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Impact of different aeration conditions on the content of extractable nutrients in soil

T. Włodarczyk[1]*, *W. Stępniewski*[2], *M. Brzezińska*[1], *and G. Przywara*

[1]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland
[2]Chair of Land Surface Protection Engineering, Technical University of Lublin, Nadbystrzycka 40B, 20-618 Lublin, Poland

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A b s t r a c t. A pot experiment with triticale *cv.* Jago was conducted to test the effect of oxygen deficiency on the content of available macroelements. Oxygen stress (flooded conditions) distinctly conserved all the chemical species content but only at lowest density of soil combined with flooded conditions the decline of uptake of N-NH_4^+ and P and K was significant. A significant increase in (p <0.001) uptake of the investigated elements occurred in higher values of air filled porosity (*Eg*). The most sensitive element with respect to *Eg* value changes was phosphorus, the least one was potassium. The relation between redox potential (*Eh*) on NH_4^+, NO_3^-, P and K uptake was positive in all the investigated cases. The highest relation was observed in P uptake. The parameter of oxygen availability in the soil – ODR (oxygen diffusion rate) showed a typical tendency for changes under differentiated air-water conditions. The critical ODR value (about 35 μg m^{-2} s^{-1}) for uptake of all the studied elements was observed under the investigated conditions. Statistical analysis showed a significant relation between oxygen diffusion rate and NH_4^+, P and K uptake.

K e y w o r d s: flooded soil, extractable nutrients of soil, aeration parameters of soil

INTRODUCTION

Poorly-drained and badly-aerated soils occur in many parts of the world and it has been estimated that about 12% of the world's soils have excess water (Dudal, 1976). One of the most important factors of soil conditions is soil oxygen availability even during short periods of flooding, which can severely limit plant development and nutrient uptake (Stępniewski and Przywara, 1992). Waterlogging the soil creates anaerobic conditions markedly different from those of a well-drained aerobic soil. On the other hand water stress is an ubiquitous limiting factor in agriculture. Contrary to other factors that may limit crop yields *eg* acid, alkaline or saline soils) water availability is highly variable within a given growing season and from year to year (Gutiérrez-Boem and Thomas, 1999). Nitrogen, phosphorus and potassium are the most frequently deficient nutrients in crop production. In the biosphere N is available for plants in different forms, which include molecular N_2, volatile ammonia (NH_3) or nitrogen oxides (NO_x), mineral N (NO_3^- and NH_4^+) and organic N (amino acids, peptides, *etc*). The utilization of these N sources is determined strongly by environmental and particularly by the soil conditions (von Wirén *et al.*, 1997). In well-aerated soils, mineral N especially NO_3^- is the most abundant form of available N, while NH_4^+ dominates is soils in which nitrification is inhibited, for example under waterlogging or in cold climate conditions (Sasakawa and Yamamoto, 1978). Phosphorus is considered important because high P fixation by most soils requires the addition of a large excess of P fertilizer to meet crop requirements for good production (Loneragan, 1997). Chen *et al.* (1997), have observed that K application on K-deficient soils reduced the content of active reducing substances and ferrous iron in the soil, raised the soil redox potential in the rhizosphere, increased the *Eh* value of rice roots and lowered the content of iron in the rice plants.

We conducted a greenhouse experiment to test the relationship between the oxygen status of soil and the content of available nutrients in a pot experiment with triticale.

MATERIALS AND METHODS

Brown soil, developed from loess (Orthic Luvisol) containing 1.54% organic matter, 25% of the 1-0.05 mm fraction, 70% of the 0.05-0.02 mm fraction and 5% of the <0.02 mm fraction was used in the pot experiment. A greenhouse experiment was conducted in a polyethylene foil

*Corresponding author's e-mail: teresa@ipan.lublin.pl

tunnel. Two soil physical parameters that usually change in field conditions *ie* soil moisture and soil bulk density were varied to provide a range of soil oxygen conditions. The bulk densities used were: 1.20 (d_1), 1.35 (d_2), and 1.50 Mg m^{-3}(d_3). Up to the beginning of oxygen stress, an equal level of soil water content, which corresponds to soil water tension between 80-15 kPa (w_3) was maintained. Except during periods of oxygen stress, the same control soil water content was maintained in all pots.

In order to procedure different oxygen conditions during the 14-day periods of oxygen stress, (that is, to alternate oxygen diffusion rate – ODR values), two additional levels of soil water content were applied. They were a medium water content, corresponding to soil water tension in the range 2-5 kPa (w_2), and maximum soil water content (water tension equal 0 kPa – w_1), when during the whole period of stress there was a 2-5 mm layer of water on the soil surface.

The experiment consisted of one NPK level and one triticale species *cv*. Jago. Nutrients were added before sowing to each pot at the following doses (in g per 1 kg soil): 0.1 g N (NH_4NO_3), 0.125 g K (2/3 dose in K_2SO_4 and 1/3 dose in KCl) and 0.066 g P ($CaHPO_4$ $2H_2O$).

Triticale plants thinned to 25 per pot were subjected to oxygen stress in the three following stages of their development:
– stress I – at the stage of tillering,
– stress II – at the stage of shooting,
– stress III – at the stage of the beginning of flowering.

Therefore the experimental design comprised 3 soil water contents and 3 soil bulk densities with 4 replications. This gave 108 pots (each 6 dm^3 in volume containing 6.5 kg of soil).

Platinum electrodes, 4 mm long and 0.5 mm in diameter, were used for the ODR measurements. The measurements were made with an ODR-meter having an automatic polarization voltage control (Malicki and Walczak, 1983). The electrode polarization time was 4 min, and the polarization voltage was –0.65 V versus a saturated c alomel electrode.

The redox potential (*Eh*) of soil samples was measured potentiometrically using four Pt electrodes (of the same type as for ODR) saturated calomel electrode as a reference, and a portable pH-meter (Orion).

Nitrate-N in soil was determined potentiometrically after extraction in 1 M CH_3COONH_4 using a nitrate selective electrode (Stępniewska, 1988). Ammonium-N was extracted from the soil samples with 1 M KCl according to the Nessler method (Hanna, 1964). Exchangeable P was measured using the Egner method as modified by Riehm (Schlichting *et al.*, 1995). K was determined in the calcium lactate extract by the ASA method (Schlichting *et al.*, 1995). All the measurements were done in 2.5 g soil samples.

Water content, bulk density and particle density were determined by methods described by Turski *et al.* (1983).

Each measurement was taken four times during each stress (3rd, 7th, 10th and 14th day).

RESULTS AND DISCUSSION

The influence of combination of the two physical parameters, which differentiated soil oxygen conditions *ie* soil moisture and soil bulk density on NH_4^+, P, K, and NO_3^- content, is presented in Fig 1. Concentrations of the investigated elements was highest in flooded soil (w_1) in all of the experimental treatments (except one) independently of soil bulk density, with a tendency to decrease with decreasing of water content (w_2, w_3), except of potassium content. Oxygen stress (flooded conditions) distinctly conserve the content of all elements under investigated conditions. Probably oxygen stress caused reduction of nutrient uptake by plants. Gutiérrez-Boem and Thomas (1999) observed that water stress reduced shoot growth, P absorption and concentration. Wiersum (1967) found that in tops of wheat nitrogen uptake was always less under oxygen stress than with a sufficient oxygen supply to the roots. According to Trought and Drew (1980) the anoxia of wheat roots completely inhibits potassium uptake, as in the case of nitrogen and phosphorus.

The combinations of soil water content and soil bulk densities differentiated contents of the chemical species in the soil. There were significant differences in NH_4^+, P and K (Fig. 1a, b, c) contents between highest water content (w_1), and the lowest bulk density (d_1) except of NO_3^- content (Fig. 1d) with a tendency for decreases of contents with decreasing of water content (w_2 and w_3). That tendency was maintained for more compacted soil (d_2) in the case of nitrate-N, P and K content and highest density (d_3) for P content. There were no significant decreases in the other chemical species contents.

Our results showed that flooded conditions more differentiated the elements content in the soil than soil bulk density. Ono (1989, 1990) reported that soil N mineralization is more rapid under waterlogged than under aerobic conditions. The combination of lower humidity (w_2 and w_3) with all densities did not show any significant difference.

Relation between aeration status of soil as characterized by air-filled porosity (a), redox potential (b), and oxygen diffusion rate (c) and NH_4^+, NO_3^-, P and K uptake (Δ value) is shown in Figs 2-5. This uptake was calculated from the difference between the initial contents of the nutrients, and the contents at given time of experiment. A significant increase in uptake of the investigated chemical species occurred with an increase of air-filled porosity. The most sensitive element with respect to *Eg* value was phosphorus (p <0.001), the least one was potassium (Figs 2a-5a).

The influence of redox potential on uptake of NH_4^+, NO_3^-, P, and K was positive in all the investigated cases (Figs 2b-5b). The highest correlation was observed in the case of P (p <0.001). The least sensitive chemical species with respect to lower *Eh* value was nitrate but also significant. Most of the processes contributing to the nitrogen pool in soil and its chemical competition are related to

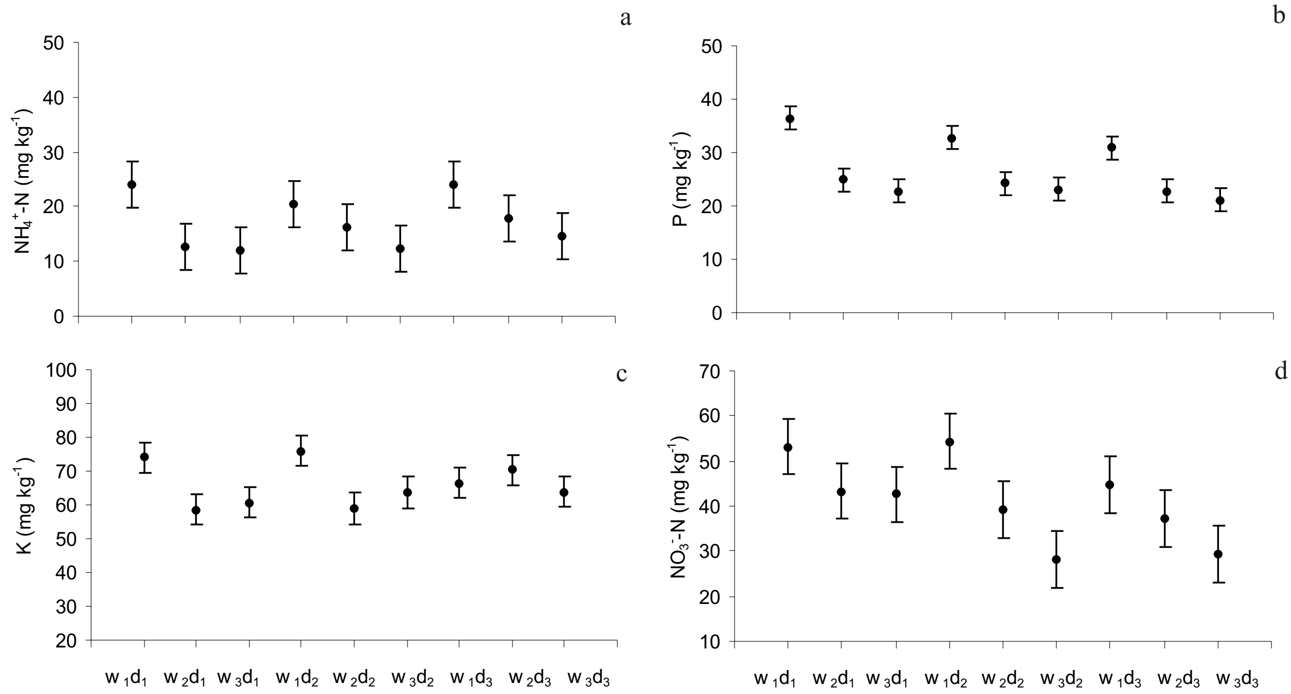

Fig. 1. NH_4^+-N (a), P (b), K (c), and NO_3^--N (d) content in the soil at three soil water contents and three bulk densities (average value over the entire growth period): w_1 – flooded soil 0 kPa; soil moisture tensions: w_2 – 2-5, w_3 – 80-15 kPa; bulk densities: d_1 –1.2, d_2 – 1.35, d_3 – 1.50 Mg m^{-3}. The bars represent 95% LSD.

oxygen status of the soil, *ie* denitrification, nitrification, processes of microbial fixation of atmospheric nitrogen, and ammonification (Gliński and Stępniewski, 1985). Flooding the soil increases the availability of both native and added P, whether judged by solubility in different extractants or uptake by rice plants (Khalid *et al*., 1979; Ponnamperuma, 1972). Due to this a negative correlation between *Eh* and P solubility has been recorded (Savant and Ellis, 1964).

The changes of oxygen availability (ODR) in the soil under the studied conditions are shown in Figs 2c-5c. Statistical analysis showed a significant relation between oxygen diffusion rate and NH_4^+, NO_3^-, P, and K uptake. The ODR characterize potential oxygen availability for plant roots. The critical ODR value which is usually considered to be below 35 μg m^{-2} s^{-1} (Gliński and Stępniewski, 1985; Stępniewski, 1980; Stępniewski *et al*., 2002) for most cultivated plants, was observed in all studied chemical species under investigated conditions. Stępniewski and Łabuda (1989) studied the influence of flooding of spring barley on its growth, yield, and N, P, K content and uptake, and found that oxygen stress caused reduction and irreversible blocking of N, P, and K uptake. Stępniewski and Przywara (1992) found that the uptake of N, P, K, Ca, Mg and Na by winter rye was decreased at low oxygen availability.

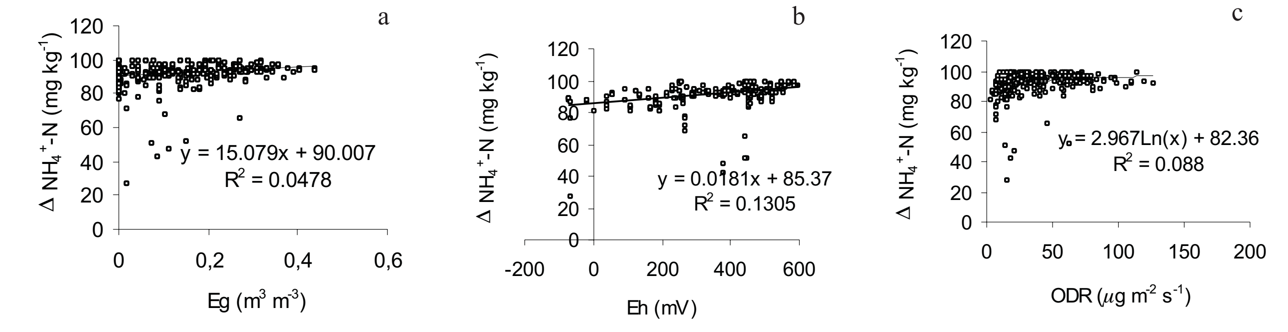

Fig. 2. Dependence of NH_4^+-N uptake (ΔN) on air-filled porosity (a), *Eh* (b) and ODR (c) in the soil (the results for all the soil water contents and bulk densities combined) (ΔNH_4^+-N is a difference between initial NH_4^+-N in the sample and the NH_4^+-N concentration under given conditions).

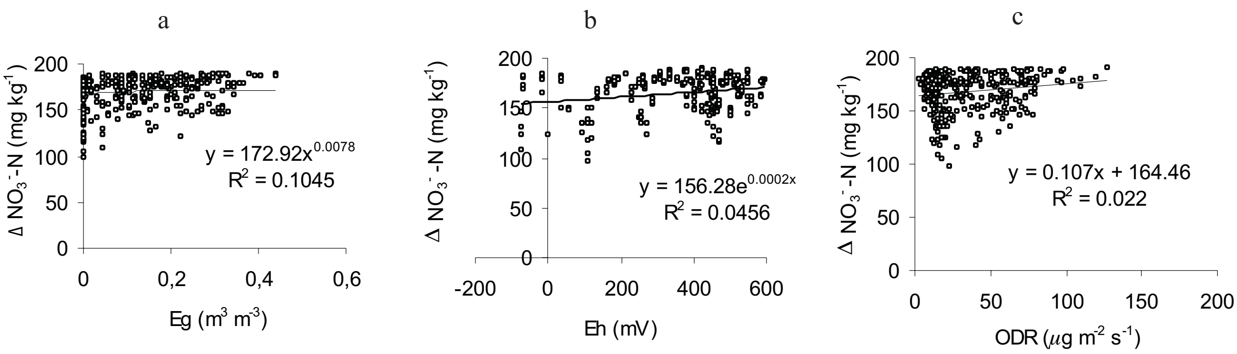

Fig. 3. Dependence of NO_3^--N uptake (ΔN) on air-filled porosity (a), *Eh* (b) and ODR (c) in the soil (the results for all the soil water contents and bulk densities combined) (ΔNO_3^--N is a difference between initial NO_3^--N in the sample and the NO_3^--N concentration under given conditions).

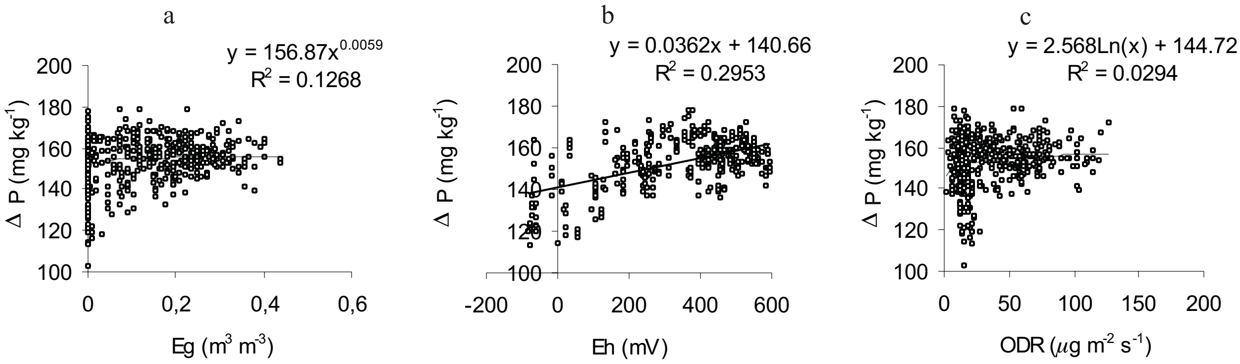

Fig. 4. Dependence of P uptake (ΔP) on air-filled porosity (a), *Eh* (b) and ODR (c) in the soil (the results for all the soil water contents and bulk densities combined) (ΔP is a difference between initial P in the sample and the P concentration under given conditions).

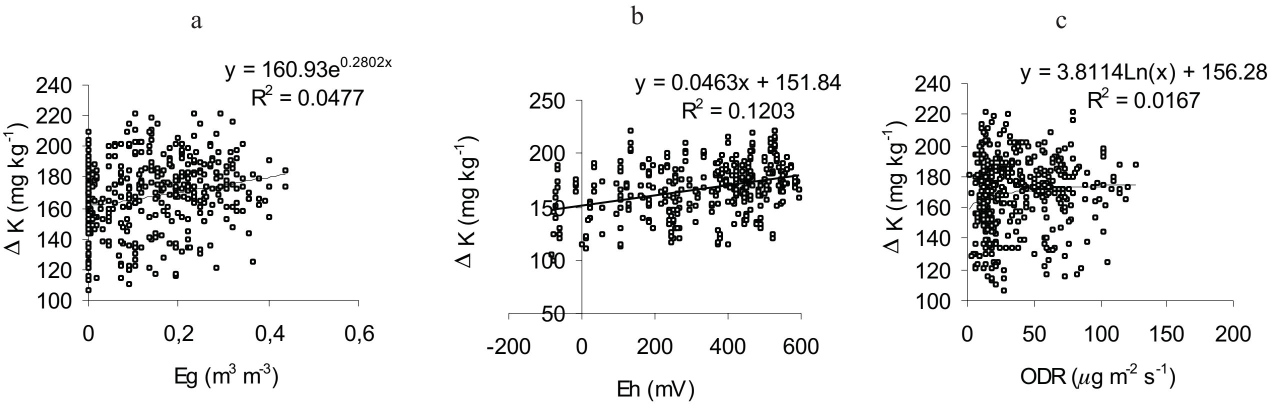

Fig. 5. Dependence of K uptake (ΔK) on air-filled porosity (a), *Eh* (b) and ODR (c) in the soil (the results for all the soil c water contents and bulk densities combined) (ΔK is a difference between initial K in the sample and the K concentration under given conditions).

CONCLUSIONS

1. Oxygen stress (flooded conditions) made distinctly worse the uptake of all nutrients under the investigated conditions.

2. The lowest soil density combined with flooded condition significantly changed the uptake of N-NH_4^+ and P and K.

3. A significant increase in uptake of investigated nutrients occurred in higher values of air-filled porosity (p <0.001). The most sensitive element with respect to *Eg* value was phosphorus, the lowest one was potassium.

4. Uptake of NH_4^+, NO_3^-, P and K showed a positive correlation with redox potential. The highest correlation was observed in P uptake (p <0.001).

5. The critical ODR value (about 35 μg m^{-2} s^{-1}) for uptake of all studied nutrients was observed under investigated conditions. Statistical analysis showed a significant correlation between oxygen diffusion rate and NH_4^+, P and K uptake in the soil.

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