THE INFLUENCE OF DEFICIENT NUTRITION ON GROWTH AND ROOT ACTIVITY OF MAIZE (ZEA MAYS L.) UNDER HYDROPONIC CONDITIONS

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Abstract: Root system plays important role in uptake of nutrients which influences the crop quality and yield. On the other hand, soil bioavailable nutrient supply is one of main limiting factor affecting development of the roots. The aim of hydroponic cultivation experiment was the determination of the nutrition deficient impact on the root system of maize (Zea Mays L.). In this experiment the root system was described by electric capacity due to we are able to find the active parts of root which are responsible for main uptake of nutrition. Three deficiency variants (nutrition solution without nitrogen, phosphorus and potassium) and one variant with all nutrition (control variant) were observing. The weight of root dry matter of variant with P deficiency was increased in time (from 20 to 77 mg/plant), on the contrary the weight of root dry matter of variant with K deficiency was decreased in time. The electric capacity has similar trend, it was increased in variant with P deficiency and it was decreased in variant with K deficiency in the 3rd term (0.078 nF).

Key Words: maize, hydroponic cultivation, deficient nutrition, root dry matter, root electrical capacity

INTRODUCTION
Maize (Zea Mays L.) is plant with huge root system. The root system has essential importance for water and nutrition uptake. The nutrition is one of the limiting factor involves the growth and development of the roots. The bioavailability of nutrients in the soil solution may determine growth, size and activity of root system. Important developmental processes, such as root-hair formation, primary root growth and lateral root formation, are particularly sensitive to changes in the internal and external concentration of nutrients (Lopez-Bucio et al. 2003). Contents and bioavailability of soil nutrients are critical factors for plant growth and productivity (Baligar et al. 1998). Nitrogen (N), phosphorus (P) and potassium (K) are the nutrients that are responsible for alter post-embryonic root developmental processes (Zhu et al. 2005, Wissuwa et al. 2005, Liu et al. 2008, Hawkesford et al. 2012, Kellermeier et al. 2013).

For evaluation of the size of root system could be use measurement of root capacitance which is a nondestructive method to estimate the size of plant root systems (Chloupek 1977, Dalton 1995). This method enables to find only the active (life) part of root because the polarization of life membranes or cells is realising there, so the live parts are electric active (Středa and Klimešová 2016). The positive relative between root electric capacity and the weight of root system was found during many experiments, for example at sunflower (Rajkai et al. 2005) or at durum wheat (Nakhforoosh et al. 2012).

The aim of this work was to characterize the effect of primary nutrients (N, P and K) deficiency on the maize root system weight and electrical capacity in the earliest stages of development.

MATERIAL AND METHODS
Vegetation pots experiment in the form of an aqueous culture with maize (Zea Mays, L.) was commenced in growth chambers of the Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Faculty of AgriSciences, Mendel University in Brno in 2014.
Maize was sown into a nutrient-free substrate and when the plants’ roots reached approximate length 3 cm (5 days after beginning of germination – DAG), they were put into vegetation pots with nutrient solutions of different composition (Table 1). The solution had been prepared by using the method of Hoagland (Hoagland and Arnon 1938). 11 litre glass pots, which were wrapped around in non-transparent film, were used as vegetation pots. In each pot the nutrient solutions were aerated at regular time terms (5 minutes in each 3 hours). The vegetation pots were in growth chambers (PlantMaster, CLF Plant Climatics GmbH, Germany) in controlled temperature, humidity and light mode (12 h day length, temperature of 23/18 °C (day/night) and relative humidity of 55/70%, photosynthetic photon flux density of 350 µmol/m²/s). When the experiment was set up, 0.5% solution of iron (ferric chloride) was added to all solutions (Laštůvka and Minář 1967). The pH value of all solutions was monitored and it was constant during the entire experiment.

Table 1 Treatments of the experiment and weights of chemicals (g per 1 litre of nutrition solution) according to Hoagland and Arnon (1938)

<table>
<thead>
<tr>
<th>Nutrient solutions</th>
<th>Ca (NO₃)₂</th>
<th>KNO₃</th>
<th>K₂SO₄</th>
<th>KH₂PO₄</th>
<th>Ca (H₂PO₄)₂</th>
<th>CaSO₄·2H₂O</th>
<th>MgSO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>complete</td>
<td>0.821</td>
<td>0.506</td>
<td>–</td>
<td>0.136</td>
<td>–</td>
<td>–</td>
<td>0.120</td>
</tr>
<tr>
<td>without N</td>
<td>–</td>
<td>–</td>
<td>0.871</td>
<td>–</td>
<td>0.117</td>
<td>0.344</td>
<td>0.060</td>
</tr>
<tr>
<td>without P</td>
<td>1.231</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.241</td>
</tr>
<tr>
<td>without K</td>
<td>1.231</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.117</td>
<td>–</td>
<td>0.241</td>
</tr>
</tbody>
</table>

As model crop was used maize variety SY ONDINA. Syngenta (2004) presents this variety like mid-early hybrid with FAO 290, for grain and silage use, flinty dent grain type, hybrid is stable, adapted to growing in various climatic zones, moderately high plants, high harvesting potential, high starch content, highly tolerant to rust and helminthosporiosis. During the experiment the sampling of plants was in regular terms of 7 days (13 DAG, 20 DAG, 27 DAG).

Immediately after sampling, the electrical capacity of the root system was determined (Chloupek 1977, Dalton 1995). It was measured by LCR meter ELC-131D at a frequency of 1 kHz in nanofarads (nF) in distilled water of constant composition (in a bottle according to Woulf). One electrode was attached to the plant hypocotyl and the other electrode was inserted in a constant position at the bottom of the bottle. The electric capacity was measured in the electrical circuit where the alternating current passes between the root system and water. The plants were divided into root and aboveground parts after determination of electrical capacity and afterwards the dry matter weight of these parts were established.

The Statistica 12 CZ programme was used for statistical evaluation of the electrical capacity of the root system. The effect of the deficient nutrient on the formation of the root system was evaluated by ANOVA analysis of variance. The differences among the treatments were evaluated by follow-up tests according to Fisher (LSD test) at 95% (P<0.05) level of significance.

RESULTS AND DISCUSSION

Table 2 shows that the root dry matter weight of plants from complete solution and plants with P deficiency were increasing during the experiment. The root architecture of plants can undergo several changes in response to P deficiency. The long-term P deficiency can cause the excessive root elongation (Anuradha and Narayana 1991) which might be responsible for increasing the dry matter of plants with P deficiency. The increase of lateral root growth and secondary root branching at the expense of primary root elongation were observed in maize (Mollier and Pellerin 1999, Zhu et al. 2005), beans (Lynch and Brown, 2001) and rice (Wissuwa 2005). The ratio between the root weight and the whole plant weight in variant with P deficiency did not change a lot during the terms (25.78–28.95) in contrast to the variant with complete solution (the ratio was descending during the terms).

First, the weight of plants with nitrogen deficiency was decreased (in 1st and 2nd term) but the raising of weight is obvious in the last 3rd term. When the plant is long-term in the condition of N deficiency, it starts to change the structure of root system. The plant enhances the creating of lateral root in order to extend the nitrogen uptake (Chun et al. 2005, Hawkesford et al. 2012). Maize reduces the
number of primary roots but increase the total root length under low-N conditions (Liu et al. 2008). Maizlish et al. (1980) present when numbers of primary root per plant of maize increased with increasing nitrogen, but the elongation rate of an individual primary root did not respond strongly to increased N.

The bigger reduction of root weight was found in the K deficiency variant. The ration between dry matter weight of whole plant and root was 20.63% in the last term. Baligar et al. (1998) present that plants with insufficient K nutrition reduce the root growing. The seedlings of Arabidopsis showed a strong reduction of lateral root elongation in potassium deficiency (Kellermeier et al. 2013). Similarly Armengaud et al. (2004) present plants of Arabidopsis grown on K-free medium developed visible symptoms potassium deficiency on 10 days after germination, which included chlorosis of older leaves and a typical growth arrest of lateral roots.

Table 2 Dry matter weight of whole plant and root (mg/plant) and proportion of root dry weight to total plant weight (%), 1st term 13 days after sowing, 2nd term 20 days after sowing and 3rd term 27 days after sowing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Part of plant</th>
<th>Dry matter weight (mg/plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st term</td>
<td>2nd term</td>
</tr>
<tr>
<td>Complete solution</td>
<td>Whole plant</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>18 (32.73%)</td>
</tr>
<tr>
<td>Nutrient solutions without N</td>
<td>Whole plant</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>24 (42.86%)</td>
</tr>
<tr>
<td>Nutrient solutions without P</td>
<td>Whole plant</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>20 (26.32%)</td>
</tr>
<tr>
<td>Nutrient solutions without K</td>
<td>Whole plant</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>16 (34.04%)</td>
</tr>
</tbody>
</table>

Figure 1 Electrical capacity of maize root system (nF). Means followed by the different letters are significantly different (P<0.05)

From Figure 1 is obvious the difference in electric capacity among each term. The value of electric capacity was rising during the experiment, excepting K deficiency variant. The plants from deficiency solution have almost ever lower electric capacity then control plants, only in the last 3rd term) P
Deficiency plants had little bit higher electric capacity than control plants (not significance). Baligar et al. (1998) present that P deficient nutrition induces enhancing length of primary root and the secondary root branching which increases the density of root-hair. Similarly Johnson et al. (1996), Dubrovsky (1997) and Zhu and Lynch (2004) reported increasing the root system forms of short lateral roots with large numbers of root hairs, when plants were exposed to low P conditions. The mentioned changes in root architecture increased absorptive surface which means higher electric capacity.

The plants from N and K deficient variants have significantly lower electric capacity in contrast to control plants. The most expressive different is in the last term, N deficient plants have of 55.24% lower electric capacity than control variant and K deficient plants have of 68.55% lower electric capacity in contrast to control plants. Similar small electric capacity was noticed in K deficient sunflowers (Škarpa 2011). Potassium significantly influences the cell turgor that drives cell expansion and elongation. The low K concentration in cytosol decreases the cell turgor, which is needed for the elongation of root hairs (Lew 1991).

**Figure 2** Relation between the electrical capacity (nF) of root maize and their root dry matter weight; a – complete solution, b – nutrient solutions without P, c – nutrient solutions without N, d – nutrient solutions without K

Figure 2 shows high correlation between the electrical capacity and root dry matter weight of maize. The significant relation was measured in variant with nutrient solution without phosphorus (r = 0.999; P<0.01), the relation of the others variants were not significant (P<0.05). McBride et al. 2008 studied four maize genotypes in the pots experiment and they were determinated significant relation between electric capacity and root weight. Really close correlation was also found at sunflowers (Rajkai et al. 2005). The relation between electric capacity and root dry matter weight was also noticed by Ozier-Lafontaine and Bajazet (2005) at spinach.
CONCLUSION

Nutrients deficiency in maize nutrition had significant effect on dry matter weight of whole plant and root and root electrical capacity. The root dry matter weight of plants from complete solution and plants with P deficiency were increasing in time. First, the roots weight in variant with N deficiency was decreased, but it was enhanced in 3rd term. The biggest roots weight reduction and their share in the whole plants weight was detected in variant with K deficiency. High correlations between the root electrical capacity and root dry matter weight were found in variants with all nutrients deficiency. This relation was significant in variant with phosphorus deficiency. Knowledge of roots development in deficient environment can be exploited by breeding of varieties for different deficiency conditions.

ACKNOWLEDGEMENTS

The research was financially supported by the non-project research of Faculty of AgriSciences, Mendel University in Brno.

REFERENCES


