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Original Research

Effect of Selected Physical Parameters on Respiration Activities in Common Polish Mineral Soils

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Abstract

The aim of our study was to analyze the impact of such soil physical parameters as water potential (pF), microdiffusion of oxygen (ODR), redox potential (Eh), and air porosity (Eg) on respiration activity (RA), defined as CO_2 evolution after a 10-day soil incubation at 20ºC. Moisture content was determined for a range of pF values (0, 1.5, 2.2, 2.7, and 3.2) that corresponded to water availability for usability by microorganisms and plant roots. Selected soil samples were extracted from the following soils layers: surface (0-30 cm), subsurface (30-60 cm), and subsoil (60-100 cm), and were classified (FAO) as *Orthic Podzol*, *Eutric Histosol*, and *Haplic Phaeozem*. ODR, Eh, and Eg increased with higher soil water tension, but generally a high variability of a examined factors was observed. Respiration processes in the surface layers were the most intensive (71.5-91.2 mg CO_2 $kg^{-1}d^{-1}$), whereas those in the subsurface and the subsoil samples were reduced by 65-98% to the level 1.6-19.2 mg CO_2 $kg^{-1}d^{-1}$. Our results revealed significant ($p<0.001$) relationships between soil RA and pF, ODR, and Eh as Eg level. However, correlation coefficients (r) varied as they were indirectly dependent on soil type and depth.

Keywords: soil respiration activity, redox potential, oxygen availability, air porosity

Introduction

Soil is the largest terrestrial carbon (C) source which, through soil respiration, contributes 10 times greater annual flux of CO_2 to the atmosphere than that from fossil fuel combustion [1]. Soil respiration is defined as the process of CO_2 release by soil microorganisms and plant roots. Therefore, RA of soils can provide one of the most important characteristics of soil biological activity and reflects an intensity of soil organic matter decomposition and mineralization, and an abundance of microorganisms in soil [2]. Soil respiration is an integrated signal from all biotic and abiotic processes that occur in soil, and therefore is a sensitive indicator of variabilities in soil carbon cycling that may derive from anthropogenic environmental changes [3]. As climate and land-use changes have a potential to enhance or reduce soil CO_2 fluxes, measurements of soil respiration have received a lot of recent attention [2-5].

An effect of equilibrium between biological process of O_2 uptake combined with CO_2 production in the soil environment and physical processes of gas transport between soil and atmosphere is soil aeration status [6]. RA can be quite variable depending mainly on physical and chemical soil properties such as abundance and diversity of soil microorganisms, substrate availability, aeration, soil temperature, and moisture [2, 5].

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Table 1. Basic characteristics of the investigated soil samples [10].

Type of soil	Location	Depth [cm]	Granulometric composition [%]			C_{org} [%]	pH [H_2O]
			1-0.02 [mm]	0.02-0.002 [mm]	<0.002 [mm]		
Orthic Podzol	Kolnica SW Poland	0-30	76	10	14	1.06	7.34
		30-60	52	37	11	0.79	7.03
		60-100	60	32	8	0.08	6.71
Eutric Histosol	Rzędziny NW Poland	0-30	91	5	4	3.51	6.94
		30-60	91	7	2	0.28	7.09
		60-100	95	1	4	0.13	6.44
Haplic Phaeozem	Złota SE Poland	0-30	68	24	8	7.51	9.38
		30-60	59	23	18	7.52	9.12
		60-100	63	29	8	7.97	8.75

Soil water availability can have both direct and indirect effects on soil RA through regulation of soil temperature [5, 7]. Soil RA is not sensitive to temperatures below 5ºC, but is more responsive at higher temperatures (10 and 20ºC) [7]. A common conceptual relationship assumes that soil CO_2 loss is low under dry conditions, but reaches a maximum rate at intermediate soil moisture levels (near field capacity – pF 2.2), and decreases under high soil moisture conditions when anaerobic processes prevail, depressing aerobic microbial activity [7]. Under high soil moisture conditions, the effect of soil water on RA is regulated primarily by oxygen concentrations. However, under low water availability conditions soil bacteria maintain a basic metabolism as in dormancy, which can be reflected in substantial reductions in respiration per unit of biomass or reductions in total respiratory biomass [7].

Another important factor influencing soil RA is ODR, which is thought equal to the amount of oxygen potentially available for plant roots. Naasz et al. [8] indicated that oxygen availability for roots not only depends on gas flow, but also on source-sink relationships involving root and microorganism respiration. In some organic soils high microbial respiration could potentially take up all available oxygen. These authors [8] also noted that for a high microbial respiration rate (i.e. equal to 120 mg of O_2 $m^{-3}\cdot s^{-1}$), the reduction in root oxygen uptake reached 60% for peat soil. These rapid reductions in oxygen content can lead to sustained anoxic conditions important for the root environment.

Soil oxygenation state is closely related to soil redox transformations and, moreover, influence the type of respiration and microorganism population [6]. Eh is an aeration parameter also related to substrate availability and energy transformation, and so can play a crucial role in maintaining soil microbial abundance, diversity, and community structure [9]. However, it is important to recognize the effect of Eh on soil RA.

Furthermore, it is still unclear how soil RA responds to ODR, Eh, or Eg in the soil environment, as there has been a lack of studies with statistical descriptions of relationships between these parameters. In order to get a clear picture of an RA response on variable aeration parameters in this work, the effect of pF, ODR, Eh, and Eg on soil RA was tested under laboratory conditions and described using a statistical correlation coefficient for each best fit.

Experimental Procedures

Description of Soils

The study used three types of the FAO-classified soils: *Orthic Podzol* (17º20' N, 50º45' E), *Eutric Histosol* (14º20' N, 53º32' E) and *Haplic Phaeozem* (20º34' N, 50º23' E), each taken from three different depths (0-30; 30-60 and 60-100 cm). The relevant characteristics of the soil are reported in Table 1. The Institute of Agrophysics of the Polish Academy of Sciences in Lublin has a collection of samples of mineral soils representative for territory of Poland. The basic aim of the bank soil sample (BSS) formation was to create the possibility of comprehensive characterization of soils as a medium of production processes in agriculture, making it possible to refer the results obtained to the structure of the soil cover of the country [10]. The current experiment was realized on soil material that originated from the BSS described above.

Determination of Soil – Retention Curves

A stainless-steel pressure chamber containing a porous plate saturated with water at the bottom was used in the experiment at atmospheric pressure [11]. Soil samples were transferred to plastic cylinders (h=5 cm, V=100 cm^3) and placed on a plate inside the chamber in order to obtain a hydraulic contact between a sample and the porous plate. A laboratory set LAB o12 (Soil Moisture Equipment Company, USA) was used and the pressure was applied for the following water potentials (pF): 0, 1.5, 2.2, 2.7, and 3.2, corresponding to a range of available water, and its quality for microorganisms and plant roots.

ODR, Eh Measurements, and Eg Calculations

ODR was measured by an ODR-meter manufactured by the Institute of Agrophysics, Polish Academy of Soil Sciences (Lublin), based on the Lemon and Ericcson method [12]. The ODR technique used a set of platinum microelectrodes as cathodes and a reference anode cell. The instrument offered an automatic polarization of platinum electrodes to the $O_2 \rightarrow O^{2-}$ potential. As oxygen is consumed at a cathode, more oxygen must diffuse radially to the electrode in response to the accumulated gradient [13]. This is analogous to oxygen consumption by respiration at the root surface, or by microbial respiration [14]. Four platinum wire electrodes (0.5×4 mm) were placed at a depth of 2 cm and polarized to -0.65 V versus the saturated calomel electrode for 4 min. The data were recorded in three replicates for each sample.

Eh measurements were performed with a pIONeer 65 device (Radiometer Analytical S.A.). The measurements were taken after stabilization of the readings.

Eg was calculated by taking into account water content, soil density, and solid phase density according to the method described by Stępniewski et al. [15].

Respiration Activity Measurements

The RA was measured as the CO_2 gain after 10 days of incubation of the soil samples (at proper values of pF) in glass vessels at 20ºC. Concentration of CO_2 in the head space was analyzed by a gas chromatograph (Varian CP-3800 equipped with a TCD detector). All gas analyses were performed in triplicate. The values of RA were expressed in mg CO_2 kg^{-1} soil·day^{-1}.

The respiratory quotient (RQ) was calculated from the ratio:

$$RQ = CO_{2\ evolved} / O_{2\ consumed}$$

Statistical Analysis

Statistical analysis was performed using Statgraphics 3.0 and Statistica 8.0 software (STATSOFT, USA). A one-way ANOVA test investigated significant ($p<0.05$) changes of aeration factors (ODR, Eh, Eg) in a range of pF 0-pF 3.2. However, in order to determine significance effect ($p<0.05$) of each physical parameter (pF, ODR, Eh, Eg) on the RA, the linear regression method was applied.

Results and Discussion

Water Retention Capability of Soil

Incubation of the samples under different controlled moisture conditions altered significantly the physical parameters. Soil water content was described by pF curve as a function of soil water tension [16] that provided information about the ability to retain water by soil pores at a particular water tension, so how tightly water was held between soil aggregates. Soil water potential is defined as pF=log h (cm H_2O), where h denotes the height of the water column (cm) [13]. A value of pF equal to 0 corresponds to the full aquatic capacity, such that all soil pores are filled with water. pF of 2.2 is typical field water capacity, whereas a pF value as high as 4.2 is considered the wilting point for the plant [13].

The relationships between soil water content (% v/v) and pF for the three depths of *Orthic Podzol*, *Eutric Histosol*, and *Haplic Phaeozem* are presented in Fig. 1.

The particular soil types demonstrated different abilities to retain water. For example, full water capacity in the surface layers ranged from 29 to 42% v/v at pF 0, and between 12-20% v/v at pF 3.2. In the subsurface layers ranges of 17-34% v/v (pF 0) and 7-17% v/v (pF 3.2) were encountered, whilst in the subsoil layer the ability to hold water remained on the level 15-25% v/v and 5-18% v/v for pF 0 and pF 3.2, respectively. Among the investigated soils, *Haplic Phaeozem* had the highest ability of water retention at each layer of the soil profile (Fig. 1), whereas *Eutric Histosol* and *Orthic Podzol* showed lower capabilities for water retention as found in the surface layer. However, the lowest values of water content (15-17% v/v at pF 0 and 5-7% v/v at pF 3.2) were encountered in subsurface and subsoil of *Eutric Histosol*. A similar capability of *Eutric Histosol* for water maintainenance was indicated by Włodarczyk and Witkowska-Walczak [17], as well as Walczak et al. [18].

The soil-water interactions of soils are of great importance to soil fertility and therefore are of interest to agricultural engineers and farmers. Moreover, information about

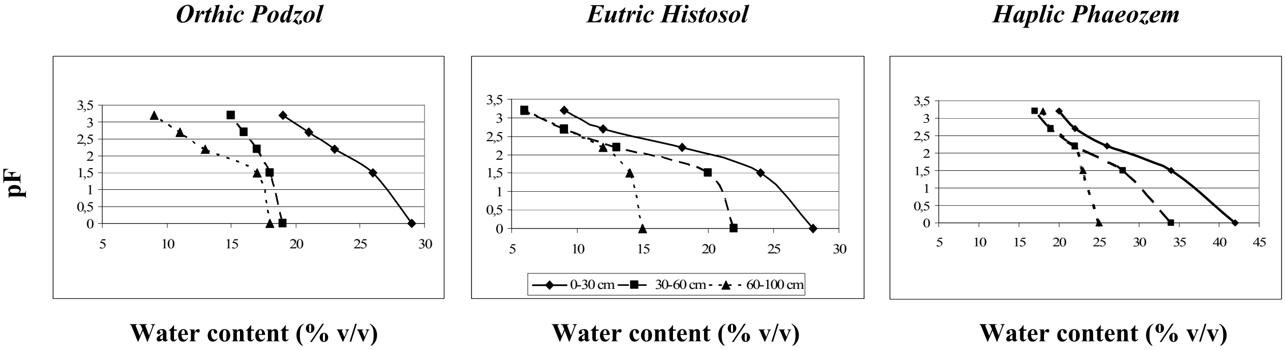

Fig. 1. The relationship between soil water content (% v,v) and pF values. The curves are related to three depths (0-30, 30-60, and 60-100 cm) of the investigated soil types.

water holding capacity is important for agronomic and hydrologic characteristics of soils, as it expresses how much water can be stored in the soil for plants to use during periods without rain or irrigation [19]. This provides an indication of soil sensitivity to drought, and could be used to calculate the probability of deep drainage or groundwater recharge to take place. It is known from literature that organic carbon content (C_{org}) can be a crucial factor for the improvement of water-retaining ability [20-22]. Our results confirm this statement as the highest retention capability was noted in *Haplic Phaeozem*, which was rich in C_{org} (8.75-9.38%), while the lowest capability of holding water was noted in Eutric Cambisol, which could be ascribed to C_{org} content as low as 6.4% for the subsurface and 7.1% for the subsoil layer.

Relationships between Physical Parameters and pF

Dependencies of ODR, Eh, and Eg on pF are presented in Fig. 2. These data indicate that a decrease in water content (i.e. higher values of pF) caused significant increases in ODR, Eh, and Eg as confirmed by low values of p coefficients. The only exceptions from low *p* were two cases of subsurface layer (30-60 cm), which had a more linear growth of Eh and Eg versus pF, but no significant character ($p>0.05$).

ODR measurements yielded in the range from 7.5 to 12.5 μg O_2 $m^{-2}\cdot s^{-1}$ at pF 0 and from 48 to 84 μg O_2 $m^{-2}\cdot s^{-1}$ at pF 3.2. In general, an increase of oxygen availability was associated with growth of the soil profile depth. This is consistent with previously published data [13, 18].

All the soil types used in the experiment manifested an increase in Eh with the soil water tension between pF 0 and pF 3.2. Eh varied between +350 and +520 mV, which are in a similar range as reported earlier by Stępniewski et al. [23], who established that Eh intervals in properly oxygenated mineral soils form Poland ranged between +400 and +600 mV.

The Eg factor alternated from 0.05 m^3m^{-3} (pF 0) to 0.29 m^3m^{-3} and demonstrated an increasing trend with pF values. A similar level of Eg at different soil moisture conditions have been assigned both by Gliński et al. [6] for the soil profiles taken from Central Europe, and by Zou et al. [24] for soil on which pine was cultivated.

Soil Respiration Activity

The averages of RA in the investigated soil types during 10 days of incubation at 20ºC in the range pF 0-pF 3.2 are presented in Table 2.

The values of RA determined at pF 0 in *Haplic Phaeozem* were approximately 1.3-5.3 times higher than RA noted in *Eutric Histosol* or *Orthic Podzol*, respectively. At the other pF values (2.2-3.2) RA remained at a similar level both in *Haplic Phaeozem* as *Eutric Histosol*. Not only *Orthic Podzol* differed significantly ($p<0.01$) from other soil types, but also it was manifested by the lowest values of RA.

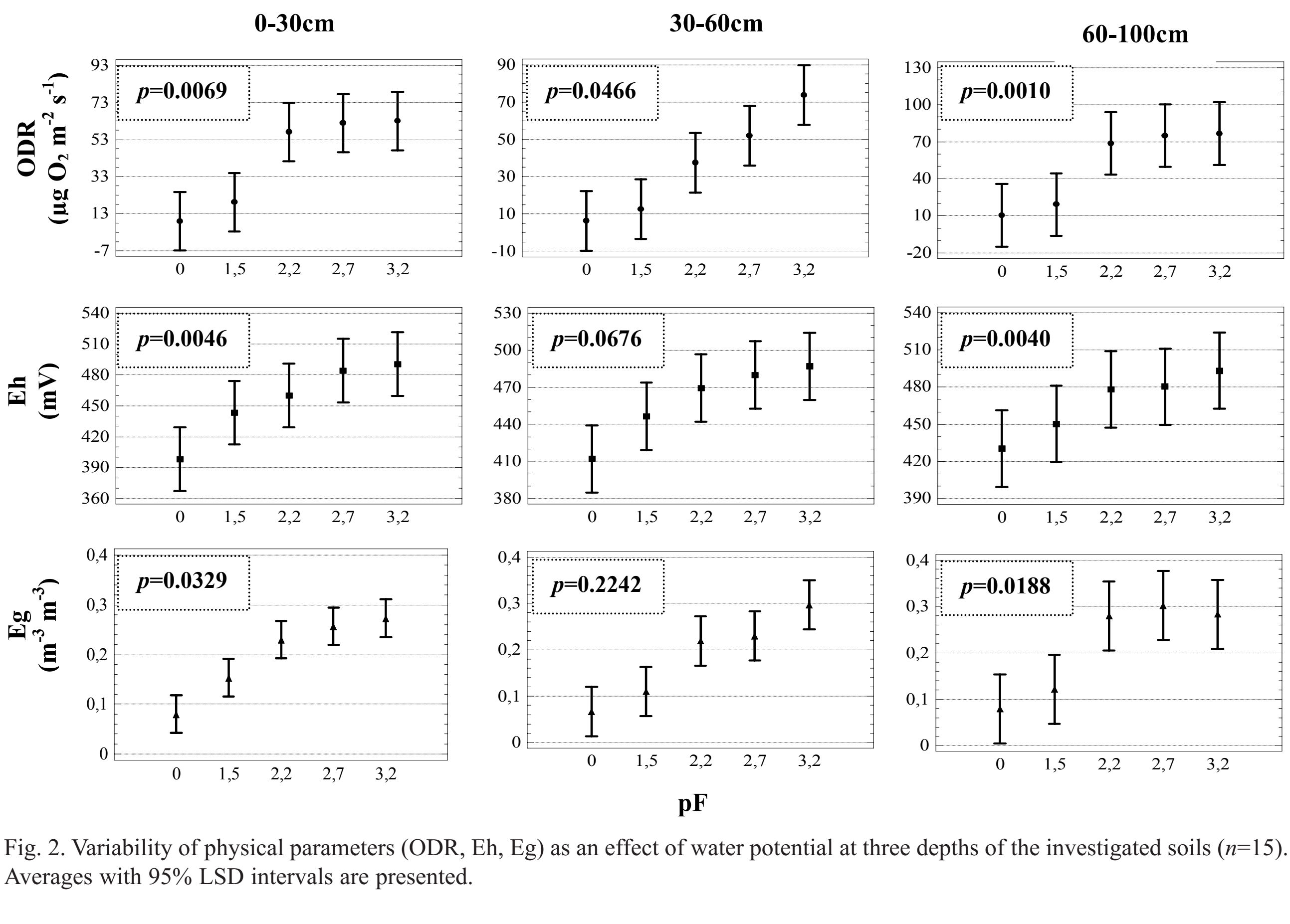

Fig. 2. Variability of physical parameters (ODR, Eh, Eg) as an effect of water potential at three depths of the investigated soils (*n*=15). Averages with 95% LSD intervals are presented.

Table 2. CO_2 evolution during soil incubation at 20ºC (CO_2 equilibrium content in soil headspace).

Soil respiration activity CO_2 ($mg \cdot kg^{-1} d^{-1}$)						
Soil type	DEPTH (cm)	pF 0	pF 1.5	pF 2.2	pF 2.7	pF 3.2
Orthic Podzol	0-30	16.85	19.75	19.84	23.61	20.98
	30-60	6.58	8.07	8.43	7.99	8.60
	60-100	5.79	7.02	7.46	8.16	6.76
Eutric Histosol	0-30	66.44	89.26	71.80	65.47	71.36
	30-60	11.50	11.85	14.74	15.27	16.50
	60-100	11.67	12.02	15.27	19.57	5.35
Haplic Phaeozem	0-30	89.88	91.20	78.56	72.85	71.36
	30-60	19.66	22.29	16.24	7.64	13.70
	60-100	1.58	1.58	7.46	7.64	10.44

No significant effect ($p<0.05$) of pF on RA was found in surface layers of *Orthic Podzol* and *Eutric Histosol*. But in the case of *Haplic Phaeozem*, a negative significant correlation ($p<0.001$) between pF and RA was noted (Table 3). Generally, a decrease of RA with depth in the soil profile was common. RA reached maximum values at the surface layers, which corresponded to the highest level of CO_2 evolution in *Haplic Phaeozem* (91.2-71.6 $mg \cdot kg^{-1} d^{-1}$) and to the lowest in *Orthic Podzol* (16.8-23.6 $mg \cdot kg^{-1} d^{-1}$).

The most remarkable drop of RA was by 98.2% in the subsoil of *Haplic Phaeozem* (pF 0), which was observed in relation to CO_2 evolution from the surface layer. RA noted in subsoil of *Orthic Podzol* and *Eutric Histosol* at full water capacity conditions (pF 0) were smaller by 65.6 and 82.4%, respectively. These results are consistent with other studies [4, 25, 26], showing an increase of RA after 7-10 days of soil incubation at the range of 69-170 mg CO_2 $kg^{-1} d^{-1}$. Sapundijeva et al. [27] measured the growth in CO_2 evolution even up to 20 days, whereas Taok et al. [28] found RA increasing during 7-8 days of incubation. Our data demonstrated maximum rates of microbial respiration at the highest water content (lowest tension), which is also consistent with the study of Linn and Doran [29].

Respiratory Quotient (RQ)

The RQ in soils is defined as the ratio of mole of O_2 uptake per mole of CO_2 respired [30, 31]. The RQ values (Fig. 3) were calculated on the molar changes in CO_2 and O_2 at the range of pF 0-pF 3.2 and at 20ºC. According to Chapman and Thurlow [32], a temperature lower than 22ºC increases the RQ and may favour conditions for the mineralization of cellulose rather than for lignin, which was the reason for the selection of temperature in our study.

RQ reached the highest values in *Orthic Podzol,* which ranged from 0.9 to 1.2 in the surface layer, from 0.8 to 0.9 in subsurface, and from 0.8 to 1.1 in subsoil. In *Eutric Histosol* RQ remained on a similar level (0.9) in surface, and 0.9-1.1 both in subsurface as subsoil. The lowest values of RQ were found in *Haplic Phaeozem,* which remained at the 0.9 level in the surface layer, and ranged between 0.7-0.8 and 0.5-0.8 in subsurface and subsoil, respectively.

Dilly [30] reported that RQ value is frequently higher than 1.0 under anaerobic or partially anaerobic conditions, if the oxygen supply is insufficient and when alternative electron acceptors are available (i.e. NO_3^-). However, even in aerobic soils with good oxygen supply anaerobic

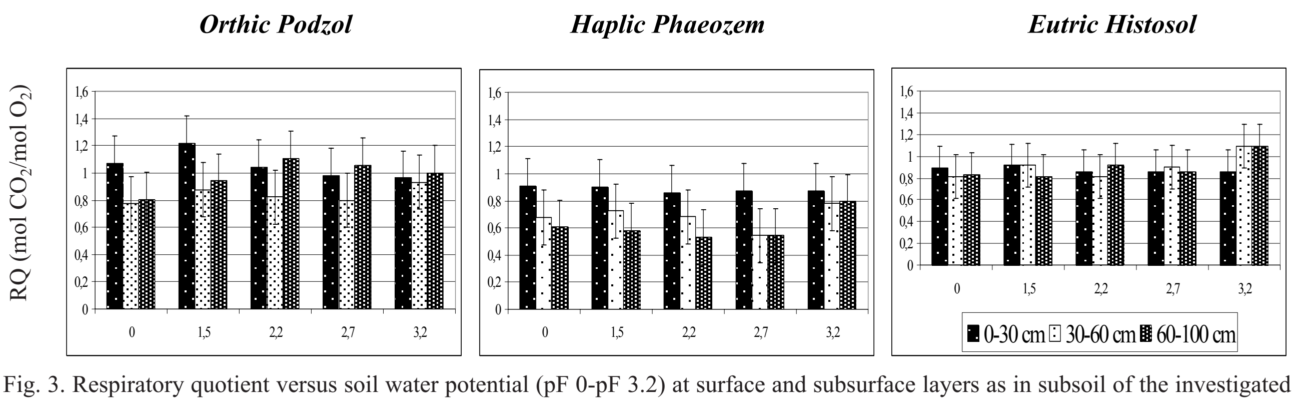

Fig. 3. Respiratory quotient versus soil water potential (pF 0-pF 3.2) at surface and subsurface layers as in subsoil of the investigated soils. Average values with standard deviations are presented.

Table 3. Relationships between RA and soil physical parameters (pF, ODR, Eh, Eg), n=15.

Respiration activity (mg CO_2 $kg^{-1}d^{-1}$)	Depth (cm)	pF	ODR	Eh	Eg
Orthic Podzol	0-30	n.s.	n.s.	n.s.	n.s.
	30-60	**0.90*** **	**0.62*** **	**0.55* **	**0.68** **
	60-100	**0.69** **	**0.81*** **	**0.75** **	**0.86*** **
Eutric Histosol	0-30	n.s.	n.s.	n.s.	n.s.
	30-60	**0.92*** **	**0.99*** **	**0.82*** **	**0.97*** **
	60-100	n.s.	n.s.	n.s.	n.s.
Haplic Phaeozem	0-30	**-0.88*** **	**-0.86*** **	**-0.85*** **	**-0.91*** **
	30-60	n.s.	**-0.70** **	**-0.60* **	**-0.56* **
	60-100	**0.90*** **	**0.90*** **	**-0.69** **	**-0.95*** **

*, **, *** – indicate significance at the 5, 1 and 0.1% levels, respectively,
n.s. – not significant differences

microsites may still exist. In our experiment those conditions took place both in the surface layer of *Orthic Podzol* (pF 0-pF 2.2) and in the subsoil (pF 2.2-pF 3.2). Similarly, RQ exceeded 1.0 in the subsurface and subsoil of *Eutric Histosol* at pF 3.2. Linn and Doran [29] found that RQ of soils incubated at 65% water content ranged from 0.9 to 1.1 and were characteristic of aerobic microbial respiration, whereas an increase of RQ from values 1.3 to 1.7 indicated a shift toward anaerobic metabolism. They also stated that reduced-oxygen diffusion (at higher water content) resulted in enhanced anaerobic respiration as indicated by an increase in RQ to values considerably higher than one. In general, RQ decreases as the C/O ratio in the components being metabolized increases (i.e. mineralization of humic acids results in RQ of 0.909) [30]. As mentioned above, RQ equal to 0.9 was reached in this study in surface layer of *Haplic Phaeozem*, all layers of *Eutric Histosol* (pF 0-pF 2.7), and at pF 1.5 in subsurface and subsoil of *Orthic Podzol*. The low RQ values might suggest that aliphatic organic compounds, amino acids or refractory compounds containing relatively low O_2 content were predominantly mineralized [4]. Those conditions are thought to have occurred predominantly in *Haplic Phaeozem* subsurface and subsoil, which was confirmed by attributing RQ values to this type of soil. Furthermore, a nitrification process may be responsible for lowering the RQ value by extra O_2 uptake [4].

Our study also determined the effect of depths on RQ values based on the investigated soils. Variability of RQ at three parts of the soil profiles (0-30, 30-60, 60-100 cm) are presented in Fig. 4. When all data from three soils together (n=45) were taken into account, there was a significant impact ($p<0.01$) of the depth on RQ values in the soil profile. The highest level of RQ (mean 0.94) was reached in the surface layers, lower at subsurface (0.82), and the lowest at subsoil (0.70).

Similarly to the study by Dilly [30], our analysis determined the highest RQ values in the topsoil with a moderate content of organic matter. However, Dilly [30] indicated that RQ might not be a sensitive enough measure to decide whether a soil is partially anaerobic. In any case, a high RQ indicates that more CO_2 is evolved per unit of consumed O_2.

Correlations between RA and pF, ODR, Eh, Eg

Statistical relationships between RA and physical factors are presented in Table 3. Significant influence ($p<0.05$) of tested parameters on RA was stronger in the subsurface and subsoil than in the surface portion of the soil profile. Although soil water content is a factor governing soil respiration, no significant relationships were observed in the surface layers of *Orthic Podzol* and *Eutric Histosol*. This founding is comparable with observations of Jiang et al. [1]. In the subsurface, significant effect of physical parameters on RA was noted in *Eutric Histosol*, which was confirmed by higher values of r coefficient than in *Orthic Podzol*. However, in the subsoil of *Orthic Podzol* the tendency was opposite, where the stronger impact of pF, ODR, Eh, and Eg on RA was found as demonstrated by significant positive correlations ($p<0.001$).

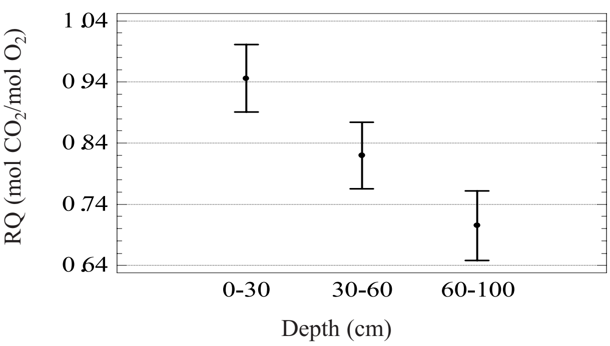

Fig. 4. Respiratory quotient at different depths (cm) of the soil profiles (n=45, $p<0.01$). Averages with 95% LSD intervals are presented.

A response of *Haplic Phaeozem* RA on pF, ODR, Eh, and Eg was completely different from the two other types of soil. In the surface layer significant negative ($p<0.0001$) correlations were associated with high values of *i* coefficient (Table 3).

Significant positive correlations between RA – water content (r=0.89***) were indicated by Linn and Doran [29] in the surface layer (0-7.5 cm) of *Pachic Argiustolls* soil and by Rigobelo and Nahas [33] in a topsoil 0-20 cm (r=0.51***). In contrast, our results revealed positive correlations between pF and RA deeper in the soil profiles with *r* equal to 0.90*** in subsurface of *Orthic Podzol* and *r* equal to 0.92*** in subsoil of *Eutric Fluvisol*. On the contrary, Wan et al. [5] noted a negative correlation of soil moisture and RA (*r* equal to -0.58***), analogously to the case of *Haplic Phaeozem* (r=-0.88***) in our experiment.

Both our and other studies demonstrated that RA can be highly sensitive to environmental factors, such as soil temperature and soil water content. However, prior to our study little attention had been paid to the influence of ODR, Eh, and Eg on soil RA. Therefore, our work focused on these relationships and determination of statistical correlations. Nevertheless, the interpretation of our results has been challenging because of the lack of available literature data from similar studies, with determined *r* coefficients as goodness of fit between physical parameters and RA. Consequently, more research on other soil types and under different conditions are needed for the complete understanding of soil processes as affected by physical parameters.

Conclusions

Our laboratory study revealed that the high soil water tension was responsible for the increase in ODR, Eh, and Eg from 7.5-84 μg O_2 $m^{-2} \cdot s^{-1}$, 350-20 mV, and 0.05-0.29 m^3m^{-3}, respectively.

Respiration processes were the most intensive in the surface parts of the soil profiles, in the range of 91.2-71.6 mg CO_2 $kg^{-1}d^{-1}$ in *Haplic Phaeozem*, 66.4-89.2 mg CO_2 $kg^{-1}d^{-1}$ in *Eutric Histosol*, and 16.8-23.6 CO_2 mg·$kg^{-1}d^{-1}$ in *Orthic Podzol*. Subsurface and subsoil were characterized by 65-98% reduction of soil RA in reference to surface layers. The topsoil parts of the profiles offered favorable conditions for gas exchange, manifested by the highest respiration rates at pF 1.5 for *Eutric Histosol* and *Haplic Phaeozem*, and pF 2.7 for *Orthic Podzol*.

The values of RQ coefficient were higher than 1.0 in the surface layer (pF 0-pF 2.2) and in subsoil (pF 2.2-pF 3.2) of *Orthic Podzol,* as well as in subsurface and subsoil of *Eutric Histosol* (pF 3.2). The lowest RQ level (0.5-0.8) was noted in *Haplic Phaeozem* subsoil. A significant drop ($p<0.01$) of RQ values with the increase of soil depth ranged from 0.94 to 0.7 in surface and subsoil, respectively.

Physical aeration factors (pF, ODR, Eh, Eg) had a statistically significant impact on RA. However, in general the effect was stronger in subsurface and subsoil of the investigated soils. The moisture factor (pF) had a significant influence on RA only in the topsoil of *Haplic Phaeozem* (r=-0.88***). In contrast, significant positive correlations pF-RA were determined in subsurface and subsoil of *Orthic Podzol* (r=0.90***, and 0.69**, respectively), subsurface of *Eutric Histosol* (r=0.92***), and in subsoil of *Haplic Phaeozem* (r=0.90***).

RA in *Orthic Podzol* was positively correlated with ODR, Eh, and Eg, both in subsurface and in subsoil, whereas in the case of the subsurface layer of *Eutric Histosol* the significant positive effect of these factors on RA was noted, but not its after layers. However, RA of *Haplic Phaezoem* was shown to be negatively related to the ODR and Eg at each depth of the soil profile. Negative correlations were also derived between RA and ODR in the surface and subsurface layers, with *r* equal to -0.86*** and -0.70***, respectively. A positive relationship between RA and ODR was also noted in subsoil (r=0.90***).

Finally, an important conclusion is that RA indirectly depended on the soil physical parameters related to soil aeration status. However, these dependences require further investigations and inclusion of other soil types in order to explain and further explore the significance of these correlations.

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