conditions for plant development and growth not always available. They are affected by such properties as: structure, bulk density, aggregation, pore size, soil air composition, profile characteristics, etc.

The aim of the present paper was to investigate changes in oxygen diffusion rate (ODR), redox potential (*Eh*), relative gas diffusion coefficient (D/D_0), Fe^{+2} content, catalase and dehydrogenase activities with respect to different land use (farm field, experimental field and forest soil) in the soil samples taken from the surface (Ap) and subsurface (E) horizons of an Orthic Luvisol. The measurements were performed at differentiated soil water tensions after preincubation of soil cores on water tension plates.

The investigations were carried out as a part of an international project supported by the Austrian Federal Ministry of Science, Research and Art in 1992-1995.

MATERIALS

Soils

The profiles represented the same soil unit, i.e., Orthic Luvisol developed from a typical loess but differentiated with respect to land use. The first profile (Forest) represented natural, mostly deciduous oak-hornbeam forest habitat with pine admixture (*Querco-Carpinetum)*. The second (Farm) was located on an unmechanized private farm field were most of the field work was carried out using horses, and the third (Exp.) on the experimental field of the Agricultural University with the use of heavy machinery.

The measurements comprised the following horizons:

- Farm field (after potato harvesting): Ap - O.M.-1.4%, bulk density 1.23 Mg m^{-3}, total porosity 53% and E - O.M.- 0.4%, bulk density 1.48 Mg m^{-3}, total porosity 44%.

- Experimental field (after maize harvesting): Ap - O.M.- 1.5%, bulk density 1.39 Mg m^{-3}, total porosity 47% and E - O.M.- 0.3, bulk density 1.41 Mg m^{-3}, total porosity 47%.

- Forest site: only E horizon - O.M.- 0.7%, bulk density 1.35 Mg m^{-3}, total porosity 49%.

Measurements

Undisturbed soil samples in 100 cm^3 brass cylinders (51 mm in diameter and 49 mm hight) were collected in late autumn, 1991. The measurements of all the above mentioned parameters were taken at the soil moisture tensions of 63 hPa (pF 1.8), 159 hPa (pF 2.2), and 500 hPa (pF 2.7). The cores representing each horizon after capillary saturation were equilibrated with particular soil moisture tensions on kaolin tension plates. When the measurements were completed, the cylinders were resaturated and, after subsequent equilibrations with tension plates, used to determine ODR and *Eh*.

The measurements of Fe^{+2} were performed in the extract of 0.05 M H_2SO_4 (2.5 g of the wet soil plus 25 ml of the sulphuric acid solution, shaken for 5 min with the use of α,α'- dipyridyl in acetate buffer solution of pH 4.5.

Dehydrogenase activity was measured for tripicate samples by the TTC method (2,3, 5-triphenyltetrazolium chloride) reduction to formazan during incubation for 20 h at 30 ^oC, at pH = 8.2 according to the procedure of Casida *et al.* [1]. All the analytical results were calculated on the basis of oven-dry (105 ^oC) soil mass.

Catalase activity was measured for the samples taken from each soil core by manganometric titration of surplus H_2O_2 under acidic conditions according to the procedure by Johnson and Temple [4].

The measurements of relative gas diffusion coefficient (D/D_o) were performed according to the unstedy-state method by Stêpniewski [7], with modification of the sample holder described by Stêpniewski [6], using oxygen as a diffusing agent. The soil core in this method is situated horizontally. Nonshrinking cores in this device are held in a cylinder, but shrinking cores (if they are stabile enough) can also be installed after their removal from the cylinder.

Soil air fills that 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, was calculated as a difference between the total porosity of the soil (*Eo*) and its current moisture content by volume (Θ):

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

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

The oxygen diffusion rate (ODR) method consists in amperometric measurement of electric current intensity corresponding to oxygen reduction on a platinum cathode placed in the soil and negatively polarised 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 [5] 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 polarisation time was 4 min, and the polarisation voltage was - 0.65 V versus a saturated calomel electrode. Four platinum wire electrodes were placed at the depth of 2 cm.

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

The analysis of variance and regression analysis were used in statistical processing of data concerning all soil samples. Linear and exponential models were used for the description of the analysed relationships.

RESULTS AND DISCUSSION

Catalase activity with respect to land use is presented in Fig. 1. Catalase activities in the horizons under consideration ranged from 10 to 45 μmol $KMnO_4$ g^{-1} and tended to decrease with depth. The lowest values were found for the E horizon of the experimental field. Gliñski *et al.* [3] observed that an average catalase activity in all the studied horizons ranged from 44.8 to 59.1 μmol $KMnO_4$ g^{-1} and showed a tendency to decrease with the increasing soil water tension. Stêpniewski *et al.* [9] noted, that catalase activities in the Ap horizons were the highest for a Fluvicalcaric Phaeozem from Slovakia (up to 105 μmol $KMnO_4$ g^{-1}) and the lowest for a cultivated Orthic Solonetz from Hungary with gypsum amelioration (below 24 μmol $KMnO_4$ g^{-1}). The values found in this paper are closer to the lower values of the Hungarian Solonetz.

Dehydrogenase activities at different soil moisture tensions and with respect to land use are presented in Fig. 2. Dehydrogenase activities in the Ap horizon were the highest, and decreased with soil moisture tension. The phenomen of changes in dehydrogenase activity related to soil aeration status was observed earlier. Hungarian soils [8] and forest soil from Poland exhibited very low dehydrogenase activities which did not exceed 0.007 nmol formazan g^{-1} min^{-1} at the moisture tension of 500 hPa. The range of average values (for 15 soils and all the horizons) of the activity was from 0.0082 nmol formazan g^{-1} min^{-1} (for 500 hPa) to 0.0163 nmol formazan g^{-1} min^{-1} (for 0 hPa) [3].

Stępniewski *et al*. [9] found a close relationship between oxygenation indicators ODR, *Eh* and Fe^{+2} and dehydrogenase activity. In the Orthic Luvisol from Poland under the present study dehydrogenase activities were not significantly correlated with ODR, *Eh* and Fe^{+2}.

The values of redox potential and oxygen diffusion rate at different soil moisture tensions and with respect to different land use practices are presented in Figs 3 and 4. In all the horizons the values of *Eh* are between 350 and 515 mV and are not significantly differentiated in relation to soil moisture tension and depth. This confirms that no reduction processes occurred in the soil at moisture tension > 60 hPa. A possible reason for higher *Eh* values may be the presence of nitrates. Redox potential was significantly lower in both horizons from the experimental field.

The values of ODR in all the investigated horizons are between 25 and 125 μg m^{-2} s^{-1}. All the horizons show an increase of ODR with the increase of moisture tension from 63 hPa to higher values (159 and 500 hPa). Maximum ODR values at 500 hPa vary from 90 to 130 μg m^{-2} s^{-1}. Minimum ODR values at 63 hPa vary from 25 to 55 μg m^{-2} s^{1}. The ODR values at the farm field were significantly higher than under the forest, which may be connected with differentiated total porosity; i.e., 53 and 49 %, respectively.

The critical ODR values, which are usually considered to be about 30 μg m^{-2} s^{-1} [2], occur only in the Ap horizon of the experimental field. Thus the range of critical ODR values is very limited.

Gas diffusion coefficient D/D_o values at different moisture tension and different land use are presented in Fig. 5. D/D_o at 63 hPa was significantly lower than at 500 hPa which is related to different moisture conditions and, as a result, to different air - filled porosities.

The contents of Fe^{+2} at different soil moisture tension levels and land use are presented in Fig. 6. It should be noted that lower content of Fe^{+2} (less than 10 mg kg^{-1}) in the soil under farm field conditions occurred at higher redox potential (above 420 mV) and higher relative gas diffusion coefficient (D/D_o = 0.03 at moisture tension 500 hPa). Gliñski *et al.* [3] observed that an average content of Fe^{+2} varied from 44 mg kg^{-1} (at 0 hPa) to about 24 mg kg^{-1} (at 500 hPa) and was correlated positively with soil water content and negatively with *Eg*, D/D_o, k and ODR.

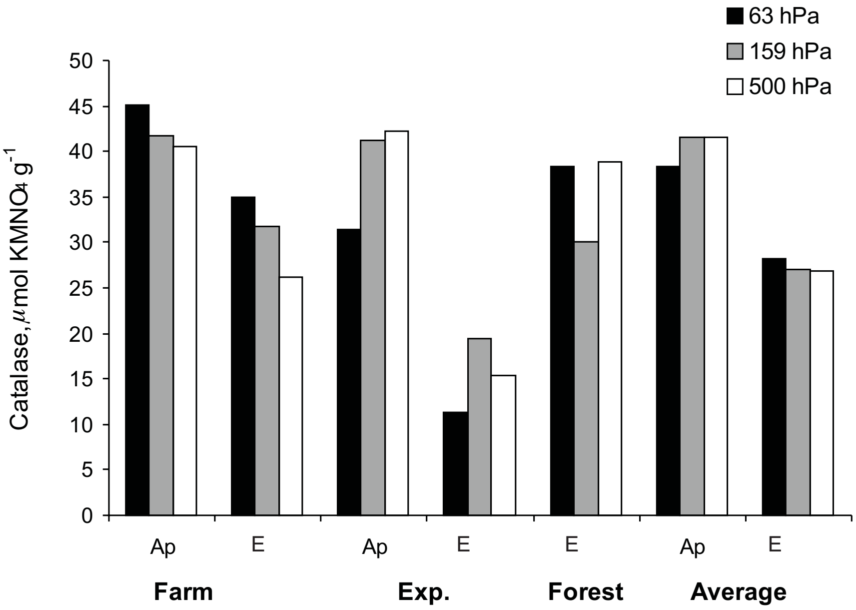

Fig. 1. Catalase activity at different moisture tensions in individual soil horizons.

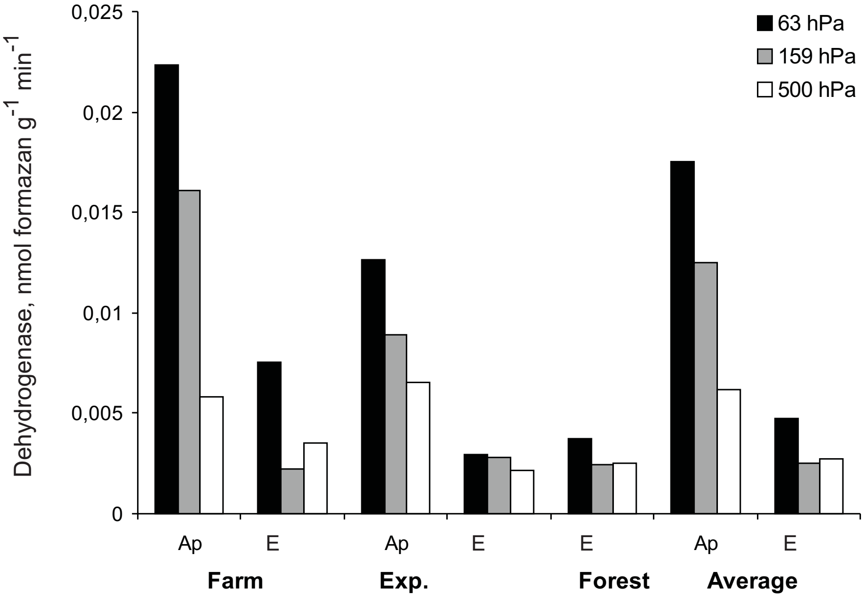

Fig. 2. Dehydrogenase activity at different moisture tensions in individual soil horizons.

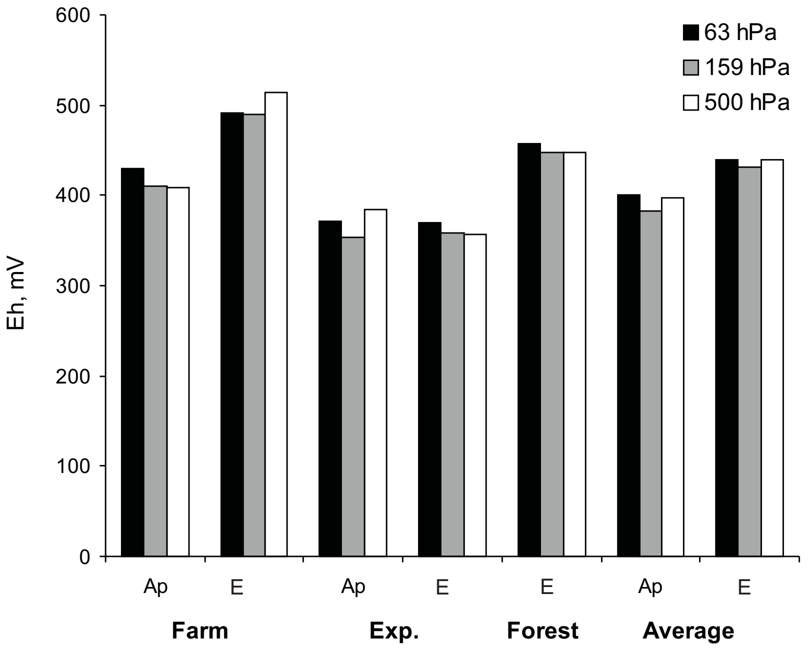

Fig. 3. Redox potential (*Eh*) at different moisture tensions in individual soil horizons.

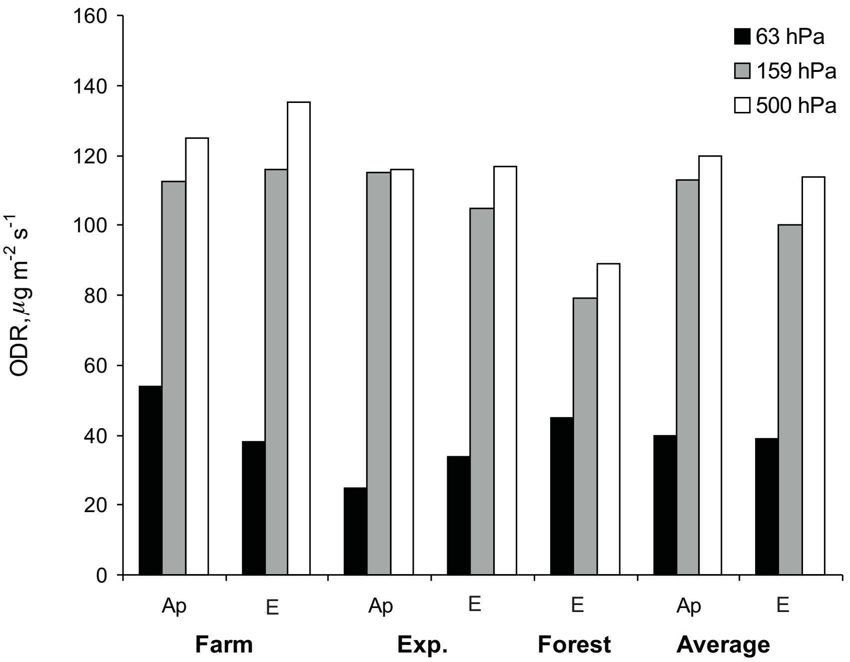

Fig. 4. Oxygen diffusion rate (ODR) at different moisture tensions in individual soil horizons.

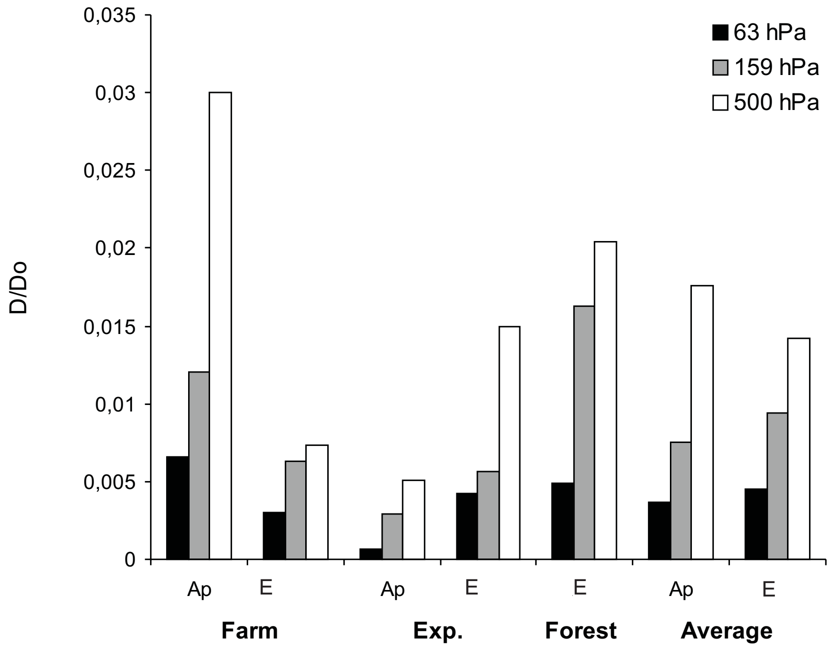

Fig. 5. Relative gas diffusion coefficient (D/D_o) at different moisture in individual soil horizons.

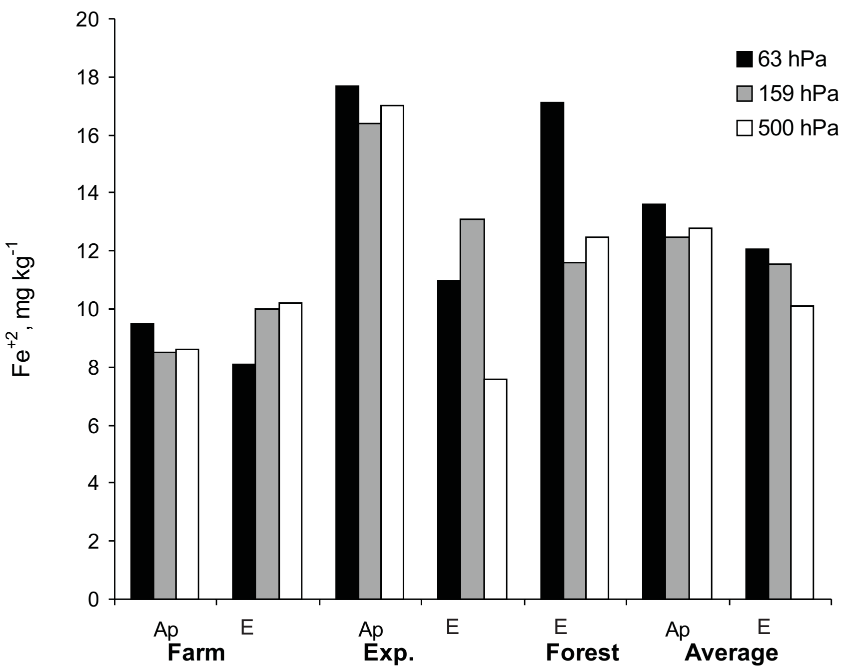

Fig. 6. Fe^{+2} at different soil moisture tensions in individual soil horizons.

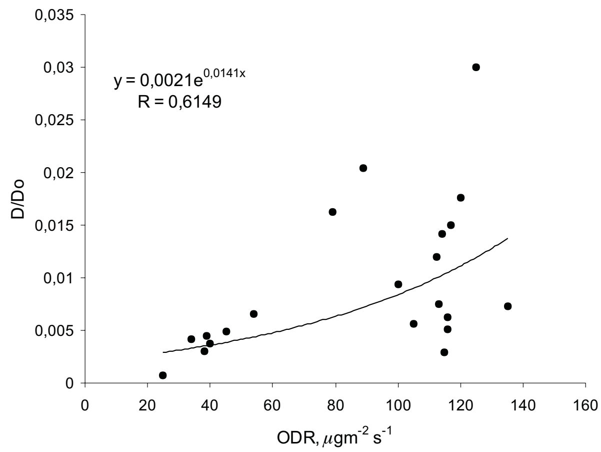

Fig. 7. Relative gas diffusion coefficient (D/D_O) versus oxygen diffusion rate (ODR).

Among possible relationships between the investigated parameters (*Eg*, D/D_O, catalase activity, dehydrogenase activity, *Eh* and ODR) only those between D/D_O, *Eh* and ODR appeared to be significant.

Relative gas diffusion coefficient versus oxygen diffusion rate is presented in Fig. 7. As it can be seen both the parameters are correlated. The maximum diffusion coefficient at 500 hPa of soil moisture tension for the Orthic Luvisol studied was 0.03. Stêpniewski *et al.* [7] found that the highest values of the gas diffusion coefficient at the same moisture tension were observed for Phaeozem profiles from Slovakia (D/D_O = 0.1), while those for Arenic Chernozem from Czech Republic, for Chernozem from Austria and for Fluvic Gleysol, Vertic Gleysol and Orthic Solonetz from Hungary D/D_O reached the values 0.04, 0.05 and 0.012, respectively. The literature data [2] announce D/D_O = 0.02 as an upper, and D/D_O = 0.005 as a lower critical value. For this lower value, the average ODR level in the case of Orthic Luvisol was lower than 43 μg m^{-2} s^{-1}.

Figure 8 shows a positive linear correlation of relative gas diffusion coefficient with air

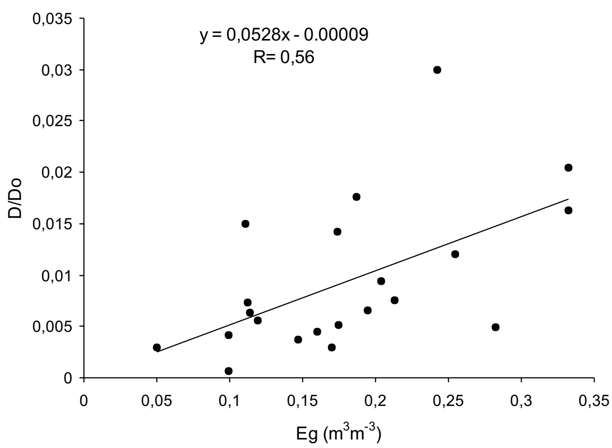

Fig. 8. Relative gas diffusion coefficient (D/D_O) versus air-filled porosity (*Eg*) of soils.

-filled porosity. Determination of air-filled porosity is the oldest and the easiest method for the estimation of soil aeration state. D/D_o = 0.005 considered as the lower critical value for gas exchange in the soil occurred at air-filled porosity of about 0.10 m^3m^{-3}. For the Ap horizon in the brown soil developed from loess (Eutric Cambisol) Stêpniewski [7] noticed lower values of air-filled porosity (about 0.05 $m^3 m^{-3}$) for the critical (D/D_o) values of gas exchange. The corresponding air content in another brown loess soil (Eutric Cambisol) at D/D_o = 0.005 is 0.18 $m^3 m^{-3}$ at different degrees of compaction [6]. The discrepency of the above values indicates, that gas diffusivity is a specific soil characteristics highly dependent on the site.

CONCLUSIONS

Results of the investigations carried out on Orthic Luvisol showed differentiation in aeration properties which were related to land use, soil horizons, water tension and interrelations between aeration parameters.

1. Oxygen diffusion rate varied from 25 to 125 $\mu g\ m^{-2}\ s^{-1}$. All the investigated soil horizons showed a gradual increase of ODR with increasing soil moisture tension. The ODR values for the farm field were higher than those for the forest and experimental field.

2. Redox potential ranged from 350 to 515 mV and was lower for all the horizons from the experimental field soil than for the horizons from farm and forest soils.

3. Relative gas diffusion coefficient increased with soil moisture tension and was the highest in the Ap horizon of the farm soil.

4. The content of Fe^{+2} in the farm soil was below 10 mg kg^{-1} and was lower than in the two other soils.

5. Dehydrogenase activity decreased with soil moisture tension and was highest in the plough horizon of the farm field.

6. Catalase activity varied from 10 to 45 μmol $KMnO_4\ g^{-1}$ and was not distinctly related to soil moisture tension.

7. Significant correlations of D/D_o with ODR and with Eg were found. The limiting value of D/D_o = 0.005 corresponded to ODR= 43 $\mu g\ m^{-2}s^{-1}$ and Eg = 0.10 m^3m^{-3}

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