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Influence of oxygen conditions on the yield and mineral composition of triticale cv. Jago

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A b s t r a c t. Plants in the farmland ecosystem are subject to impeded aeration at some stages in their development. The achievement of long term tolerance to prolonged periods of poor aeration by some plants holds considerable economic and environmental significance. Short periods of flooding can damage the roots and this in turn, may lead to the appearance of stress symptoms. Soil flooding reduces shoot and root growth, dry matter accumulation, and causes the disturbance of plant mineral composition. The influence of differentiated soil aeration on triticale cv. Jago mineral composition and the uptake of nutritive components by grain was studied in a greenhouse pot experiment. Soil aeration was differentiated by manipulating soil water tension and bulk density. The soil bulk densities used during the experiment were: 1.20, 1.35 and 1.50 Mg m^{-3}. The soil water tensions used were 15-80 kPa (control), 2-5 kPa and 0 kPa (2-5 mm of water ponded on the soil surface). The 2-5 hPa and 0 kPa water tensions were applied beginning at 3 growth stages (stress I at tillering stage, stress II at shooting, stress III beginning of flowering) for a period of 15 days. The yield of grain mass at full maturity decreased significantly when soil hypoxia were imposed at the tillering stage. The analysis of variance showed a significant reduction of the straw mass and total yield of triticale at higher bulk densities. The concentrations of N, P, K in grain at full maturity were not significantly correlated with oxygenation indexes (ODR and Eh). The uptake of N, P, K by triticale grain increased linearly with redox potential in the range of 100-580 mV. Nitrogen uptake by triticale grain was positively correlated with ODR in the range of 20-80 μg m^{-2} s^{-1}. Phosphorus and potassium uptake were not found to be correlated with ODR. The tested cultivar of triticale was less sensitive to a deficiency of oxygen as compared to another cereals plants such as rye, wheat and barley.

K e y w o r d s: triticale, yield, N, P, K uptake, ODR, Eh

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INTRODUCTION

Plants in most farmland ecosystems are subjected to incidental or prolonged impeded aeration at some stages of their development. The achievement of tolerance to prolonged poor aeration by some plants is of considerable economic and environmental significance.

Many environmental factors are important in regulating yield and nutrient accumulation by plants in the presence of anoxic conditions.

In well - aerated media, roots receive a supply of oxygen from their immediate surroundings. The gas diffuses from the soil air into the thin film of water and mucigel at the epidermal surface, and diffuses as dissolved O_2 across the cell wall and into the cytoplasm.

The yield of cultivated plants depends largely on soil conditions. Short periods of flooding can damage the roots and this in turn, may lead to the appearance of stress symptoms such as decreased growth of shoots, leaf epinasty and necrosis. The physiological effects of flooding on most plants include a decrease in uptake and transport of ions through roots. Soil waterlogging reduces shoot and root growth, dry matter accumulation and final plant yield [1,4]. Waterlogging can also depress absorption of water [6,11], reduce photosynthesis [12] and alter root and shoot hormone relations [9].

Physiological effects of flooding on most plants include a decrease in the uptake and transport of ions through roots [3,5,13]. Changes in supplies of growth substances from roots to shoots could perhaps modify gas exchange. But there is a reason to think that the inhibition of ion transport to leaves, independently, could also exert a marked effect on leaf gas exchange. Soil flooding virtually arrests ion uptake by 'unadapted' roots with the pronounced lowering of the average concentration of ions in the leaves, due to translocation from older to younger leaves.

Throught and Drew [15] observed that decreases in concentrations of nitrogen, phosphorus, potassium, calcium and magnesium in the shoots of wheat seedlings soon after the start of waterlogging were mainly attributed to the inhibition of ion uptake and transport by the roots in the oxygen deficient soil.

Some research has been done on the accumulation of N, P and K in the grain of winter wheat (*Triticum aestivum* L.) and the translocation of these nutrients in the plant as related to aeration conditions, e.g., [7,14], but little work has been done on the accumulation of dry matter in the grain, straw and roots of triticale at different growth stages.

The object of this investigation was to evaluate the effect of soil flooding at three growth stages of triticale (cv. Jago) on grain, straw and total yield and the mineral composition of grain at full maturity.

METHODS

The experiment was conducted in a greenhouse. The study material was triticale (cv. Jago) grown to full maturity on a brown (Orthic Luvisol) loess soil (Ap horizon from Elizówka), containing 1.54% organic matter, 25% of 1-0.05 mm fraction, 70% of the 0.05-0.002 mm fraction and 5% clay. The experimental cycle comprised 108 pots with a volume of 6 dm^3, and a height of 25 cm. All the pots were filled with 6.5 kg of soil (on an oven dry basis), and 48 seeds were sown into each pot. Ten seedlings per pot were cultivated to full maturity.

Soil oxygen conditions were differentiated by manipulating two physical parameters which commonly vary under field conditions, i.e., soil moisture and soil bulk density. Some control level of the soil moisture content was maintained in all the pots up to the beginning of stress, i.e., 0.14-0.18 kg kg^{-1} corresponding to a soil moisture tension between 80 and 15 kPa. Three levels of soil compaction were used: 1.20, 1.35, 1.50 Mg m^{-3}.

In order to differentiate oxygen conditions as characterised by oxygen diffusion rate (ODR) and redox-potential (Eh) values during two weeks of oxygen stress, two additional moisture levels were applied along with a controlled moisture level. These were a medium - level moisture (corresponding to soil moisture tension 2-5 kPa), and a maximum moisture content (moisture tension equal 0 kPa), when during the whole stress period there was a 2-5 mm layer of water on the soil surface. Thus, nine levels of soil oxygenation were applied in the experiment with their physical parameters shown in Table 1.

Triticale plants were subjected to oxygen stress lasting for 15 days at the three following stages of their development:

Stress I- at the tillering stage.

Stress II - at the shooting stage.

Stress III - at the commencement of flowering stage.

Platinum electrodes, 4 mm long and 0.5 mm in diameter, were used for the ODR and the Eh measurements. The ODR measurements were made with an ODR-meter with automatic polarisation voltage control [10]. The electrode polarisation time was 4 min, and the polarisation voltage was - 0.65 V versus a saturated calomel electrode. Each measurement was taken four times during each stress (2-nd, 5-th, 9-th and 14-th day). The measurements were always taken with 8 platinum electrodes placed in the soil at a depth of about 6-7 cm. The redox potential was measured potentiometrically using Pt electrodes (of the same type as for ODR), a saturated calomel electrode, and a laboratory pH meter (Radiometer, Kopenhagen). The electrodes were placed at a depth of 6-7 cm. The measurements were taken after stabilisation of the readings. The ODR and Eh value for each pot was the arithmetical mean of 32 individual measurements.

The plants were harvested after the grain had ripened. The grain, straw and root dry mass and grain mineral composition were determined.

Table 1. Physical parameters of brown loess soil (Ortic Luvisol) from Elizówka under experimental conditions

Oxygenation level	Soil bulk density (Mg m^{-3})	Soil moisture tension (kPa)	Moisture content by weight (kg kg^{-1})	Volumetric moisture content (m^3 m^{-3})	Air-filled porosity (m^3 m^{-3})
1	1.20	0	0.40	0.48	0.06
2	1.20	5-2	0.27-0.29	0.32-0.35	0.22-0.19
3	1.20	80-15	0.14-0.18	0.17-0.22	0.37-0.32
4	1.35	0	0.34	0.46	0.02
5	1.35	5-2	0.24-0.25	0.32-0.35	0.16-0.13
6	1.35	80-15	0.14-0.18	0.19-0.24	0.29-0.24
7	1.49	0	0.28	0.42	0.01
8	1.49	5-2	0.21-0.23	0.32-0.35	0.11-0.08
9	1.49	80-15	0.14-0.18	0.21-0.27	0.22-016

The plant mineral composition was determined after wet combustion in H_2SO_4 with an addition of H_2O_2. The nitrogen content was estimated by potentiometric titration with NaOBr, P - by the vanadate-molibdenum method and K by flame photometry.

All the data was subjected to analysis of variance using Statgraphics 5.

RESULTS AND DISCUSSION

The yield of vegetative parts, grain and total yield (roots + vegetative parts + grain) as influenced by different oxygen conditions at three stages of plants development has been presented in Figs 1-6.

The inadequate oxygen supply to the root system (soil flooding) did not influence the straw mass of the plants tested (Fig. 1). As shown by the analysis of the variance, a significant reduction of the straw mass was observed for plants stressed during the shooting stage at different bulk densities. It showed a significant decrease in straw mass from 22.7 g at 1.20 Mg m^{-3} to 13.4 g at 1.50 Mg m^{-3} (Fig. 2).

The analysis of variance showed a significant reduction in grain mass from 10.8 g (II - stress applied during the shooting stage) to 8.7 g (I - stress applied during the tillering stage). It was found that the grain mass at the earliest development stage was lower by about 20%, compared to the grain mass of plants stressed at the shooting stage.

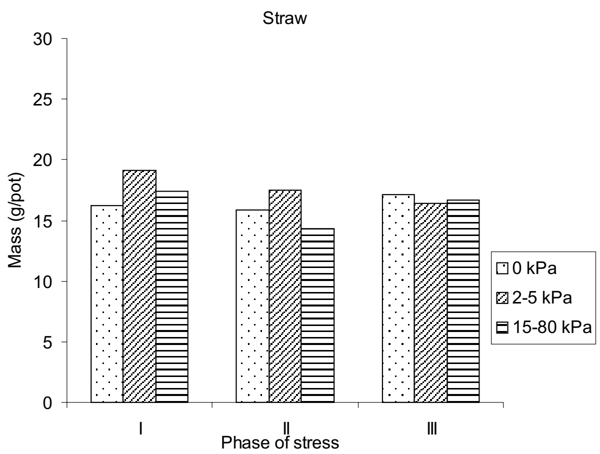

Fig. 1. Dry mass of straw of mature triticale cv. Jago plants subjected to differentiated soil moisture conditions at three growth stages.

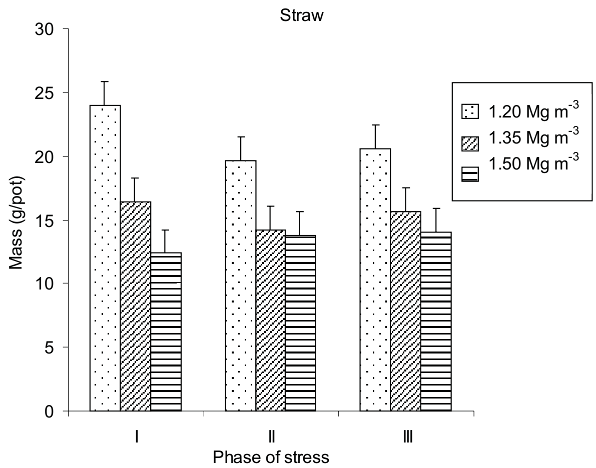

Fig. 2. Straw dry mass of triticale cv. Jago at different soil bulk densities (means of 12 pots). The bars represent 95% LSD confidence intervals for interaction factors. $LSD_{95\%}$ = 2.14. The analysis of variance showed that the general means of the straw mass of the plants (32 pots) grown at highest bulk density 1.50 Mg m^{-3} (13.4 g/pot) was significantly lower than those of bulk density 1.20 Mg m^{-3} (22.7 g/pot).

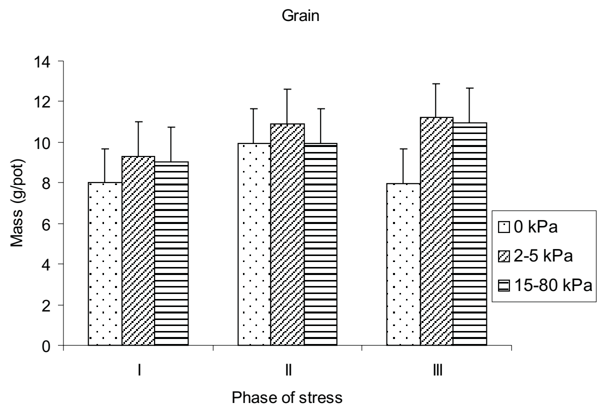

Fig. 3. Grain mass of triticale cv. Jago under different moisture conditions (means of 12 pots)at three phases of the applied stress. The bars represent 95% LSD confidence intervals for interaction factors. $LSD_{95\%}$ = 1.69. The analysis of variance showed the lowest general means of the plants (32 pots) subjected to the I stress (8.7 g) as compared to those of the II stress 10.8 g.

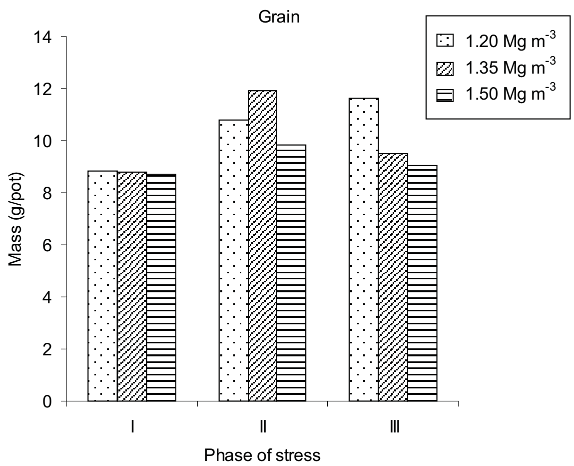

Fig. 4. Grain dry mass of triticale cv. Jago at different soil bulk density.

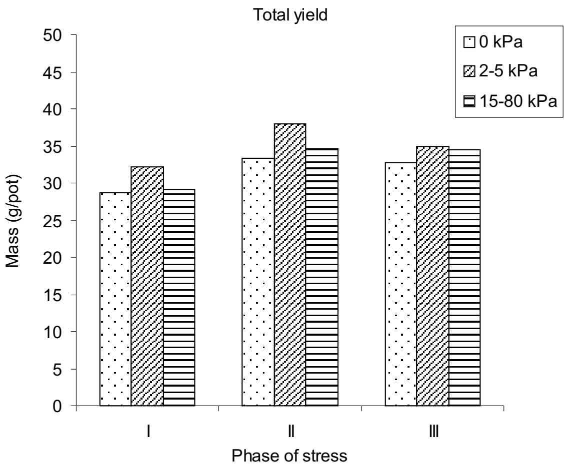

Fig. 5. Total dry mass of triticale cv. Jago under different moisture conditions at three phase applied stress.

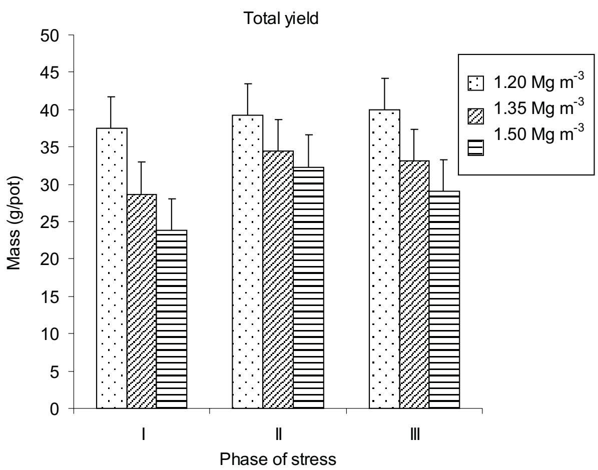

Fig. 6. Total dry mass of triticale cv. Jago under different soil bulk density. The bars represent 95% LSD confidence intervals for interaction factors. $LSD_{95\%}$=4.26. The analysis of variance showed that the general means of the total plants mass (32 pots) was significantly lower with an increase of bulk density from 40.3 g at 1.20 Mg m^{-3} to 33.0 g at 1.35 Mg m^{-3} and to 28.4g at 1.50 Mg m^{-3}.

Considering the phase at which the stress was applied, it was concluded that this influenced the triticale yield. In the cases studied, stress at the tillering stage caused the greatest significant decrease of grain yield (Fig. 3). The lowest grain yield of triticale was obtained at 1.35 and 1.50 Mg m^{-3}, but these differences were not significant.

The plants were grown under redox-potential values varying from 170 to 500 mV. Redox-potential increased with moisture tension to 170, 380 and 495 mV at 0, 2-5 and 80-15 kPa, respectively.

Gliñski *et al.* [8] estimated critical and limiting Eh values for the emergence of 9 crops (rye, oats, winter wheat, spring barley, maize, sugar beet, tomato, flax and bean). The critical value varied within 340-450 mV and the limiting value within the range of 400 to 540 mV.

Soil waterlogging reduces shoot and root growth, dry matter accumulation and the final yield of plants [1,3].

Few papers have reported the response of winter rye to soil flooding at different development stage of the plants. A significant decrease in straw, root and grain mass, and a lowering of total yield occurred for low ODR values. The reduction in grain yield was not clearly connected with the stage at which the stress was applied, whereas the reductions in straw and total yield decreased when stresses were applied later [12]. Dechnik *et al.* [2] observed an increase in N and a decrease in P (without an effect on K) in winter rye grain associated with up to four weeks of flooding at stem elongation.

Figure 5 showed, that the inadequate oxygen supply to the root system (soil flooding) did not influence the total mass of the plants tested.

The total yield (roots + vegetative parts + grain) as influenced by different bulk density at three stages of plants development is presented in Fig. 6.

The analysis of variance showed a significant reduction of total yield as influenced by bulk density from 40.3 g at 1.20 Mg m^{-3} to 33.0 g at 1.35 and to 28.4 g at 1.50 Mg m^{-3} (Fig. 6).

The Eh decreased with the increase of soil bulk density to 435, 345 and 315 mV at 1.20, 1.35 and 1.50 Mg m^{-3}, respectively.

The ODR also decreased with an increase of soil bulk density to 49, 37 and 30 μg m^{-2} s^{-1} at 1.20, 1.35 and 1.50 Mg m^{-3}, respectively.

The concentrations of N, P, K in grain at full maturity were not significantly correlated with oxygenation indexes (ODR and Eh).

Our results, for plants analysed at maturity show less treatment effect on mineral composition than found for plants analysed immediately after stress was imposed, a situation most commonly reported in the literature [7].

The nitrogen, potassium and phosphorus uptake by the triticale grain (Fig. 7) decreased at low Eh values. The lowest N, P, K uptake was about 25-40 % of that in adequate oxygen conditions. The nitrogen uptake by the triticale grain cv. Jago decreased at low ODR values. Optimum plant response requires > 30 μg m^{-2} s^{-1}.

The uptake of N, P, K by the triticale grain increased linearly with Eh in the range of 100-580 mV. The nitrogen uptake by the triticale grain was positively correlated with ODR in the range of 20-80 μg m^{-2} s^{-1}. The phosphorus and potassium uptake were not found to be correlated with the ODR.

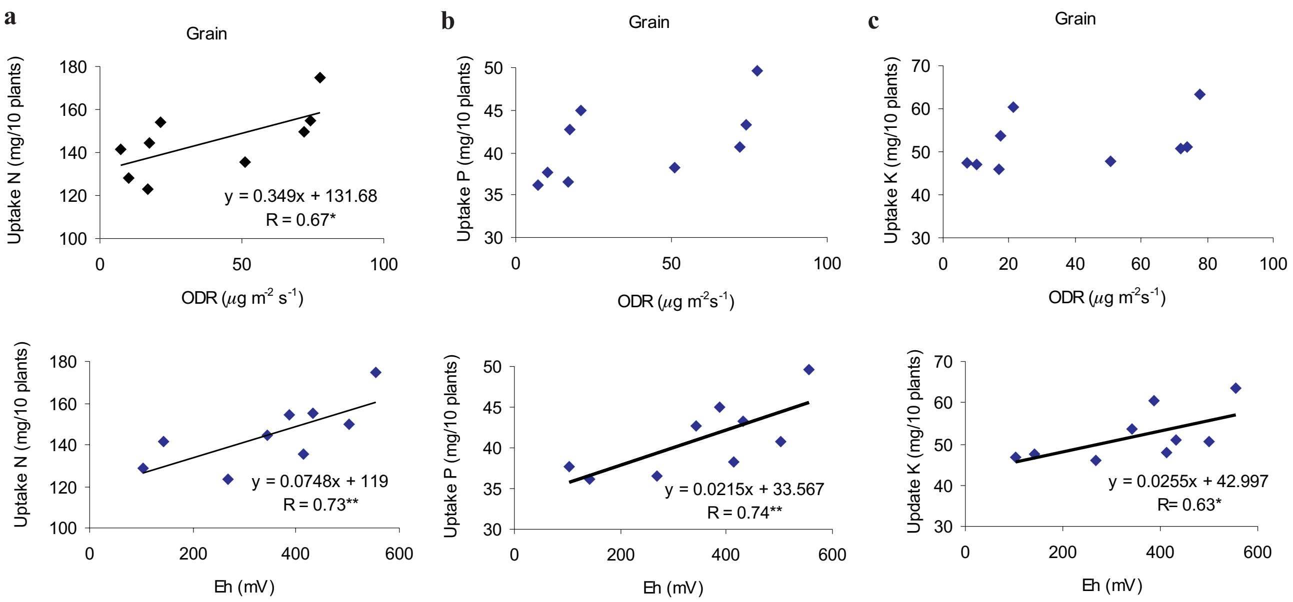

Fig. 7. Relation between oxygenation indexes (ODR, Eh) and nitrogen (a), phosphorus (b), and potassium (c) accumulations in triticale grain cv. Jago.

CONCLUSIONS

1. The grain mass of the plants stressed at the tillering stage was lower by about 20% compared to that of the plants subjected to stress at the shooting stage.

2. The uptake of N by triticale grain increased linearly with ODR and Eh, while that of P and K - with Eh.

3. The tested cultivar of triticale was less sensitive to a deficiency of oxygen in comparison to other cereals plants such as: rye, wheat, barley.

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