EFFECT OF NUTRIENTS DEFICIENCIES ON ROOT ARCHITECTURE AND GROWTH OF WINTER WHEAT

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Abstract: The study of the effects of N, P, K deficiencies on root architecture and growth was tested in phenotyping platform with winter wheat (Bohemia variety). The experiment was arranged with 4 treatments: Complete nutrient, Without N, Without P and Without K. The root were grown on the surface of vertically fixed black filter paper sheets (30x60cm), covered from both sides by black plastic sheets (PVC-P). The system was setup with a micro-irrigation channel in the top of sheets to ensure circulation of hydroponic medium as hydroponic system. Eighteen days after transplanting, we took the root images by the standard RGB digital camera. To evaluate the root architecture parameters the “SmartRoot” software was used. The results showed that nutrient deficiency had effect on root architecture of winter wheat. N deficiency increase in total seminal root and lateral root length and root/shoot ratio, while P deficiency resulted in increase of mean root diameter, total root area when compared to the control. N deficiency also decreased root and shoot dry weight and total leaf area. However, nutrient deficiency slightly decreased lateral density. There was a slight effect of K deficiency on root architecture when compared to the complete nutrient application. The increasing of leaf dry weight was related with the increased of root dry weight.

Key Words: winter wheat, SmartRoot, nutrients deficiencies, root system architecture (RSA), root phenotyping

INTRODUCTION

Root systems are an importance organ which are responsible for capturing resource from below-ground such as nutrients and water. Improvement of crop production was directly influenced by modifications in geometry and function of root-system architecture (RSA). A strong root system can be helpful in the biological control of plant diseases, and improvement of root system promotes active acquisition of water and nutrients for the production of high yields. Nutrient availability have profound impact on RSA by altering the number, length, angle, and diameter of roots and root hairs (Benjamin et al. 2013). In nutrient deficiency, root weight often increases in a quadratic manner with the addition of chemical fertilizer. Increasing nutrient supplies in the soil may also decrease root length bot increase root weight. On the other hand, root with adequate nutrient supplies may also have more root hair than nutrient deficient roots (Fageria, Moreira 2011). When roots grow under phosphorus deficiency, roots exhibit a shallower architecture that results from the inhibition of primary root elongation and increase in lateral root formation (Williamson et al. 2001). In contrast roots grow under nitrogen deficiency stimulates primary root and particularly lateral root elongation but not lateral root initiation (Linkohr et al. 2002, López-Bucio et al. 2003). Under severe N deficiency, the formation of lateral root is almost completely absent (Krouk et al. 2010). These examples indicate that the difference of nutrient availability can effects on RSA that depend upon which type and concentration of nutrient is supplied.

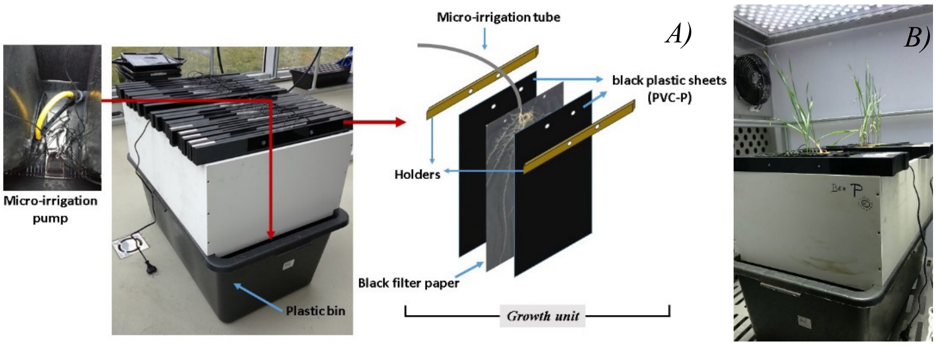
The aim of this work is to study the effect of N, P and K deficiency on root architecture and growth in winter wheat at establishment state. And to present a new simple technique which have been develop for measuring root architecture.

MATERIAL AND METHODS

a) The phenotyping platform

The phenotyping system (see Figure 1A–B) consisted of a plastic bin, 12 growth units, and a pump for controlling watering system (see Figure 1A). Each growth unit consisted of 30x60 cm of black filter paper sheets then covered from both sides by black plastic sheets (PVC-P). On the top of these sheets were fixed on the top with holder which was setup with a micro-irrigation channel to ensure circulation of hydroponic medium and evenly wetting of paper sheets. Each bin system was equipped with a watering system consisting of a suction pump connected with micro-irrigation tube.

Figure 1 Phenotyping system, growth unit (A) and the Phenotyping platform which were kept in growth chambers that allows manipulation with light and temperature (B).



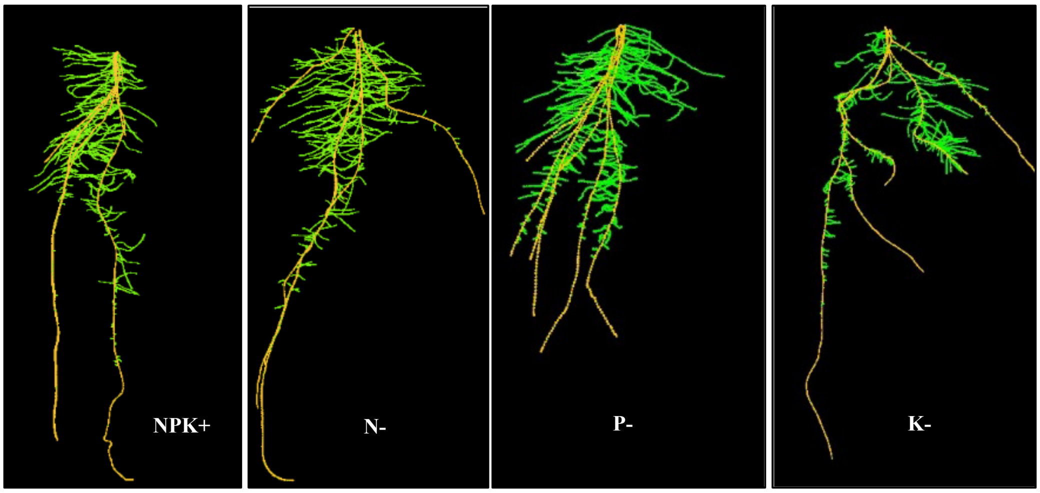
b) Experimental design

This experiment were carried out with the winter wheat hybrid Bohemia within phenotyping platform which were designed as hydroponic system. The experiments were arranged in 4 treatments of hydroponic solution with 3 replications. Four treatments consisted of the control which is complete nutrient solution (+NPK), N deficiency (-N), P deficiency (-P) and K deficiency (-K). Hydroponic solutions we used in this experiment was Knop's hydroponic solution (pH 5.7) which was shown in table 1. Salts which were added in hydroponic solutions for maintaining the same level of osmotic potential of every treatment by without any stress. The roots were grown on the vertical surface of phenotyping platform. Seeds were germinated on filter paper. After radicle emerges from seed, it was transplant into each growth unit which was set up with micro-irrigation tubes. The 12 growth units were moved into the bin and connected the micro-irrigation tube with micro-irrigation pump to facilitate circulation of hydroponic medium within bin. The phenotyping platform were kept in growth chamber (see Figure 1B) which allow manipulation of temperature and light intensity. Temperature and light were gradual increased from 20°C and 0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at night to 30°C and 680 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at day respectively. Eighteen days after transplanting, we took the root images by the standard RGB digital camera. The root architecture parameters were evaluated by using the "SmartRoot" software (see Figure 2). The root data we obtained were total root length, surface area of root and shoot, mean diameter, and lateral density. Root and shoot biomass were also measured.

Table 1 Knop's Hydroponic solution which was used in the experiment. Total volume is 1,000 ml

Solution	+NPK	-N	-P	-K
1g $Ca(NO_3)_2$	√	-	√	√
0.25g $MgSO_4.7H_2O$	√	√	√	√
0.01g $FeCl_3.6H_2O$	√	√	√	√
0.25g KH_2PO_4	√	√	-	√
0.125g KCl	√	√	√	-
0.09g NaCl	-	-	-	√
0.03g $CaCl_2$	-	√	-	-

Figure 2 The example of root images after root tracing by SmartRoot software



RESULTS AND DISCUSSION

The results showed that nutrient deficiency had effect on root architecture of winter wheat (see Figure 3A–H). The roots in the N deficiency treatment gave the highest total seminal root (SR) length and total lateral root (LR) length by 32% and 15% compared to the control (see Figure 3A) but, there were no significant (see Table 2). However, Fageria and Moreira (2011) stated that when there is deficiency of a determined nutrient, root try to grow longer to take nutrients from lower soil depths. Regarding mean root diameter (see Figure 3B), there was no effect between N deficiency, K deficiency, and the control, while P deficiency showed the opposite effect. P deficiency significantly promoted both of SR and LR diameter. In barley, high concentration of NO^{3-} had no effect on the diameter of the seminal axis (Drew et al. 1973).

P deficiency increased both of SR and LR area when compared to the other treatment and significantly increased the total root area (up to 170%) when compared to the control (see Figure 3C). The treatment of N deficiency had a slight effect on root area when compared to the control. No significant difference was found in root area between K deficiency and the control (see Table 2). Moreover, N, P and K deficiencies decreased lateral root density by 7.7–38.7% (see figure 3D). However, there was some research showed that low P level in soil solution promoted lateral root growth by reducing the primary root elongation and increasing lateral root elongation and density in Arabidopsis (Williamson et al. 2001, Linkohr et al. 2002).

There was no significant of nutrient deficiency on root dry weight (see Table 2) nevertheless nutrient deficiencies decreased root dry weight by about 14.1–46.8%, especially N deficiency (see Figure 3E). Some researchers stated that N (Noulas et al. 2010) and P (Baligar et al. 1998) improved root dry weight of wheat. Forde and Lorenzo (2001) reported that plant growing on concentrated nutrient solution develop a short, compact and densely branched root system, while in diluted solution or water the roots were long and more sparsely branched. In complete nutrient treatment had significant highest shoot dry weight (see Figure 3F). N deficiency profoundly decreased shoot dry weight. In the same with leaf area, N deficiency significantly decreased leaf area (see Figure 3G). Because Nitrogen is a major constituent of several of the most important plant substances. Nitrogen deficiency most often results in stunted growth, slow growth, and chlorosis (Hopkins, Huner 2008). Root/shoot ratio of winter wheat was profoundly enhanced by the absence of N (see Figure 3H). P and K deficiency also slightly improved root/shoot ratio. Effects of nutrient deficiencies on plant development showed a decrease in shoot/root ratio, particularly in fast-growing species adapted to sites of high fertility (Chapin 1980). There was high positive regression between root dry weight and shoot dry weight with $R^2 = 0.72$ (see Figure 4). The increasing of leaf dry weight was related with the increasing of root dry weight.

Figure 3 Effect of nutrients deficiencies on total SR and LR length (a), mean root diameter of SR and LR (b), total root area of SR and LR (c) lateral density (d), root dry weight (e), shoot dry weight (f), total leaf area (g), and root/shoot ratio (h) of winter wheat. Column presented mean±Standard deviation, n=3

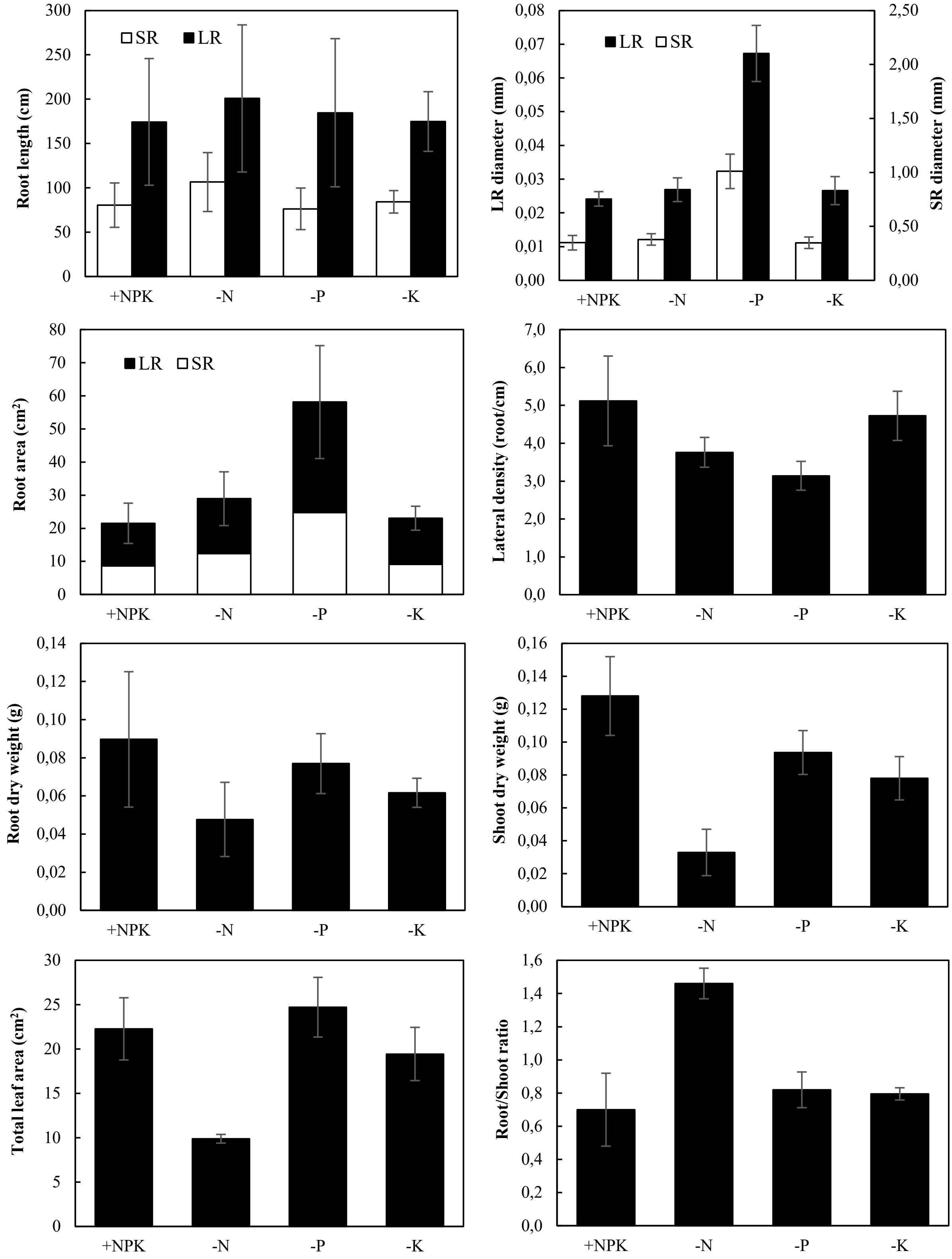


Figure 4 The regression of root dry weight and shoot dry weight

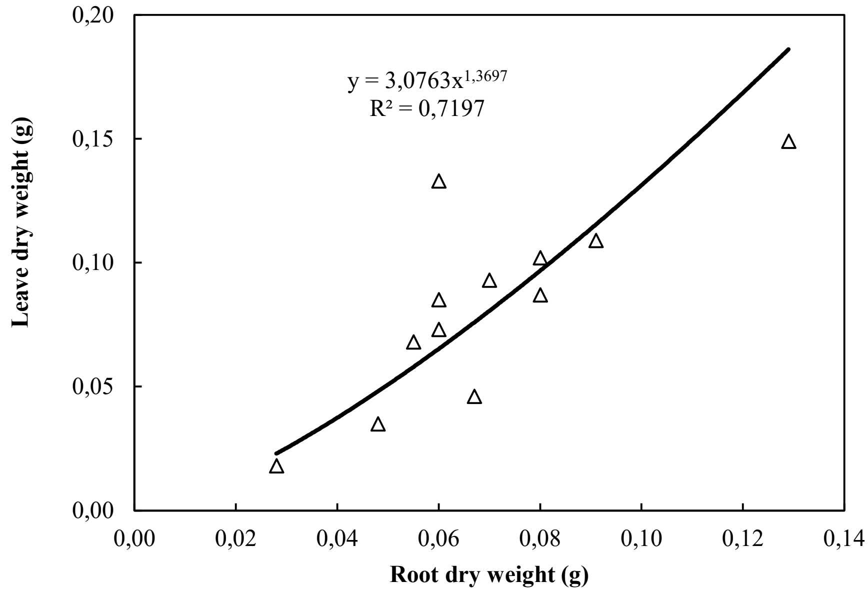


*Table 2 The mean square error and F-value from ANOVA test. Significant values was indicated: ns, no-significant; **, P<0.01; *, P<0.05*

Traits	Mean square error	F-value	Significance
SR length	440.674	0.824	0.534 ns
LR length	6073.622	0.374	0.776 ns
SR diameter	0.009	35.576	0.000**
LR diameter	0.000	32.911	0.001**
SR area	8.701	19.605	0.003**
LR area	86.190	3.197	0.105 ns
Total root area	137.453	6.251	0.038*
Lateral density	0.526	4.642	0.053 ns
Root dry weight	0.001	1.840	0.240 ns
Shoot dry weight	0.000	16.022	0.003**
Total leaf area	12.686	7.306	0.028*
Root/Shoot area	0.013	28.512	0.001**

CONCLUSION

Roots play important roles in plant growth and development cycle and their development is remarkably sensitive to nutrient application. The results showed that N deficiency increased in seminal root length, lateral root length and root/shoot ratio but they decreased root and shoot dry weight and leaf area. P deficiency resulted in an increase of root area and mean root diameter. There was a slight effect of K deficiency on root architecture when compared to the complete nutrient application.

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REFERENCES

Baliger V. C., Fageria N. K., Elrashidi M. 1998. Toxicity and nutrient constraints on root growth. *HortScience,* 33(6): 960–965.

Benjamin D. G., Ricardo F. H. G., Swetlana F., and Nicolaus von W. 2013. Plasticity of the Arabidopsis root system under nutrient deficiencies. *Plant Physiology*, 163(1): 161–179.

Chapin III F. S. 1980. The mineral nutrition of wild plants. *Annual review of ecology and systematics,* 11: 233–260.

Drew M. C., Saker L. R., Ashley T. W. 1973. Nutrient supply and the growth of the seminal root system in barley I. The effect of nitrate concentration on the growth of axes and laterals. *Journal of Experimental Botany,* 24(6): 1189–1202.

Fageria N. K., Moreira A., 2011. The role of mineral nutrient on root growth of crop plants. *Advances in agronomy,* 110: 251–331.

Forde B., Lorenzo H. 2001. The nutritional control of root development. *Plant and Soil,* 232(1–2): 51–68.

Hopkins W. G., Huner N. P. A. 2008. *Introduction to Plant Physiology.* 4th ed. John Wiley & Sons.

Krouk G., Lacombe B., Bielach A., Perrine-Walker F., Malinska K., Mounier E., Hoyerova K., Tillard P., Leon S., Ljung K., Zazimalova E., Benkova E., Nacry P., Gojon A. 2010. Nitrate- regulated auxin transport by NRT1.1 defines a mechanism for nutrient sensing in plants. *Developmental cell*, 18(6): 927–937.

Linkohr B. I., Williamson L. C., Fitter A. H., Leyser H. M. O. 2002. Nitrate and phosphate availability and distribution have different effects on root system architecture of Arabidopsis. *The Plant Journal,* 29(6): 751–760.

López-Bucio J., Cruz-Ramírez A., Herrera-Estrella L. 2003. The role of nutrient availability in regulating root architecture. *Curr Opin Plant Biol*, 6(3): 280–287.

Noulas C., Liedgens M., Stamp P., Alexiou I., Herrera J. M. 2010. Subsoil root growth of field grown spring wheat genotypes (*Triticum aestivum* L.) differing in nitrogen use efficiency parameters. *Journal of plant nutrition*, 33(13): 1887–1903.

Williamson L. C., Ribrioux S. P. C. P., Fitter A. H., Leyser H. M. O. 2001. Phosphate availability regulates root system architecture in *Arabidopsis*. *Plant Physiology*, 126(2): 875–882.