INFLUENCE OF NUTRIENT CONCENTRATION AND ENVIRONMENTAL CONDITIONS ON THE WHEAT ROOTS AND SHOOTS*

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The development of various root and shoot traits at the juvenile stage of 8 wheat cultivars has been analyzed under gradually increasing nutrient concentrations in a climatic chamber. The largest effect of gradually increasing concentration of macro- and micro-nutrients has been found in dry matter of roots and shoots. Dry matter of roots is more sensitive to nutrient concentration to compare with the above ground biomass (% of change). Increasing nutrient concentration in nutrient solution has had especially influence in volume of roots, their number, number of leaves, length of leaves and in dry matter of the above ground biomass. The lowest influence has been found in the number of seminal roots (high degree of genetic control). Under increasing concentration of nutrient three phases of development in majority of the measured traits have been observed: First, the increase of the measured values of the analyzed traits to the maximum at different nutrient concentration for each measured trait, second phase was represented by a plateau of measured values and third phase is gradual decrease of values of these traits at high concentration of nutrients. Substantial effect on the root and shoot parameters has been observed for different types of root environment during cultivation, i.e. soil, fine or coarse sand and standard nutrient solution or distilled water.

nutrient concentration; root environment; different types of root environment; root growth; root traits; shoot traits; root : shoot ratio; wheat

INTRODUCTION

Analysis of the root system is still neglected. Plant root system has a number of important functions in growth and yield formation (Haberle, Bláha, 1990). Cultivar – i.e. genotypic differences are at all measured traits

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(number of root tips, length of roots, dry matter of roots, length of the largest root depth of the penetration of roots, root : shoot ratio).

The numerous measurable parameters of the root systems, physiological activity and their relationships to the growth of the above-ground parts are integrated into shoot/root ratio. The root system seems to be very suitable as a perspective selection criterion in plant breeding because plant root systems have a number of important functions in growth and yield formation. The improved response of cultivars to the nutrients and stress conditions is accessible via screening, selection and breeding on the basis of available plant resources. The root development is under genetic control and can be modified by plant breeding (Taylor, Terrel, 1982; Baligar, Duncan, 1990; Clarkson, 1995; Marschner, 1995; Nilsen, Orcutt, 1996).

Soil conditions may become a limiting factor for growth and the normal physiological function of the root system in certain types of soil and moisture regimes.

Seed provenance has also a very important effect on the biological value of seeds at the first phases of plant development and especially on the root system and on the yield formation.

The order of importance of individual traits of the root for plant production depends on environmental soil and air conditions and on the influence of abiotic and biotic stresses. There are lots of possibilities of utilisation of genetic resources for shortage of influence of stresses, i.e. from agronomical point of view influence of negative environmental conditions. A wider genetical diversity of crops and cultivars also contributes to a more stable production and a balances agroecosystem. At the present there are substantial opportunities for improving the availability of *ex situ* conserved plant genetic germplasm and number of important recent developments. The current estimates are that over 6 million of genetic resources are conserved *ex situ*. In June 1996 the first Global Plan for the Conservation and Sustainable Utilisation of Plant Genetic Resources for Food and Agriculture was adopted by representatives of about 150 countries.

An improved response of cultivars to the conditions of nutrient and stress is accessible by way of screening of available plant genetic resources, through selection and breeding. For example, considerable genetic variation of root mass exists between clones of perennial ryegrass. Root mass is positively related to competitive ability (Ennick, Hofman, 1983). Special attention is paid to the level of dry matter ratio of root and shoot (R : S), number of roots, depth of root penetration into the soil, length of roots, volume of roots at different phases of development. It seems that for wheat varieties with higher R : S ratio, higher tolerance to soil stresses exists (Bláha, 1992). For triticale and rye greater root : shoot ratio exists than for wheat in time of advanced growth stages (Sheng, Hunt, 1990). The varieties with the highest ratio of roots dry matter to the above ground biomass are those with large probability characterized with higher uptake of nutrients, higher yield stability, higher resistance to drought and other traits, but exceptions exist (Bláha, Vančura, 1990).

The cultivars with a complex resistance to the abiotic stress factors and with high R : S ratio have larger probability of ecological stability. The difference among the substrates used on root parameters was also observed by several other authors.

It is known that already more than one factor limits growth and reproduction of plants at any one time. Why is it that there are in biology many studies on single factor responses in plants and far fewer studies on interaction of multiple factors on plant stress physiology? One reason for this phenomenon is nature of science – to determine the basic impact of different nutrient level on plant root system.To determine the impacts of one factor on a system, all other factors must be stable.

The different levels of nutrient concentration (especially very high and low) are also special forms of abiotic stresses. This study was conducted in order to provide some basic information regarding the common effect of the influence of single factor-nutrient levels on root traits on the basis of analysis of 8 different cultivars of wheat and the influence of different root environment.

MATERIAL AND METHODS

The eight cultivars were evaluated in experiments (Mironovskaja 808, Košútka, Sparta, Selekta, Viginta, Regina, Zdar, Iris). Cultivars were selected on the basis of different morphological and physiological traits, traits determining productivity and quality resistance to drought, and other abiotic stresses. Plants have been cultivated in growth chamber. Cultivars of winter wheat were tested for development of root and shoot traits at the juvenile stage in distilled water, 18 h in nutrient solution followed by distilled water, in standard nutrient solution and in fourth different nutrient concentrations (Tab. I) with aeration and regular exchange (every 72 hours, 25litre containers).

After 5 days long germination at low temperature, the standard, juvenile, sprouting plants were selected and transferred to a constant temperature room. Environmental conditions were maintained as follows: 20 °C for roots and shoots with 18 / 6 hours period of light / darkness. Light intensity was 450 $\mu mol.m^{-2}.s^{-1}$. Three weeks after beginning of the experiments, different parameters of the roots and shoots were measured.

I. Change of different values of traits (per 1 plant) in different nutrient concentrations – average accross of all cultivars

Nutrient concentration	Average length of roots (cm)	Length of largest root (cm)	Total length of roots (cm)	Number of roots	Volume of roots (cm^3)	Dry matter of roots (g)	Length of shoot (cm)	Number of leaves	Dry matter of shoots (g)
Distilled water	6.42	10.15	34.42	5.57	0.139	0.0063	18.70	2.28	0.0174
18 h of cultivation	7.06	10.73	40.74	5.96	0.131	0.0082	21.00	2.37	0.0232
0.1x concentration	9.14	14.78	47.23	5.61	0.204	0.022	23.63	2.19	0.0310
1x concentration	8.85	14.71	44.47	5.68	0.202	0.032	24.13	2.64	0.0290
2x concentration	6.48	10.15	35.79	5.73	0.189	0.026	19.82	2.55	0.0260
3x concentration	6.46	10.10	35.86	5.73	0.220	0.0092	19.80	2.53	0.0290
6x concentration	4.69	7.09	24.50	5.77	0.090	0.011	17.23	2.44	0.0470

Different nutrient concentrations with pH 6,5 with stepwise increase on different nutritive elements have been used for our experiments. The concentrations used were in mmol: (standard concentration) $NaNO_3$ – 0.11, $Ca(H_2PO_4)_2 . 2 H_2O$ – 0.03, K_2SO_4 – 0.08, $MgSO_4 . 7 H_2O$ – 0.03 and equivalent concentration of micronutrients (Fe, Zn, Cu, Na, B, Mo) up to the following concentrations of macronutrients (6x higher concentration) $NaNO_3$ – 6.36, $Ca(H_2PO_4)_2 . 2 H_2O$ – 1.67, K_2SO_4 – 4.89, $MgSO_4 . 7 H_2O$ – 1.82 and equivalent concentration of micronutrients (Fe, Zn, Cu, Na, B, Mo).

The same seed stock has been used throughout all the experiments. The chosen varieties had different pedigree in order to avoid the common parents influence.

At the end of the growing period twelve different root and shoot parameters were measured by using standard methods (B l á h a , 1992). Regression equations were calculated for all cultivars for different traits, for increasing nutrient concentrations in nutrient solution. In regression the traits in distilled water were used as independent variable. Only traits with statistically significant regression are presented (5%). Average length of roots, depth of penetration of roots (length of the longest root is equal to main root), total length of roots, number of seminal roots, volume of roots, dry matter of roots, dry matter of the above ground biomass, number of leaves, dry matter : water content ratio and R : S dry matter weight ratio. The R : S ratio is calculated by dividing the dry weight of roots by corresponding dry weight of shoot at every cultivar. Each type of experiment was repeated five times.

RESULTS

Relatively large effect of gradually increasing concentration of macro- and micro-nutrients was found in dry matter of roots and shoots. Dry matter of roots is more sensitive to nutrient concentration than that above ground biomass. Only traits with statistically significant influence of increasing nutrient concentration (5%) are presented (Tab. I). Low, almost negligible effect was found for number of 1 roots (= seminal roots), perhaps because this trait is under strong genetic control (Tab. I).

The largest effect of high nutrient concentration (6x) in nutrient solution was found for volume of roots, number of roots, number of leaves, length of leaves and for dry matter of the above ground biomass in 6x nutrient concentration (Tab. II). In this nutrient concentration decrease in different traits of roots exists. High concentration of macronutrients and micronutrients is from physiological point of view strong abiotic stress. From morphological point of view, plants which are cultivated in this nutrient level are similar to the plants cultivated at distilled water.

Under increasing concentration of nutrients three phases of development of every measured trait of root were observed. The stepwise increase of the values reaching maximum, in the second phase keeping the values at maximum and during the third phase decrease due to high concentration of nutrients was recorded. For each cultivar and each measured trait the different form of dependence was obtained.

II. Average values of root traits (per plant) expressed in high level of nutrients (6x)

Cultivar	Average length of roots (cm)	Length of largest root (cm)	Total length of roots (cm)	Number of roots	Volume of roots (cm^3)	Dry matter of roots (g)	Length of shoot (cm)	Number of leaves	Dry matter of shoots (g)
Mironovskaja 808	4.60	7.63	23.3	5.03	0.125	0.009	19.54	2.50	0.025
Košútka	5.30	7.77	27.3	5.18	0.101	0.007	15.94	2.35	0.026
Sparta	5.08	8.44	23.3	4.64	0.130	0.006	17.85	2.43	0.064
Selekta	4.22	6.04	23.9	5.63	0.090	0.004	14.84	2.40	0.026
Viginta	4.85	7.34	25.8	5.25	0.009	0.008	18.95	2.35	0.027
Zdar	5.28	7.62	26.6	5.25	0.100	0.006	19.10	3.00	0.068
Iris	4.20	6.65	22.7	5.40	0.103	0.002	15.30	2.40	0.023
Regina	5.20	7.10	23.2	4.53	0.910	0.005	19.06	2.60	0.022

In majority of cultivars the maximal increase of roots dry matter prevails at the average nutrient concentration (3x) (Fig. 1a, b). At the side of high nutrient concentrations decreases of dry matter of roots exist, however at different intensity depending on the cultivar. On the other hand, for high concentration of nutrients some cultivars exhibit increase in dry matter of shoots.

As additional information the analysis of influence of different types of environment conditions at standard nutrient concentration was undertaken on the basis of experiments in soil, standard nutrient solution, distilled water, fine sand, coarse sand and in glass tubes, with circulation of nutrient solution or regular exchange of nutrient solution, aeration. From these experiments it follows that substantial influence of the root environment on the root morphological traits really exists (Tab. III).

DISCUSSION

Strong influence of different stress conditions on root traits root development and also on yield formation, grain quality and plant biomass production was obtained (B l á h a , O p a t r n á , 1998) Different stress conditions had high effect especially on the first phase of root growth and root morphology.

The basic aim of the presented work was analysis of influence of different nutrient concentration on the root and shoot traits and at different types of cultivation medium (i.e. variability of root traits). The similar results were obtained at winter wheat cultivars: Hana, Vlada, Asta, Siria, Estica, Simona, Torysa and Blava at winter cultivar of triticale Dagro, at rye cultivar Dankovské and at winter barley cultivars Borvina and Sigra.

A wide range in nutrient efficiency exists within the cultivars (B l á h a et al., 1997) and it seems to be possible that a special breeding programme of

III. Values of traits (per 1 plant) in different root environment – average of all cultivars

Environment	Average length of roots (cm)	Volume of roots (cm^3)	Fresh weight of roots (g)	Dry matter of roots (g)	Fresh weight of shoots (g)	Dry matter of shoots (g)	Root : shoot ratio
Soil	19.43	0.414	0.371	0.049	0.694	0.0657	0.75
Nutrient solution	28.17	0.694	0.716	0.098	0.728	0.1169	1.47
Distilled water	42.74	0.674	0.315	0.089	0.603	0.0493	1.95
Fine sand	22.92	0.629	0.340	0.095	0.277	0.0867	1.12
Coarse sand	24.28	0.670	0.350	0.051	0.291	0.0742	0.71

crop cultivars for different conditions will be successful. There is still a lack of information regarding changes in anatomy and morphology of roots under different conditions and especially on their effect on nutrient and water uptake.

In submitted experiments with juvenile plants only characters of seminal root system were measured. Characters of seminal root system are of higher heritability than these of adventitious ones. It is known that the seminals appeared to be more suitable for selection (G ó r n y , L a r s o n , 1989).

Different maximum of roots and shoot development at the different nutrient concentration at the different cultivars suppose differences in nutrient absorption and especially at different nutrient distribution and utilisation. Only a few cultivars exhibit maximal increase of dry matter of root at low level of nutrient concentration (B l á h a , 1992).

Plants seldom enjoy optimal environmental conditions but are often subject to extremes of physical conditions. The different combinations of abiotic stresses affect vigour, viability and other traits of seeds, shoot and especially root traits development. To study the plant stress physiology is important to basic and applied botanical sciences. Morphological, anatomical, and metabolic responses to abiotic stress (drought, high and low temperature, radiation, flooding, wind, magnetic field, heavy metals, pesticides, toxins, low pH, salinity, different level of macro and micronutrients...) are some of the primary processes of microevolution by natural selection. In agriculture it is increasingly important for scientists to improve environmental stress tolerance in crops. In general crops are limited to about 25% of their potential yield by the impacts of environmental stress (B o y e r , 1982).

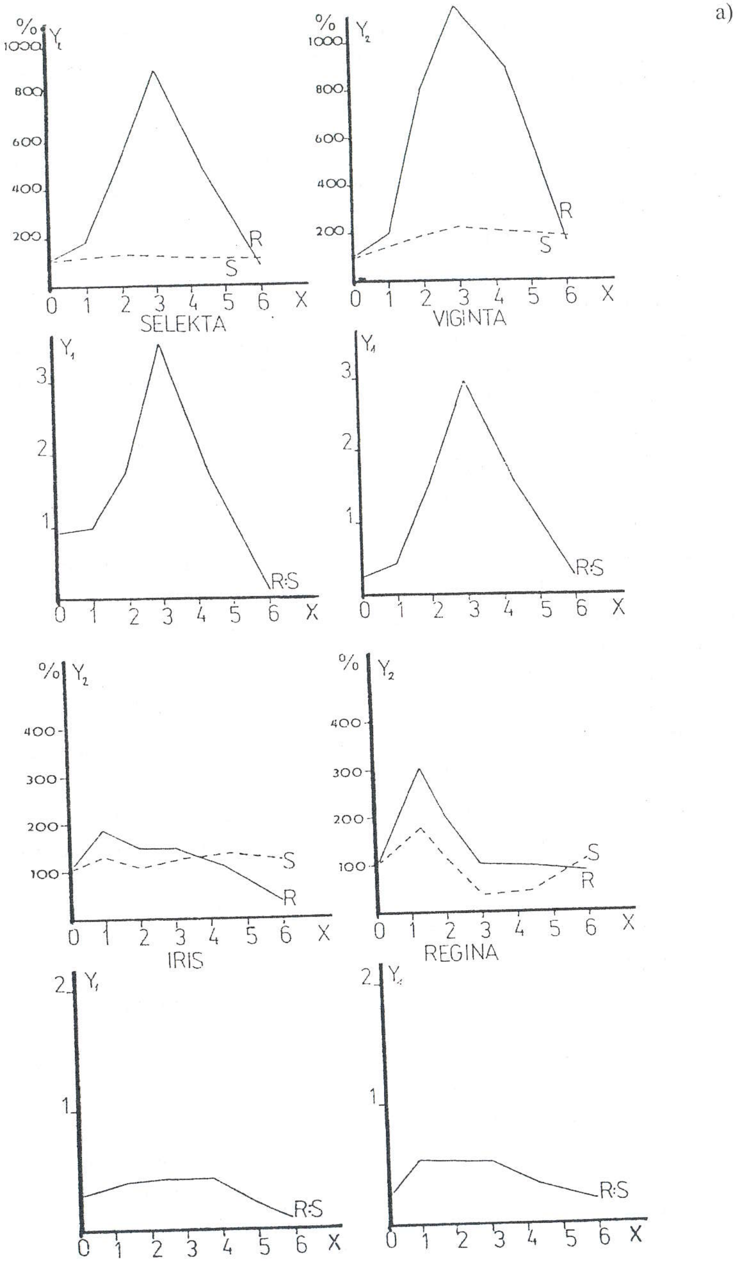
According to development of root : shoot (R : S) ratio of dry matter, different types of reaction for tested cultivars could be (probably) distinguished:

A) The cultivars with similar development of dry matter of roots and shoots, i.e. without a substantial change of R : S ratio.

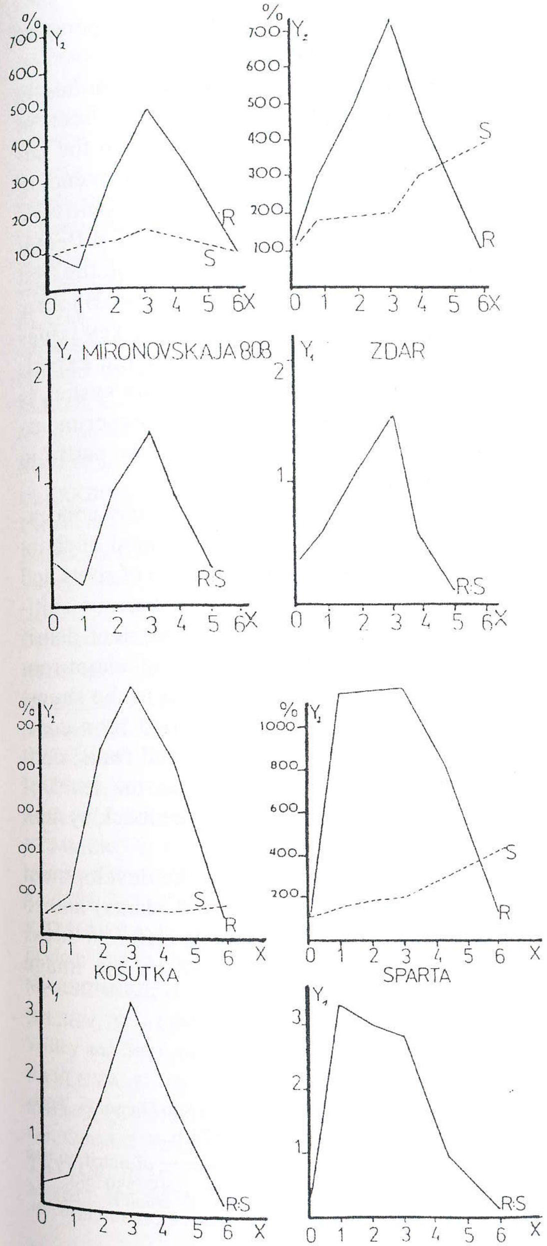
B) The cultivars where growth of roots is faster than that of shoots at the lower concentrations and slower decrease of the roots growth than that of shoots at the higher concentration of nutrients.

C) The cultivars where, after the maximum growth of roots at the lower concentration of nutrients and followed by maximum growth of shoots at the higher concentration of nutrients.

The more work is necessary to evaluate the significance of root parameters under limited and different nutrient supply and to solve problems encountered in the course of their determination. The habit of root system of seedlings is also considerably influenced by light spectrum and by nutrient level (B l á h a , a)



b)



1.a, b The relative influence of different concentration of nutrients in nutrient solution on the root (R), shoot (S) development and on the root : shoot dry matter ratio. 100%, standard is distilled water

X axis: Nutrient concentration, 0 = distilled water, 1 = 18h of cultivation in nutrient solution, 2 = 0.1x concentration, 3 = 1x concentration (normal), 4 = 2x concentration, 5 = 3x concentration, 6 = 6x concentration
Y axis: %

1985; Pavlová, 1983). The R : S ratio is influenced also by temperature (Kummerow, Ellis, 1984; Hess, 1983 etc.).

In agriculture the plant breeding system influences directly or indirectly also the tolerance of cultivars to the abiotic stresses as it could be seen in case of comparison of modern and old winter wheat cultivars from the beginning of the 20th century (Bláha, Michalová, 1993). Understanding stress responses is essential for attempts to breed stress resistant cultivars. From the agronomic point of view influence of combinations of different levels of different abiotic stresses has influence on the seed traits and the first phases of plant development(root and shoot) and the yield formation (Bláha et al., 1993). Regulation of vigour of sprouting plants is one of the key issues for developing crop production (Bláha, Opatrná, 1997). In our experiments water culture prevails. In many respects the form of the root system is very similar in soil and in water (Hacket, 1970). But in our experiments the habit, morphology, of the root system in water culture is only partly in accord with that one grown in soil (Tab. III).

Our presented results support the hypothesis that different nutrient concentration in water solution has the major influence on the development of shoot dry matter and especially on root dry matter. Different maximum of roots and shoot development under different nutrient concentrations for various cultivars implies differences in nutrient absorption and different nutrient distribution and utilization (Kutschera et al., 1992). In case of shoot-root relations the nutrient uptake by the roots, nutrient translocation to the shoots and subsequent redistribution among plant organs are controlled by a complex exchange of substrates and information between shoots and roots, concentration of ions and energy providing substrates, as well as the level of hormones concentration. These are important factors of the feedback system coordinating root activity according to shoot demand.

At future research work a special attention will be paid to the development of root traits and morphology of juvenile plants (10 days old plants) and to the other developmental and growth stages at standard and at different stress conditions.The morphology of root system will be analysed by the image analyser LUCIA-D (Bláha, Janáček, 1997).

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BLÁHA, L. (Výzkumný ústav rostlinné výroby, Praha-Ruzyně, Česká republika):

Vliv koncentrace živin a vnějšího prostředí na vlastnosti kořenů a nadzemní část u obilovin.

Scientia Agric. Bohem., *29*, 1998: 81–92.

Sledovali jsme tvorbu kořenového systému (a nadzemní biomasy) juvenilních rostlin u 16 odrůd ozimé pšenice v substrátu s postupně se zvyšující koncentrací živin ve standardních podmínkách klimaboxu.

Největší vliv postupně rostoucí koncentrace makroprvků a mikroprvků byl nalezen u sušiny kořenů a nadzemní biomasy. Sušina kořenů je více citlivá k odlišné koncentraci živin při porovnání s nadzemní biomasou.

Průměrný vliv rostoucí koncentrace živin (vyjádřený v procentech změny) byl zaznamenán u těchto znaků: objem kořenů, počet kořenů (adventivní a zárodečné), počet listů, délka listů a sušina nadzemní biomasy.

Nejnižší vliv postupně se měnící koncentrace živin byl zjištěn u počtu zárodečných kořenů (genetická fixace s malým vlivem prostředí).

V podmínkách rostoucí koncentrace živin byly pozorovány klasické tři fáze růstu u kořenů a nadzemních orgánů: První fázi představuje růst hodnot měřených znaků do maxima, kterého je u jednotlivých znaků u jednotlivých odrůd dosaženo u rozličných koncentrací, druhá fáze je charakterizována téměř standardními hodnotami P (plateau) sledované křivky hodnot a třetí fáze je charakterizována postupným poklesem hodnot sledovaných znaků v průběhu rostoucí koncentrace živin.

Významný vliv na parametry kořenové soustavy byl pozorován u odlišných substrátů, ve kterých jsou kořeny kultivovány (hrubý písek, jemný písek, půda, živný roztok aj.). Naskytuje se také otázka, které prostředí je pro kultivace nejvhodnější při výzkumu kořenového systému jednotlivých odrůd.

koncentrace živin; kultivační substrát; růst kořenů; znaky kořenů; nadzemní biomasa; poměr kořeny : nadzemní část

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