INFLUENCE OF LOW pH AND ALUMINIUM IONS ON THE NUTRIENT UPTAKE AND GROWTH IN JUVENILE PHASE OF CEREAL CULTIVARS

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It can be concluded on the basis of laboratory experiments with cultivars of wheat, triticale and barley that there are great differences among cultivars at the juvenile phase in root development in acid conditions accompanied by aluminium toxicity. Low pH and aluminium affect the growth of the root system more than in the shoot. Cultivar differences in nutrient uptake and nutrient distribution, to the roots and shoots exist (N, P, K, Ca, Mg, Na). Transport in plants of K and N is oriented acropetally, P and Mg is distributed cyclically between the root and shoot. Ca ions are bound in the roots to pectic compounds. Na releases Ca^{2+} from the pectins and this process at the same time slows down its transport from the roots. Microelements are bound in the roots (Zn, Fe, Mn). Cultivars with higher nutrient absorption and with higher distribution of nutrients to the shoot biomass are more tolerant to acid soils. It is necessary to prepare individual analyses for every element according to individual differences of transport. In the shoot of cereals with good tolerance to the low pH – low differences in individual analysis, in nutrient content between standard and low pH conditions exist. There is also a possibility of using of this phenomenon to select cultivars already in the juvenile phase of development with efficient nutrient uptake and utilization at low level of pH.

cereals; cultivar differences; tolerance; low pH (4.5); aluminium toxicity; nutrient uptake; nutrient distribution; shoot/root ratio; morphology

INTRODUCTION

The yield of crops at a majority of acid soils all over the world is considerably lower than their potential yield (P o l l e et al., 1978). The total area of the arable land with the soil acidity is about 10 million square kilometers and represents a large potential for the food production.

Acid soils with pH below 5.5 constitute 31.4 per cent of the arable land in the Czech Republic (Š v a c h u l a, 1991). The low pH with aluminium toxicity conditions reduces an uptake of nutrients, roots growth and activity of microflora, increases the sensitivity to water stress and as a result, the plants have reduced growth of an above-ground biomass and the yield.

It is important to breed cultivars with a stable yield and with genetically fixed tolerance to the above-mentioned and other stress factors (high temperature, drought, low level of nutrients etc.).

In acid mineral soils the major constraints to plant growth are the following (M a r s c h n e r, 1995): increase in concentration and toxicity of H^+, manganese, aluminium and decrease in magnesium, calcium, potassium, phosphorus and molybdenum solubility. There is especially an inhibition of root growth and water uptake.

The main aim of the presented work is analysis of influence of low pH on the root and shoot growth, nutrient uptake and nutrient distribution to the root and shoot at juvenile phase of development.

MATERIAL AND METHODS

This study was conducted to analyse hypothesis that low pH substantially affects nutrient uptake and distribution already at the juvenile phase of development and hypothesis, that cultivar differences are distinguishable at juvenile phase of growth. In presented work the cultivars of wheat, triticale, barley and rye were used:

Wheat: Beaver, Siria, Estica, Trane, Ritmo, Mona, Asta, Bruta, Simona, Senta.

Triticale: Ring, Korm, Malmo, Presto.

Barley: Kamil, KM 2099, Kromir, Kromoz, KM 948, Okal, KM 1799, Marinka, Borwina, Luxor.

Rye: Albedo.

In all outlined experiments the same seed stock was used and chosen varieties had different pedigrees.

After 5 days of germination at low temperature average standard sprouting plants were selected. Plants were cultivated under standard conditions in growth chamber. Environmental conditions were maintained at 20 °C at day, 15 °C at night, 18 h light and 6 h darkness.

Plants were grown hydroponically in nutrient solution (D u f f e k, 1972): $NaNO_3$ – 1,06 mmol, $Ca(H_2PO_4)_2.2\ H_2O$ – 0,278 mmol, K_2SO_4 – 0,816 mmol, $MgSO_4.7\ H_2O$ – 0,304 mmol and equivalent concentration of micronutriens: Fe, Zn, Cu, Na, B, Mo. Two variants were tested: nutrient solution at pH 4.5 with 36 mg/kg concentration of aluminium ions and at standard conditions (pH 6.5).

Two weeks after the beginning of experiments in growth chamber, different parameters of roots and shoots were measured by standard methods: dry matter of roots and shoots, length of roots, volume of roots, total length of main roots, root: shoot ratio and nutrient uptake.

Nutrient content (K, Ca, Mg and Na) was analysed by AAS-4 flow analyser and N and P were analysed by analyser SAN PLUS SYSTEM (SKALAR). Program for statistical analysis of growth and nutrient uptake – NONLIN-3 were used (D v o ř á k et al., 1991).

In all the outlined experiments the same seed stock was used and the chosen varieties had different pedigrees in order to avoid the influence of common parents.

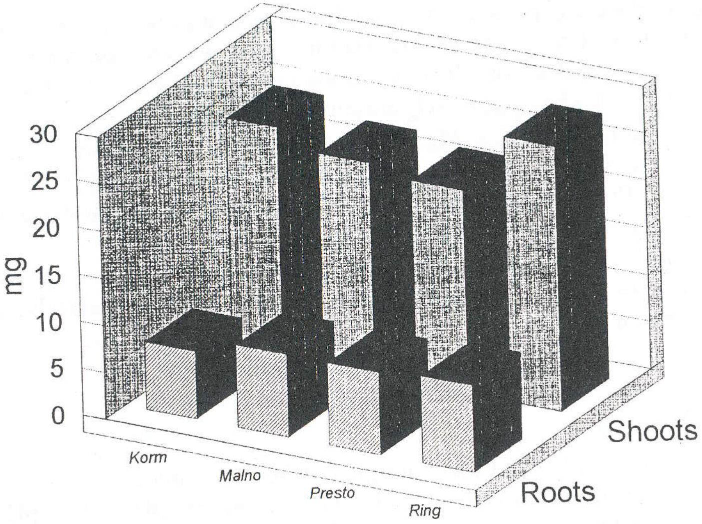
RESULTS

It can be concluded that there are great differences among cultivars at the juvenile phase in root development in standard, in low pH (= low pH with aluminium) and between standard and acid conditions (Tab. I). The reduction of the root system is not always in relation with reduction of shoot (Fig. 1 to 6). The best tolerance to the acid conditions at triticale exists. The most sensitive cultivars at barley were found out.

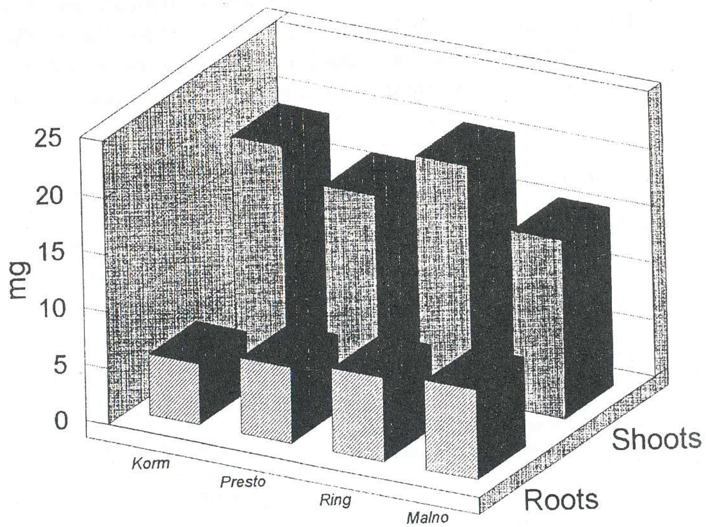
Cultivar differences and differences among wheat, triticale and barley in nutrient uptake and nutrient distribution (N, P, K, Ca, Mg, Na) to the roots and shoots at low pH and at standard conditions exists (Tabs. II, IV, VI, VII). At low pH conditions lower nutrient content at root and at shoot was obtained

I. Average weight of dry matter of root and shoot. shoot root ratio of different cereals and tolerance index to low pH

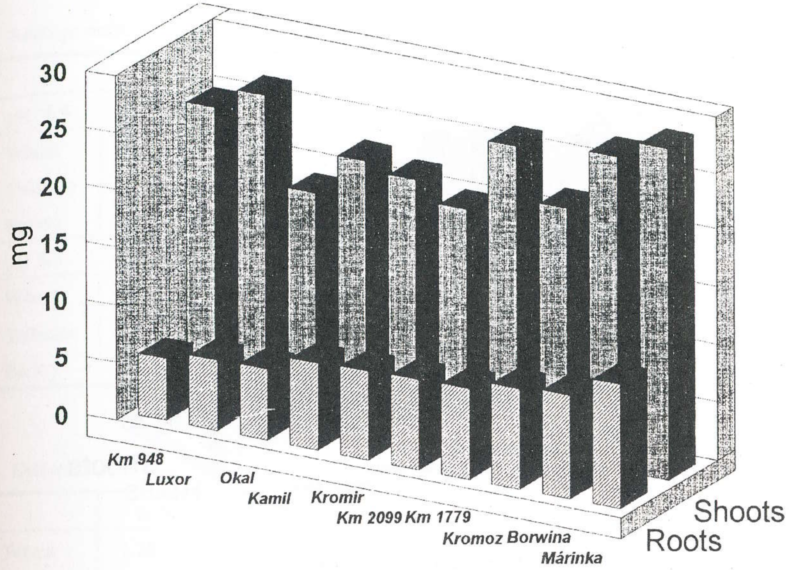
pH 6.5	shoot	root	shoot + root	pH 4.5	shoot	root	shoot + root
Wheat	25.6	8.6	34.2	wheat	18.4	6.5	24.9
Triticale	24.2	8.5	32.7	triticale	18.0	6.8	24.8
Barley	23.8	7.6	31.4	barley	19.0	6.4	25.4
	shoot – index	root – index	whole plant – index	shoot/root ratio			
Wheat	0.72	0.75	0.73		wheat	triticale	barley
Triticale	0.74	0.80	0.76	pH 6.5	2.97	2.84	3.13
Barley	0.79	0.84	0.80	pH 4.5	2.83	2.64	2.96



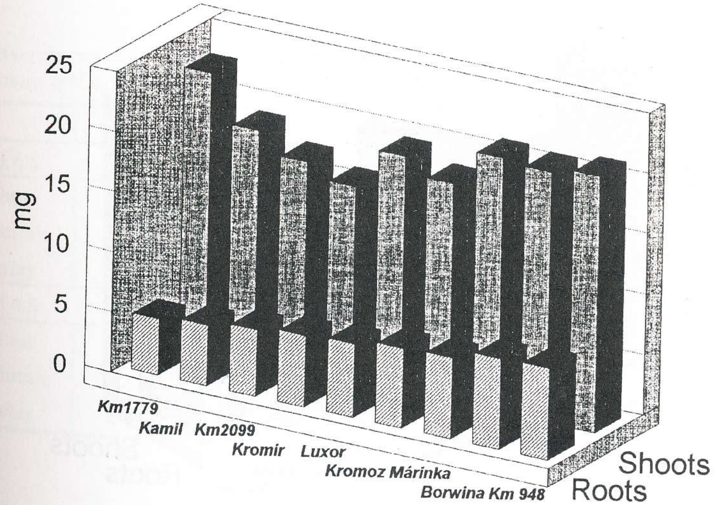
1. Growth of root and shoot of triticale: standard conditions



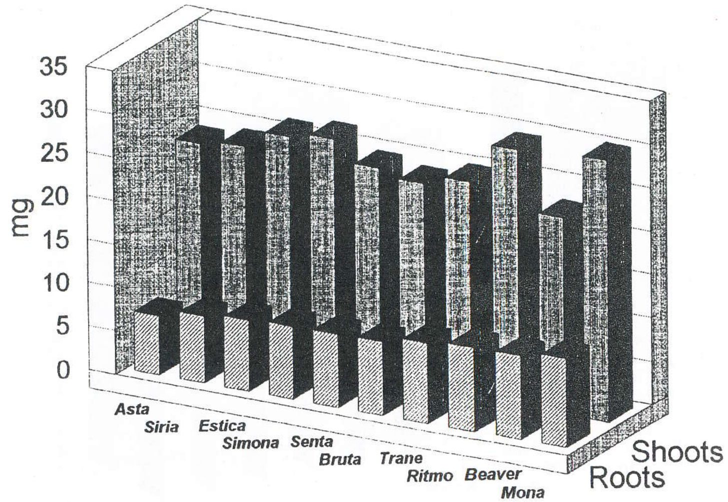
2. Growth of root and shoot of triticale: low pH



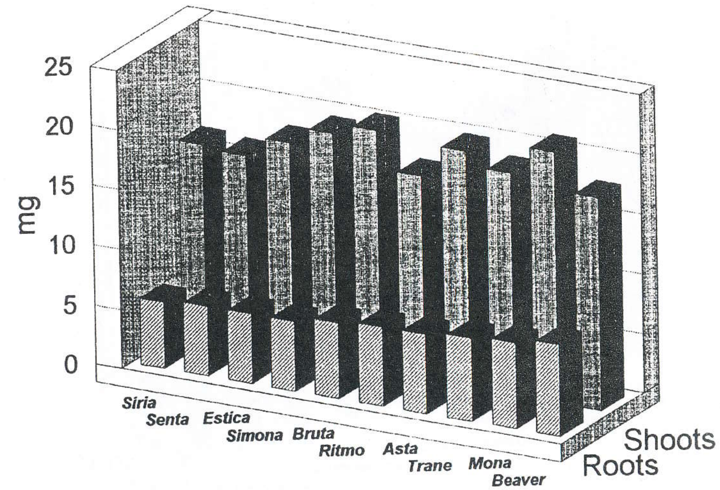
3. Growth of root and shoot of barley: standard conditions



4. Growth of root and shoot of barley: low pH



5. Growth of root and shoot of wheat: standard conditions



6. Growth of root and shoot of wheat: low pH

II. Average nutrient content in roots of cereals – low pH (4.5) and standard conditions (pH 6.5)

	N %	P %	K %	Ca %	Mg %	Na %
pH 6.5						
Wheat	1.671	1.189	5.155	0.750	0.245	0.468
Triticale	1.610	1.480	5.570	1.020	0.337	0.502
Barley	0.852	1.108	4.638	0.682	0.247	0.594
pH 4.5						
Wheat	0.469	1.077	4.479	0.372	0.134	0.498
Triticale	1.170	1.182	4.152	0.342	0.145	0.562
Barley	0.278	1.057	3.641	0.353	0.144	0.634

III. Differences of nutrient content in roots between pH 6.5 and pH 4.5

	N %	P %	K %	Ca %	Mg %	Na %
Wheat	1.201^{***}	0.112	0.666	0.380^{**}	0.111^{***}	–0.030
Triticale	0.450	0.297^{*}	1.417^{**}	0.677^{***}	0.192^{***}	-0.060^{*}
Barley	0.573^{*}	0.058	0.997^{***}	0.329^{***}	0.105^{***}	-0.040^{***}

* statistical significance 5% , ** statistical significance 1%, *** statistical significance 0.1 %

IV. Average nutrient content in shoots of individual cereals – low pH (4.5) and standard conditions (pH 6.5)

	N %	P %	K %	Ca %	Mg %	Na %
pH 6.5						
Wheat	3.971	1.244	8.612	0.305	0.251	0.106
Triticale	3.327	1.447	8.555	0.347	0.290	0.132
Barley	4.027	1.234	9.975	0.311	0.279	0.396
pH 4.5						
Wheat	4.442	1.012	7.199	0.143	0.144	0.144
Triticale	4.750	1.337	8.262	0.235	0.180	0.157
Barley	4.430	1.022	7.869	0.174	0.147	0.235

(Tabs. II to V, Figs. 6 and 7). Only at nitrogen in low pH conditions an exception exists.

V. Differences of nutrient content in shoots between pH 6.5 and pH 4.5.

	N %	P %	K %	Ca %	Mg %	Na %
Wheat	–0.471	0.232**	1.386***	0.162***	0.107***	–0.038**
Triticale	1.422**	0.110	0.285	0.112*	0.110	–0.030
Barley	–0.145	0.172	2.267***	0.083	0.122***	0.129**

* statistical significance 5% , ** statistical significance 1%, *** statistical significance 0.1 %

VI. Maximum and minimum of nutrient content in cultivars of wheat, triticale and barley – shoot

	Wheat pH 6.5	Wheat pH 4.5	Triticale pH 6.5	Triticale pH 4.5	Barley pH 6.5	Barley pH 4.5
N	3.11	4.27	2.89	4.68	2.91	3.71
	5.13	4.69	4.23	4.82	5.40	5.07
P	1.65	0.87	0.97	1.12	0.82	0.75
	0.96	1.16	1.94	1.76	1.45	1.41
K	7.98	6.33	7.33	7.60	8.84	5.75
	9.07	8.06	9.71	8.91	10.97	8.84
Ca	0.28	0.12	0.23	0.21	0.27	0.12
	0.33	0.15	0.42	0.26	0.36	0.31
Mg	0.23	0.13	0.22	0.17	0.25	0.13
	0.29	0.16	0.33	0.19	0.30	0.16
Na	0.06	0.10	0.09	0.14	0.04	0.18
	0.15	0.19	0.16	0.18	0.41	0.29

Cultivars with higher nutrient absorption and with higher distribution of nutrients to the shoot biomass are more tolerant to acid soils: Triticale and several cultivars of wheat and barley (these types of cultivars are stable at yield under different field conditions).

At crop with lower tolerance to the low pH (in comparison with triticale), lower differences of P, K, Ca, Mg and Na content between the standard and stress environments exist. As to barley and triticale, the differences are statistically significant. Triticale-crop more tolerant to the low pH, statistically significant reduction of nutrients content in root (but not at shoot) exhibits. In wheat and barley is a statistically significant reduction of nutrient content in root and in shoot at acid conditions (Tabs. III and V).

VII. Maximum and minimum of nutrient content in cultivars of wheat, triticale and barley – root system

	Wheat pH 6.5	Wheat pH 4.5	Triticale pH 6.5	Triticale pH 4.5	Barley pH 6.5	Barley pH 4.5
N	0.10	0.01	1.20	0.10	0.10	0.10
	2.16	1.34	1.96	0.77	1.70	1.06
P	0.99	0.56	1.29	1.10	0.94	0.83
	1.50	1.39	1.68	1.32	1.39	1.20
K	4.89	3.35	5.05	3.71	4.19	3.04
	5.40	9.59	6.29	4.54	5.19	5.03
Ca	0.02	0.21	0.84	0.30	0.33	0.25
	0.91	0.88	1.09	0.38	1.07	0.73
Mg	0.21	0.11	0.30	0.12	0.18	0.10
	0.27	0.19	0.40	0.18	0.35	0.27
Na	0.42	0.21	0.46	0.55	0.46	0.47
	0.51	0.60	0.54	0.59	0.73	0.84

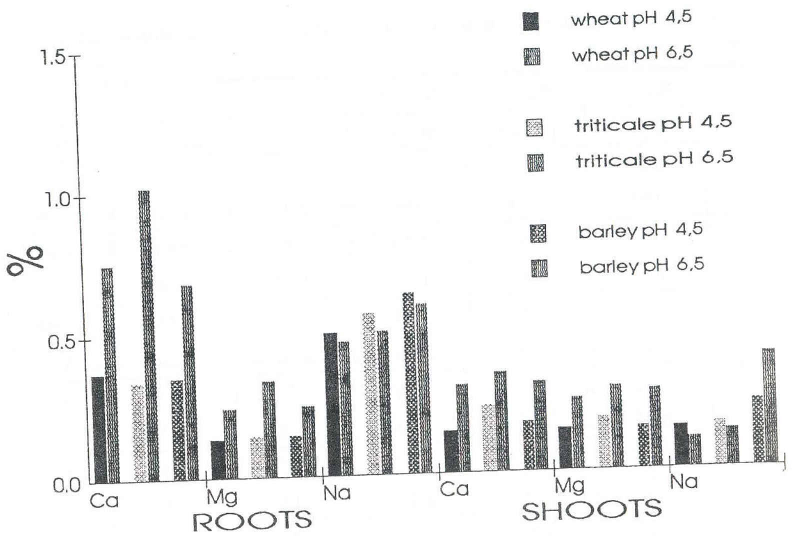
It can be also concluded that there is a possibility to select cultivars with effective nutrient uptake and utilization already in the juvenile phase of development.

DISCUSSION

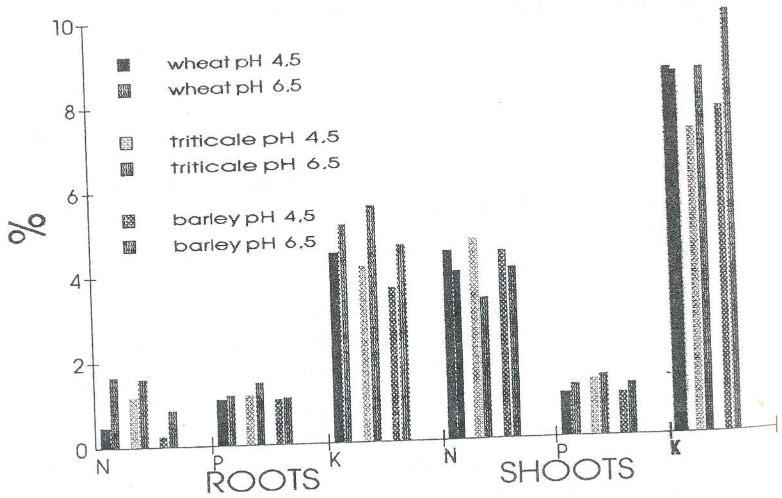
Cultivars more tolerate the low pH transport and more nutrients to the above-ground biomass (B l á h a et al., 1996). S t r i d (1996) obtained similar results especially at K and P transport. Lower influence of pH level was obtained at Ca and Mg.

There are measurable differences at the juvenile phase (two week old plants) among cultivars in nutrient content between standard and acid conditions. Younger plants are not suitable for acid conditions according to the influence of storage carbohydrates and proteins.

Cultivars under low pH conditions give lower yields than in other types of soil (B a i e r, B a i e r o v á, 1988). The development of screening methods for selection of cultivars tolerant to above named stresses is desirable, because contemporary used tests give different result (B l á h a, Š í p, 1990; R o l d á n, B l á h a, 1994).



7. Nutrient content at shoot and root of different cereals – low pH (4.5) and standard conditions (pH 6.5)



8. Nutrient content at shoot and root of different cereals – low pH (4.5) and standard conditions (pH 6.5)

Usually, transport of N is oriented acropetally, P is distributed cyclically between the root and shoot. Transport of K, similar to N, is oriented significantly acropetally. Ca ions are bound in the roots in pectic compounds. Mg can create many chelates with the possibility of cyclic transport, in a similar way as P. On the other hand Na releases Ca^{2+} from the pectins and this process at the same time slow down its transport from the roots. Thus, there is a possibility for preliminary selection of cultivars with good nutrient uptake and utilization in low pH in laboratory experiments. Genetic variability and plant ability to uptake, translocate, distribute, accumulate and use of mineral elements are important in adapting plants to specific (low pH with aluminium) toxicity of environment. The problems of mineral stress can be reduced by selecting or breeding plant genotypes with greater tolerance to the stress. It is known that the majority of traits correlated with resistance of cultivars to different abiotic stresses are independently inherited. Breeding for nutrient efficiency under stress conditions requires to establish a clear conceptual definition for nutrient uptake and efficiency, identify plant properties related to nutrient efficiency, develop screening methods on the main factors correlated with nutrients efficiency.

A very important problem of root research will be also estimating of the functionally active part of the root system. There is, however, also still a lack of detailed information of changes in anatomy and morphology of roots and their effect on nutrient uptake. Nutrient content in the environment influences the root shoot relationship (Novák, 1985).

At rye (only one cultivar) Albedo, similar results to triticale were obtained: weight of dry matter of roots for low pH and standard conditions are 5.5 and 5.2 mg, for shoots 18 mg and 22 mg a total weight of plants 23.5 and 27.2 mg; tolerance indices for roots, shoots and total weight are 1.06, 0.82 and 0.86.

Nutrient content for rye:

		N	P	K	Ca	Mg	Na
pH 6.5	shoot	2.85	1.92	9.42	0.43	0.31	0.18
	roots	0.73	1.73	3.96	1.14	0.4	0.64
pH 4.5	shoot	4.88	1.58	8.54	0.23	0.2	0.15
	roots	0.28	1.39	3.87	0.39	0.14	0.53
pH 6.5–4.5	shoot	2.03	0.39	0.14	0.2	0.11	0.03
	roots	0.45	0.34	0.09	0.75	0.26	0.11

The root system seems to be very suitable as a perspective selection criterion in plant breeding. The chemism of low pH and aluminium ions in the rhizosphere and their effects on the plant metabolism is a subject for the research abroad as well as in our country. There is still a lack of detailed information of low pH and aluminium on changes in anatomy and morphology of roots (length, total length, number of root tips, volume, diameter, etc.) and their effect on nutrients uptake. It is well known that some traits (ions efflux from the roots, roots length and diameter) of root system correlate well with nutrient uptake and utilization.

Development of root system, its geometry, density, distribution of roots in soil profile, branching pattern, length and density of root hairs affect acquisition and uptake of nutrients (Römer et al., 1988; Föhse et al., 1991). Under low soil fertility (nutrient content) and low water content increase role of root system characteristics. It applies chiefly to P, N and K (De Willigen, Van Noordwijk, 1991). Stability of shoot : root ratio measured in juvenile plants at different nutrient level and different level of influence of abiotic stresses seems to be a suitable selection criterion, for stability of yield (Strid, 1996; Bláha et al., 1996). The content and ion form of absorbed nutrients modify root growth and morphology. Intervarietal differences were observed in these reactions, too.

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Vliv nízkého pH a hlinitých iontů na příjem živin a růst v juvenilních fázích vývoje u odrůd obilovin.

Scientia Agric. Bohem., *28*, 1997 (2): 81–94.

Odrůdové diference u tvorby kořenového systému, nadzemní biomasy a jejich vzájemného poměru existují již v juvenilních fázích růstu jak ve standardních, tak ve stresových podmínkách (pH 4,5 a 36 mg/kg Al v prostředí kořenů). Redukci kořenů a nadzemní části jednotlivých obilovin v těchto podmínkách znázorňuje tab. I. Z obr. 1 až 6, na kterých je zobrazen vývoj kořenů a nadzemní části rostlin, vyplývá, že redukce kořenové části rostlin není u jednotlivých odrůd vždy v souladu s redukcí nadzemních částí. Hodnotíme-li odrůdy podle citlivosti kořenového systému kořenovým indexem, můžeme uvést, že triticale je odolnější vůči sledovanému stresu než pšenice a ječmen, které vykazují v průměru přibližně stejný stupeň tolerance. Nejcitlivější odrůdy, tj. odrůdy s největší redukcí kořenového systému, se vyskytují u ječmene (obr. 1 až 6).

Obdobně jako u hmotnosti sušiny byly nalezeny rozdíly v obsahu živin (N, P, K, Ca, Mg, Na) u biomasy kořenů a nadzemní části rostlin jak u genotypů tolerantních, tak u genotypů citlivých k nízkému pH (tab. II, IV, VI, VII). Z tab. II a V a z obr. 7 a 8 vyplývá, že jak u kořenů, tak u nadzemní části klesá obsah živin v podmínkách nízkého pH doprovázeného aluminiovou toxicitou. Plodiny tedy obsahují méně živin v kořenech i v nadzemní biomase ve srovnání se standardním prostředím. Výjimku tvoří pouze obsah dusíku u nadzemní biomasy v prostředí nízkého pH.

U kořenů pšenice a ječmene je v kyselém prostředí menší rozdíl v obsahu fosforu, draslíku, vápníku, hořčíku a sodíku mezi standardním prostředím a stresovým prostředím při porovnání s triticale. U ječmene a u triticale jsou rozdíly vždy statisticky významné. Triticale má statisticky významnou redukci obsahu prvků v kořenech,

nikoliv však v nadzemní biomase. U nadzemní biomasy i u kořenů mají statisticky významnou redukci prvků pšenice i ječmen (tab. III a V). Triticale v prostředí nízkého pH i v prostředí standardním (pH 6,5) má většinou vyšší obsah živin a v prostředí zatíženém sledovaným stresem udržuje vysoký obsah živin v nadzemní biomase (distribuce z kořenů do nadzemní části). Z výsledků lze také usoudit, že obsah jednotlivých prvků je pro predikci citlivosti jednotlivých odrůd vůči nízkému pH méně přesný než kořenový index.

obiloviny; odrůdové rozdíly; tolerance; nízké pH; toxicita hliníku; obsah živin; transport asimilátů a živin; index nadzemní část/kořeny; morfologické znaky

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