Abstract. The relationship was examined between soil moisture tension expressed as soil water potential (pF) and microdiffusion of oxygen (ODR) values. Homogenized samples from various horizons of Eutric Fluvisol and Eutric Histosol were investigated at 4 pF values (1.5; 2.2; 2.7; 3.2) using the classical Richard method. Oxygen diffusion rate (ODR) was measured in soil samples at these pF values according to the Lemon and Erickson method (1952), modified by Malicki and Walczak (1983), using platinum and reference electrodes. The highest values of ODR ranging from 59.3 to 74.9 µg O₂ m⁻² s⁻¹ were formed at pF 2.2 for Eutric Fluvisol. Meanwhile, the maximum values of ODR for Eutric Histosol ranged from 86.4 to 108.1 µg O₂ m⁻² s⁻¹ at the pF 3.2 were estimated. The lowest values for ODR for both Eutric Histosol and Eutric Fluvisol were found at pF 1.5.

Soil aeration is one of the most important determinants of soil productivity [5, 9]. Without sufficient oxygen in the soil the normal functions of most crop plants and aerobic microbes come to a standstill [6]. In general, soil aeration is governed by two processes, namely (a) transport of oxygen from the atmosphere into the soil (atmospheric air contains, by volume, 20.5% O₂ and soil air 0-20%), and (b) consumption of oxygen by biological (microbial and root) respiration or by chemical reactions [7]. It is worth considering that soil compaction reduces the total air-filled (noncapillary) pore space and reduces average pore sizes, increases mechanical resistance to root penetration, and can increase or decrease water holding capacity, depending on the amount of compaction and initial bulk density and pore size distribution [16]. With the loss of macropore space, water infiltration and gas diffusion is reduced, soil oxygen concentration is decreased and carbon dioxide concentration can increase, possibly to toxic levels [9, 16]. The first
experimental tested relationship between pF-ODR and soil porosity was performed in 1962 by Oden and Danfors [4, 12]. It also has been shown experimentally that ODR satisfactorily reflects the supply of oxygen to plant roots [6].

Meanwhile, soil water potential is defined as $pF = \log h$ (cm H$_2$O), where $h$ symbolizes the height of the water table (cm) [13]. For water, gas transport phenomena in soils include the problem of pore size distribution, pore continuity and water saturation [10]. When the oxygen demand within soil aggregates is high and O$_2$ diffusion is limited by partial or even complete water saturation (diffusive coefficient of oxygen will be reduced by a factor of 10 000 in water saturated pores) and low pore continuity, then anoxic sites may develop even if the interaggregate pore space contains sufficient oxygen [7]. Thus, in well-structured soils research on aeration should focus on oxygen transport within aggregates and on oxygen consumption [7]. Recently, attention has focused on what is known as the least limiting water range (LLWR) in soils [2, 3]. According to this concept, the range of soil water over which plants can function adequately has lower and upper limits [2]. The lower (or dry) limit is the water contents below which root elongation effectively ceases, meanwhile the upper (or wet) limit is the water content above which aeration becomes limiting [2], which has an influence in the effective use of available nutrients through the plants.

The aim of the current work was to investigate the relationship between soil moisture suction expressed as pF values and microdiffusion of oxygen on the example of Eutric Histosol and Eutric Fluvisol. As a result of this work it was possible to determine an optimum zone for the existence of plant roots in this type of soil. Moreover, estimation of critical water content, when the water film at the electrode surface becomes discontinuous, is also discussed. Below this point, none of the ODR measurement methods are useful.

**MATERIAL AND METHODS**

The studies were performed on soils taken from the bank of Polish soils gathered in the Institute of Agrophysics of the Polish Academy of Sciences in Lublin. Eutric Fluvisol and Eutric Histosol sampled from various depths were subjected to research (properties shown in Table 1). The characteristic feature of Eutric Fluvisol is the occurrence of stratification as gleyic phenomenon in the soil profile, and this type of soil is located in river valleys. On the other hand, Eutric Histosol is a peat-type soil created as a result of mucking processes and its quality depends on the quantity of peat in the soil profile.

Water potential measurements using the classical Richard method were conducted [5], and the four pF values (1.5; 2.2; 2.7; 3.2) of tested soil were estimated. Soil samples were put in an airtight chamber and a pressure applied. After achieving equilibration of the sample masses at all given pF values, the
microdiffusion of oxygen (ODR) was measured. The oxygen diffusion rate (ODR) technique uses a platinum microelectrode as a cathode with a reference anode cell with an automatic polarization of platinum electrodes to O\textsubscript{2} \rightarrow O\textsuperscript{2-} potential [12]. As oxygen is consumed at the microelectrode, more oxygen must diffuse radially to the electrode in response to the gathered gradient [13]. This is analogous to oxygen consumption by respiration at the root surface or by microbial respiration. After steady state is reached, the voltage is proportional to the radial oxygen diffusion rate. It should be pointed that ODR measurements are reliable only when the entire electrode surface is covered by the water film [6]. The ODR value, normally increasing with soil moisture, decrease sharply below a certain moisture content corresponding to break up of the water film covering the platinum surface [6]. The Institute of Agrophysics, Polish Academy of Soil Sciences, Lublin manufactured the meter used in the experiment.

Observational data were recorded in three replicates for each soil samples. Data was analysed for variance with use of the Statgrapher programme.

RESULTS AND DISCUSSION

The relationship between soil water potential (pF) and microdiffusion of oxygen (ODR) in the Eutric Fluvisol at different levels of the soil profile are shown in the Fig. 1. The highest values of ODR coefficient appear at pF 2.2, this type of dependence was observed at the surface (10-20 cm), subsurface (30-40 cm) and subsoil (80-90 cm). Microdiffusion of oxygen, determined as ODR, was greater in the subsoil layer than in the topsoil and reached 74.9 µg O\textsubscript{2} m\textsuperscript{-2} s\textsuperscript{-1}, while values between 57.6 and 59.3 µg O\textsubscript{2} m\textsuperscript{-2} s\textsuperscript{-1} were found in the surface and subsurface layers. The point equalling pF 2.2 for Eutric Fluvisol was estimated to be the critical water content because below this pF value a decrease in oxygen amount was noted, indicating the point when the water film at the electrode surface becomes discontinuous. The lowest values of ODR ranging from 14.6 µg O\textsubscript{2} m\textsuperscript{-2} s\textsuperscript{-1}
at the subsurface layer (30-40 cm) to 22.2 µg O₂ m⁻² s⁻¹ at the surface layer (10-20 cm) at pF 1.5 were noted. With decreasing soil moisture content at pF 2.7- 3.2, deterioration of the water-air conditions was considered. Water-saturated soil suffers from a lack of oxygen because it is displaced by water, and resulting in inadequate conditions for plants roots [13, 15]. When the oxygen concentration in the root environment decreases, the zone of anoxic metabolisms localized in the merystemes expands to other parts of the root system, although rarely, if ever, occupying it entirely because its upper parts are supplied with oxygen through internal diffusion from the shoots [6].

The relationship between oxygen availability expressed as (ODR) and the depth of Eutric Fluvisol at pF 2.2. is illustrated in Fig. 2. We found that oxygen availability at the surface (10-20 cm) and as at the subsurface layer was at almost the same level: 59.32 and 56.87 µg O₂ m⁻² s⁻¹, respectively. The highest value ODR coefficient was recorded at the subsoil (80-90 cm), at 74.9 µg O₂ m⁻² s⁻¹. This appears to confirm that the water-air condition in Eutric Fluvisol improves with the depth of the soil profile.

Fig. 1. Soil water potential (pF)-oxygen diffusion rate (ODR) in different layers of Eutric Fluvisol.

\[ y = -22.61x^2 + 114.75x - 72.31 \]

\[ R^2 = 0.93 \]

Fig. 2. Changes in oxygen availability (ODR) at different depths of Eutric Fluvisol at pF 2.2.
The effects of soil water potential (pF) on oxygen diffusion rate (ODR) in the Eutric Histosol at different depths of the soil profile are shown in Fig. 3. The maximum values of ODR at pF 3.2 at the surface, subsurface and subsoil were recorded and were as follows: 86.4, 96.3, 108.1 µg O₂ m⁻² s⁻¹. Similarly to the Eutric Histosol, the lowest values of oxygen diffusion rate were observed at pF 1.5. Linear increases of the microdiffusion of oxygen at all tested layers of this profile were found, starting from a minimum value of 14.5 µg O₂ m⁻² s⁻¹ at pF 1.5, through 40.1 and 51.3 µg O₂ m⁻² s⁻¹ at pF 2.2, 2.7 adequately, and finally reaching its maximum at pF 3.2, with up to 96.3 µg O₂ m⁻² s⁻¹. It is supposed that the maximum value of ODR at pF 3.2 is the point where the water film at the electrode surface becomes discontinuous, because until that point no decrease in ODR value was registered.

Changes in oxygen availability (ODR) at different depths of Eutric Histosol at pF 3.2. in are shown in Fig. 4. Significant increases in oxygen microdiffusion with increasing depth of soil profile was observed and achieved values of 86.43, 96.35 and 108.1 µg O₂ m⁻² s⁻¹ at the surface, subsurface and subsoil layers, respectively.

Fig. 3. Soil water potential (pF)-oxygen diffusion rate (ODR) at different depths of Eutric Histosol.

Fig. 4. Changes in oxygen availability (ODR) at different depths of Eutric Histosol at pF 3.2.
It appears that favourable conditions for gas diffusion in Eutric Fluvisol and Eutric Histosol became better with increasing soil depth. These results are compatible with the work of Stepniewska et al. [13]. Similar effects were obtained for the Eutric Cambisol [13]. On the other hand some others researchers observed that ODR decreased with increasing soil depth [7, 14]. ODR values might be reduced at deeper soil horizons due to increasing resistance of the components [7]. ODR behaviour in the soil depends most of all on the type of soil and organic matter content. Soil organic matter is a key attribute of soil quality impacting on soil aggregation and water infiltration [1]. By providing the energy, then the substrates and biological diverse organic matter supports the biological activity, which affects soil aggregation and water infiltration [1].

Soil aeration is clearly an important component of soil physical quality. However, it is very dynamic and varies significantly with a range of factors, especially water content and bulk density [2]. Therefore, it can be recommended in future studies to define statistically the probabilities of limiting the various stages of crop growth under different systems of soil management and climatic conditions [2].

CONCLUSIONS

Laboratory experiments have shown that:
1. The water-air conditions in the soils investigated became better and more favourable with increasing depth of soil horizon.
2. An increase of the soil water potential in the range of pF 2.7 – 3.2 caused deterioration of water-air conditions in the Eutric Fluvisol.
3. Oxygen diffusion rate (ODR) coefficient reached maximum equalled 74.9 µg O₂ m⁻² s⁻¹ at pF 2.2 in the Eutric Fluvisol.
4. Minimum values of ODR at moisture level adequate to pF 1.5 were recorded for both the Eutric Fluvisol as Eutric Histosol.
5. The highest observed values of oxygen availability were 108.1 µg O₂ m⁻² s⁻¹ in the subsoil layer of the Eutric Histosol.
6. The optimum zone was estimated for the existence of plants roots at pF 2.2 and pF 3.2 in the subsoil layer of the Eutric Fluvisol and Eutric Histosol.
7. The moment when the water film at the electrode surface becomes discontinuous for Eutric Fluvisol was at pF 2.2 and for Eutric Histosol was at pF 3.2.

REFERENCES

WPŁYW POTENCJAŁU WODNEGO NA MIKRODYFUZJĘ TLENU W GLEBACH EUTRIC FLUVISOL I EUTRIC HISTOSOL

Niniejsza praca poświęcona jest zależności pomiędzy retencją wodną gleby, wyrażoną jako potencjał wodny (pF) a mikrodyfuzją tlenu (ODR). Homogeniczne próby gleb Eutric Fluvisol i Eutric Histosol pobrane z różnych poziomów glebowych zostały poddane oznaczeniu klasyczną metodą Richardsa dla 4 wartości pF: 1,5, 2,2, 2,7, 3,2. Pomiar wydatku dyfuzji tlenu (ODR) przeprowadzono stosując metodę Lemona i Ericksona (1952), zmodyfikowaną przez Malickiego i Walczaka (1983), z użyciem elektrod platynowych i elektrody odniesienia. Najwyższe wartości ODR w zakresie od 59,3 do 74,9 µg O₂ m⁻² s⁻¹ zaobserwowano w glebie Eutric Fluvisol przy pF 2,2. Natomiast w glebie Eutric Histosol maksymalne wartości ODR zawierające się w przedziale od 86,4 do 108,1 µg O₂ m⁻² s⁻¹ wystąpiły przy wartości pF równej 3,2. Najniższe wartości mikrodyfuzja tlenu zarówno w glebie Eutric Fluvisol, jak i Eutric Histosol osiągała przy wartości pF 1,5.