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Prediction of the transfer of trace elements from soils into plants

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ABSTRACT

Transfer pathway soil – plant is being characterized in this paper. Transfer functions are used in searching for critical values of total contents of trace elements (TEs), their mobile species and mobility conditions in soils. They are derived by means of multiple regression analysis. Critical soil values are obtained by substitution of plant contents for fodder plant standards in prediction equations. The contribution is dealing with three trace elements Cd, Tl and Pb that are ecotoxicologically most important. Very mobile Cd and Pb with a low mobility are included into all fodder and food standards. Testing values of critical Cd soil contents and mobilities in relation to other soil properties were derived. What concerns Pb critical values were set up, attesting the fact that only rarely occurring high total and mobile species content in soils can induce critical transfers.

Keywords: crop soil; trace elements Cd, Tl, Pb; multiple regression analysis; transfer functions soil – plant

The fundament of the assessment of critical soil loading with trace elements (TEs) for certain organisms (or hydrosphere) is generated by modeling the transfer from soil to the other ecological media. These critical soil loadings give rise to critical loads of organisms (or hydrosphere) within the framework of some transfer pathways. Hereafter we are dealing only with the transfer pathway soil – crops from the point of view of the food chain exposure to the danger either by overloading fodder plants (zootoxicity), food plants (humanotoxicity) or by endangering the crop production (phytotoxicity).

The starting point of the investigation of this complicated problem is to discover the rules of the transfer of TEs from soils into crops. As noted in the previous papers dealing with these relations (Němeček and Podlešáková 2001, Podlešáková and Němeček 2001) and as has been mentioned by other authors (Hornburg and Brümmer 1989, 1990a, b, 1991), the prediction of the transfer rate can be derived from the contents of hazardous TEs in crops in relation to the total content of these TEs in soil, their mobile or potentially mobilizable species and from soil characteristics that affect the mobility of some TEs. The main soil characteristics that affect the mobility of TEs are: pH, clay and humus, additionally free Fe and Al content, CEC and qualitative indicators of humus and clay.

The simple relation between the total content of TEs in the crop and in the soil is called transfer factor or better (Hornburg and Brümmer 1991) transfer quotient. It is often used both in abroad and in our country. Lübben and Sauerbeck (1991) make use of this quotient for the evaluation of the influence of waste disposal on TEs content in soils and crops. This ratio is also used by Sáňka (1998) and the State Institute for Agriculture Supervision and Testing (1993) in evaluating the results of pot trials with polluted soils. Transfer quotients are suitable for the assessment of the extent of the transfer of single TEs from soils into plants and for the assessment of differences in TEs uptakes by single crops and the dependence of uptakes by crops upon soils. But they evocate the impression of the stabile interrelationships of TEs in soils and their uptakes by plants. This applies even for transfer quotients related to mobile species in soils (Hornburg and Brümmer 1991, Němeček and Podlešáková 2001). But they are not suitable for the prediction of critical conditions of crop loads.

For the prediction of the transfer of TEs into plants from soils to crops serve much better transfer functions (Hornburg and Brümmer 1991). They are being derived by means of the multiple regression analysis.

Casuistic studies of rules governing the transfer of TEs from soils with known TEs contents and mobilities, taken in the field (not with simulated pollution) contributed to the elaboration of procedures of their systematic investigation. Xian proved (1989) that the uptake of Zn and Pb by crops in an area of a zinc metallurgic factory correlated not with the total content of TEs but more with the content of mobile and potentially mobilizable species. Soon and Bates (1982) found by analogy that Cd and Zn (partly Ni) uptakes by plants are dependent on the content of mobile species of the mentioned TEs with an inversely correlation with pH. The correlation of Cd uptake by clover with the mobile species soluble in 0.01M $CaCl_2$ was found out by Whitten and Ritchie (1991), with 0.01M $NaNO_3$ by Gupta and Häni (1981). Ceśliński et al. (1996) detected also that the Cd uptake by wheat correlates with a mobile species. Many similar contributions can be found in the literature.

All the mentioned and other papers proved that transfer functions must be derived on the basis of a representative set of soil samples (from Ap and adequate horizons), characterized by a wide range of soil characteristics, crucial for the TEs mobility and comprising all forms of soil contamination in the field conditions (airborne, fluvial, from waste disposal etc.) and extremes of geogenic contents.

To obtain representative data that could be used to derive critical load values, it was indispensable to unify all methods to determine the total content of TEs and especially contents of their mobile species. Hornburg and Brümmer (1989) derived by means of the multiple regression analysis prediction equations, based on field investigations of pairs soil – plant. They came to the prediction of the content of TEs in the wheat grain on the basis of the mobile (in $CaCl_2$), potentially mobilizable (EDTA) and total content of Cd, Zn and Mn. Critical soil characteristics (pH, total Cd content, content of mobilizable species of Cd in parentheses) leading to the exceeding of the food crops limit could be derived:

– pH > 6.0, 1.0 (0.65)
– pH 5.5–6.0, 0.8 (0.5)
– pH 5.0–5.5, 0.6 (0.35)

In further contribution Hornburg and Brümmer (1990a, b, 1991) derived other prediction equations. The more complicated interrelationships were expressed by means of nomograms. For example, the transfer of the above mentioned elements from soils into the wheat grain is affected by the element soil reserve, pH, clay content and in a lesser degree by a humus content. Making use of more factors (e.g. mobile species) makes the prediction better. Total content of the TEs and its mobilizable share represent in accordance with the quoted authors the factor of quantity and mobile species approximately the factor of intensity.

Heymann and Wiechmann (1996) evaluate the transfer of Cd into vegetables. They make use of the extractants 1M NH_4NO_3 and 0.01M $CaCl_2$. They come to the conclusion that results of the both mentioned extractants do not differ too much. They derived generic critical values of the mobile species of Cd within the range of 100–200 $\mu g.kg^{-1}$. Mobile species or also total content of Cd and pH appear again in the regression equation. They give the following critical values for the total contents of Cd and pH: pH > 6.5, 1.5 $mg.kg^{-1}$ Cd, pH 6.4–6.0, 1 $mg.kg^{-1}$ Cd.

Prüeß (1992) derives also from the total contents of TEs and the content of mobile species soluble in 1M NH_4NO_3 critical values of soil pollution not only for the transport pathway soil – crop, but also for the other pathways.

According to the announcement of Peijneburg and Romkers (1999) a new system of soil pollution limits for agricultural soils is being prepared. The critical values will be obtained by means of trànsfer functions, based on multiple regression analyses. They derive TEs contents in crops from soil pH, TEs, clay and humus contents in soils.

The main signification of transfer functions insists in the prediction of soil pollution that results in the critical crop loads in relation to the food chain. Critical crop loads are therefore represented only by food and fodder plant standards. But they reflect in the agreement with Vollmer (1991) the upper limits of variance of TEs contents in crops, found by control activities. Critical crop loads, except of phytotoxicity are consequently not ecotoxicologically supported. Besides the standards of different countries differ each from other and for some elements they are even lacking. In some cases, e.g. in Germany, food and fodder raw material standards are restricted only to Cd and Pb.

From this reason we proceeded in the verifying of transfer functions, which make possible the searching for critical values of soil pollution for the transfer pathway soil – crop from data concerning critical values of crops from the viewpoint of zoo- and phytotoxicity. This critical value is compared with background contents of TEs in crops. The substitution of TEs contents in crops for their critical values in prediction equations serves to search for critical soil pollution values.

MATERIAL AND METHODS

The methodology of pot trials and field observations was described in the previous publications (Němeček and Podlešáková 2001, Podlešáková and Němeček 2001).

Prediction transfer equations were derived from the pot trials with triticale and radish that can be planted in a wide range of soil conditions (especially pH). They were derived from the set of the following variables (TO = total content in concentrated acids HF + HNO_3 + $HClO_4$, ED = potentially mobilizable species in 0.025M Na_2EDTA, MN (MC) = mobile species in 1M NH_4NO_3 – MN, in 0.01M $CaCl_2$ – MC, C = clays, H = humus, pH):

– TO, ED, MN (MC), pH, C, H – all main factors
– TO, ED, MN (MC), pH – main factors of TEs reserves and their intensity
– TO, clay, humus, pH – total content, soil factors affecting the TEs mobility

Substituting the TEs content in equations by critical crop loads, we came to the critical soil loads.

The processing of the data involves either the whole set of data or subsets lacking geogenic extremes.

This contribution is focused on the modeling of Cd, Tl, Pb transfers into crops. These elements represent TEs with a high ecotoxicological relevancy – zootoxicity.

RESULTS AND DISCUSSION

In this paper we evaluate possibilities of the transfer of Cd, Tl, Pb from soil into the hypocotyl bulb of radish and into young plants of triticale on the basis of pot trials. Only orientative attention is given to the transfer into fodder plants in the field conditions.

Cadmium

Cadmium is a trace element, characterized by the highest mobility (inversely pH-dependent) and the highest transfer into plants and the expressive zoo- and human-otoxicity. Hazards of Cd are supported by the fact that critical crop loads from the viewpoint of zootoxicity are low and therefore strict, due to its high mobility and high transfer quotients.

The value 1.1 $mg.kg^{-1}$ d.w. in the testing plant is taken for critical in German fodder plant standards. The advantage of the German standards is that critical values are expressed in dry weight whereas the Czech criteria reflect the water content in fresh materials or in hay (fodder plants). In searching for critical soil loads of Cd, we prefer the results obtained from the whole set of samples. They comprise not only common low immission loads, but also expressive loads, mainly from flood accumulation in Fluvisols.

Critical soil pollution values for the pathway soil – plant can be derived from some simple equations (* significance at 95%), e.g.

– for triticale ($n = 97$)

$\ln T = 0.488 \ln MC^* + 1.580^*$

$\ln T = 0.616 \ln TO^* - 0.308^*$

– for radish ($n = 97$)

$\ln R = 0.412 \ln MN^* + 1.232^*$

– for fodder plants ($n = 103$)

$\ln F = 0.591 \ln TO^* - 2.028^*$

$\ln F = 0.669 \ln ED^* - 1.369^*$

In this way we obtain critical values in the ranges 40–50 $\mu g.kg^{-1}$ of mobile species (MN, MC), 2.0 $mg.kg^{-1}$ of the total Cd content, pH < 3 and clay content < 5% for triticale and 50–70 $\mu g.kg^{-1}$ MN for radish with a higher transfer quotient. We have to use these critical values with precaution, because they represent limiting values of single factors without regard to their interrelationships.

The use of two factors markedly contributes to make the transfer prediction more accurate. Making use of two factors significantly specifies prediction possibilities. The derived curve (Figure 1) shows, that the critical uptake by triticale is found at a very low pH 2–3 already at a total Cd concentration, that corresponds to reference values of the background content (0.6 $mg.kg^{-1}$). Critical uptake by triticale increases above all the content 1.0 $mg.kg^{-1}$ at pH 4.5; it can occur in some agricultural soils. The generic critical values 2.0 $mg.kg^{-1}$ are reached at pH 6.5. This pH represents the mean value in agricultural soils. Similar values are (valid at pH 6.5) found in the original proposals of Cd critical values (in aqua regia) for sewage sludge disposal (BGBJ 1992). Critical total Cd content in neutral soils is approximately 2.5 $mg.kg^{-1}$.

Specific features of the prediction curve (Figure 2) rest on the fact that the value of the mobile species (MN) in soils leading to the critical uptake by radish increases at lower pH values. It increases between the pH 6.5 and 4.5

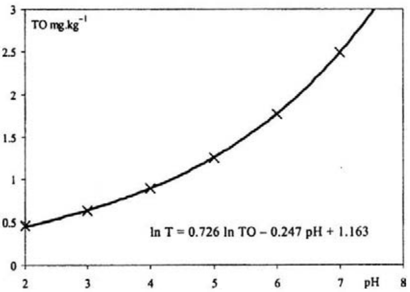


Figure 1. Dependence of critical transfer values of Cd into triticale upon the total content (TO) of Cd and pH in soils

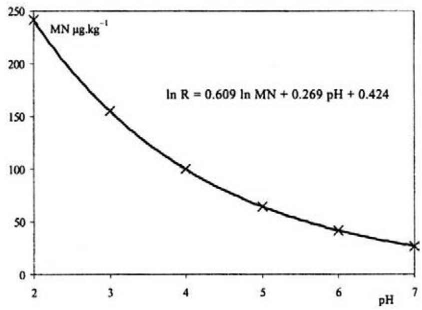


Figure 2. Dependence of critical transfer values of Cd into radish upon the content of mobile species (MN) of Cd and pH in soils

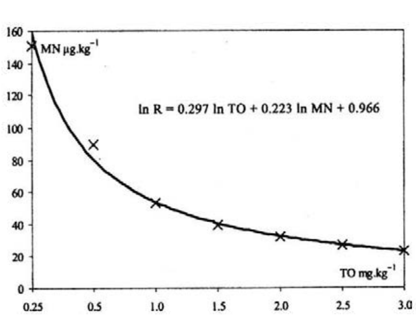


Figure 3. Dependence of critical transfer values of Cd into radish upon the total content (TO) of Cd and its mobile species (MN) in soils

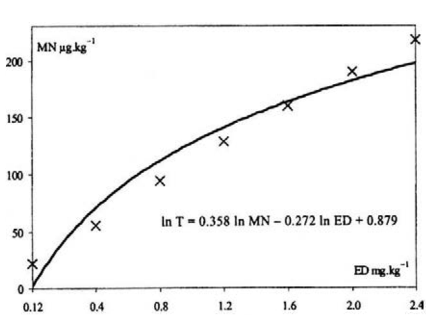


Figure 4. Dependence of critical transfer values of Cd into triticale upon the content of potentially mobilizable (ED) and mobile species (MN) of Cd in soils

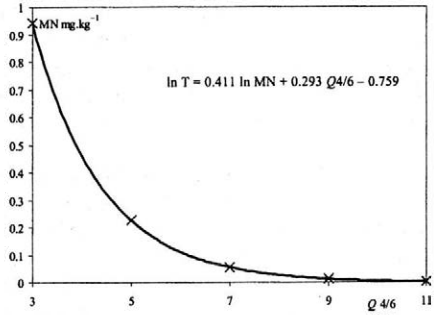


Figure 5. Dependence of critical transfer values of Cd into triticale upon the content of mobile species (MN) of Cd a humus quality ($Q_{4/6}$) in soils

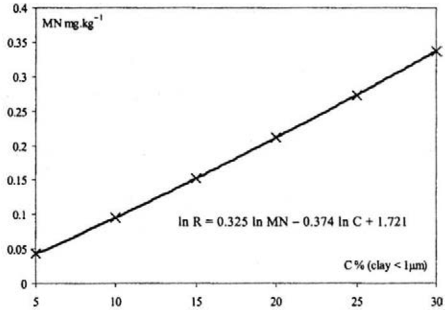


Figure 6. Dependence of critical transfer values of Cd into radish upon the content of mobile (MN) species of Cd and clay (< 1 µm) content in soils

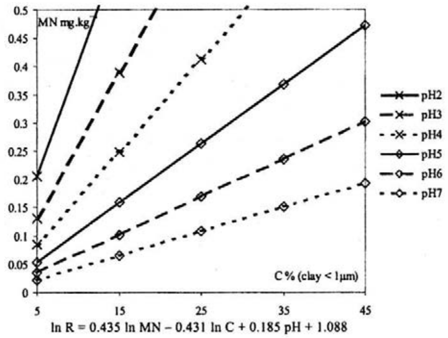


Figure 7. Dependence of critical transfer values of Cd into radish upon the content of mobile (MN) species of Cd and clay (< 1 µm) content at different pH levels in soils

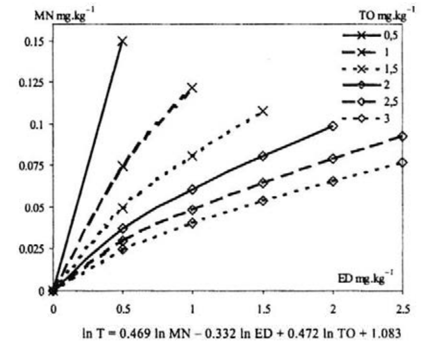


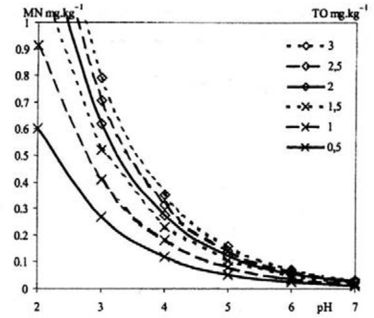
Figure 8. Dependence of critical transfer values of Cd into triticale upon the content of mobile (MN) and potentially mobilizable (ED) Cd species at different levels of the total Cd content in soils

from 40 up to 80 µg.kg^{-1}. This paradoxical increasing of the critical value (becoming less strict) of the mobile species (MN) with increasing acidity can be explained according to Brümmer and Herms (1983) by the difference between the concentration of the mobile species extractable in 1M NH_4NO_3 and the bioavailability, that is decreased due to the forming of complexes in acid conditions. The further cause is due to the fact that in case of Cd the important factor is a high solubility (TO/ED × 100) of Cd in anthropogenically impacted soils, that is (e.g. in Fluvisols) less dependent on pH, but contributes to making critical transfer values more strict.

Figure 3 proves that the increasing of the total content of TEs is accompanied by the decrease of the critical value of the mobile species. When the soil contains 2 mg.kg^{-1} of Cd the critical value of mobile species (MN) comes close to 40 µg.kg^{-1} (the lowest value derived from simple relations), whereas at the background concentration it has the highest value found 80 µg.kg^{-1}. This general relation also reflects the participation of the increasing total content, due to the anthropogenic contamination. Figure 4 presents the dependence of critical transfer values of mobile species upon the increasing contents of potentially mobilizable species. The reason is that majority of higher ED values are reached mostly in slighty acid soils, where critical transfer values can be less severe.

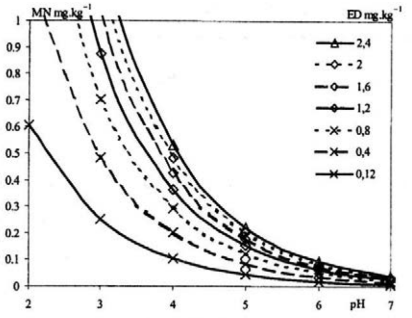
Critical values of TEs transfer are also clearly influenced by increasing the humus quality ($Q_{4/6}$) up to more than 300 µg.kg^{-1} at $Q_{4/6}$ = 4.5 of chernozems as shown in Figure 5 and clay content (Figure 6). Critical contents of the mobile species surpass then the values 100 µg.kg^{-1}. Humus of high quality and increasing clay content compensate as sorbents the generally occurring anthropogenically increased solubility, accompanying the increase of the total Cd content. Figure 6 demonstrates that the critical transfer value related to the mobile species (MN) became less strict with increasing of the clay content so that the clay content 15% (in most silt-loams) affects the increasing of the critical value of MN up to 150 µg.kg^{-1}.

Very important for the prediction of Cd transfer are relations shown in Figure 7. This figure represents a synthesis of Figures 2 and 6. The presentation differentiates distinctly the relation of the Cd transfer related to the mobile species (MN) in dependence on clay content at different pH values. This figure proves again that the strictest critical values occur at 5% clay content (20–80 µg.kg^{-1}) at very often occurring pH values. But in fine textured soils, they reach more than 200–300 µg.kg^{-1}.



ln MN = 0.603 ln TO − 0.808 pH + 1.526

Figure 9. Dependence of the content of mobile species (MN) of Cd in soils upon the pH at different of the total content levels



ln MN = 0.538 ln ED − 0.872 pH + 2.383

Figure 10. Dependence of the content of the mobile species (MN) of Cd in soils upon the pH of Cd at different potentially mobilizable (ED) content of Cd levels

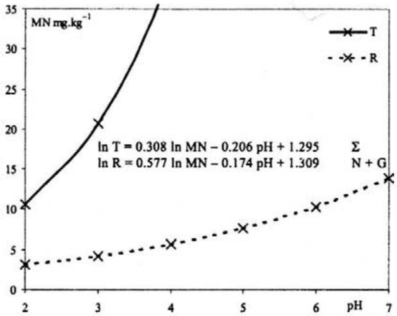


Figure 11. Dependence of critical transfer values of Pb into triticale and radish upon the content of mobile (MN) species of Pb and pH in soils

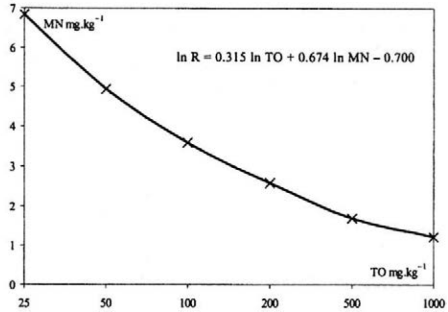


Figure 12. Dependence of critical transfer values of Pb into radish upon the total content (TO) and the content of mobile species (MN) of Pb in soils

The next more complicated relation indicated in Figure 8 points to the critical transfer values assessed in terms of mobile species (MN) in dependence on total Cd contents and their relative solubility as indicated by the potentially mobilizable species (ED). This figure reflects the combination of Figures 3 and 4, characterizing the more rigid transfer values for mobile species at higher total Cd contents (general regularity), decreasing with the growth of ED, which is accompanied by lower soil acidity.

The comparison of mean and maximum values (in parentheses) of Cd in plants and total Cd contents and its mobile and potentially mobilizable species in soils is very important for the interpretation of the experimental data obtained. The following mean and maximum values ($n = 97$) have been reached ($mg.kg^{-1}$ d.w.):

plants			soils		
triticale	0.78	(3.1)	TO	0.57	(11.1)
radish	0.97	(6.4)	ED	0.23	(3.4)
fodder plants	0.10	(2.1)	MN	0.021	(0.45)

These data testify the fact that critical values of plants are (often) exceeded in the examinated set.

Figure 9 provides evidence that the content of mobile species markedly increases when pH values decrease, in particular at the high level of Cd contents. Even at background values (0.6 $mg.kg^{-1}$) at pH 4 can be reached the concentration of MN close to 150 $\mu g.kg^{-1}$, by analogy also at the total content 2 $mg.kg^{-1}$ Cd at pH 5. Figure 10 shows similar behavior in relation to the potentially mobilizable species. These facts confirm the dangerous behavior of Cd again.

The analysis of extreme data (Table 1) validates the above mentioned facts. This analysis proves the high solubility of anthropogenic loads (ED/TO × 100 in the range 50–90%) even at slightly acid reaction. Rarely found geogenic soil loads (residual weathering products of some limestones) are characterized by low solubility (ED/TO × 100 less than 15%) and only high contents result in plant uptake.

Thalium

Thalium is regarded as an ecologically very important trace element with a high transfer quotient.

When we accept the concentration 1 $mg.kg^{-1}$ d.w. in plants as critical in accordance with German standards it turns out that this value was not surpassed in the investigated set. We found the following maximum values:

Table 1. Transfers of trace elements into plants from soils characterized by increased up to extreme contents of elements (mg.kg^{-1} d.w.)

Element	Kind of extremes	TO	ED	MN	ED/TO × 100 %	MN/TO × 100 %	pH	Radish	Triticale	Critical referent values	
										value	exceeding
Cd	G	2.53	0.36	0.015	14.2	0.59	7.0	1.05	0.84	1.1	–
	Ac	1.50	0.67	**0.260**	44.7	17.3	4.6	**6.36**	1.05		+
	F	**6.08**	3.06	**0.100**	50.3	1.64	6.4	1.01	**3.15**		+
	An	**4.95**	3.53	**0.99**	71.2	19.9	5.0	**7.92**	**9.55**		+
	F	**48.90**	47.50	**7.55**	97.1	15.4	5.5	**14.98**	**65.00**		+
Pb	Ac	87	28	0.60	32	0.690	3.9	1.50	1.05	5–10	–
	GAc	118	54	0.10	46	0.080	4.6	0.51	0.67		–
	G	203	114	0.10	56	0.050	6.1	1.00	0.75		–
	AnF	**1226**	844	5.10	**69**	0.420	5.0	**39.0**	**12.0**		+
	F	**2340**	1909	1.85	**82**	0.080	5.5	**33.8**	**27.7**		+
	F	175	158	0.10	90	0.060	6.4	0.23	0.35		–

Ac = very acid oils, An = anthropogenic loads, F = fluvial loads, G = geogenic extremes, AcG = very acid soils with geogenic loads, AnF = anthropogenic and fluvial loads
bold numeric data = exceeding of critical plant and soil loadings

plants		soils	
triticale	0.51	TO	0.353
radish	0.48	ED	0.136
fodder plants	0.011	MN	0.020

It was not possible to derive a prediction equation.

Lead

Lead is a trace element with a low mobility in soils and a low transfer quotient, but it is characterized by a high zoo- and humanotoxicity. Therefore it is involved in all systems of hygienic standards.

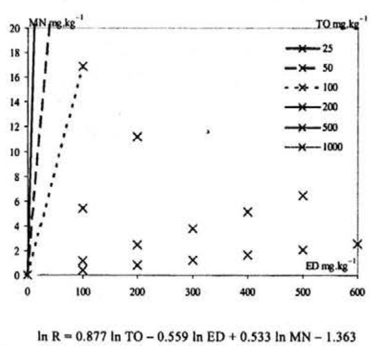
Critical concentrations in plants given in different standards fluctuate within a broad range 5–10 but also 40 mg.kg^{-1}. Based on a series of calculations, the lowest value 5 mg.kg^{-1} d.w. was used.

Simple transfer conditions are described for the whole set ($n = 97$) and the set lacking geogenic extremes ($n = 81$) by the following equations:

– for triticale $\ln T = 0.529 \ln MN^{*} + 0.584^{*}$ (the whole set)
$\ln T = 0.591 \ln MN^{*} + 0.718^{*}$ (set lacking geogenic extremes)

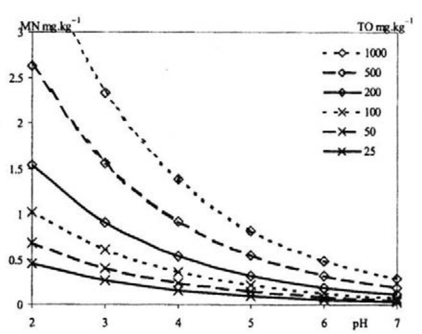
– for radish $\ln R = 0.555 \ln MN^{*} + 0.711$ (the whole set)
$\ln R = 0.763 \ln MN^{*} + 0.698$ (set lacking geogenic extremes)

– for fodder plants $\ln F = 0.762 \ln MN^{*} + 0.698$ (set lacking geogenic extremes)



$\ln R = 0.877 \ln TO - 0.559 \ln ED + 0.533 \ln MN - 1.363$

Figure 13. Dependence of critical transfer values of Pb into radish upon the mobile (MN) and potentially mobilizable (ED) species of Pb at different levels of the total content of Pb in soils



$\ln MN = -0.585 \ln TO - 0.526\, pH - 1.617$

Figure 14. Dependence of the content of mobile species (MN) of Pb in soils upon the pH and total content (TO) of Pb in soils

From a lot of these simple relations the following critical values of the mobile species (MN) and of the total content of Pb in soils could be derived.

– radish	MN3 – 4 $mg.kg^{-1}$	TO > 500 $mg.kg^{-1}$
– triticale	MN4 – 8 $mg.kg^{-1}$	TO > 400 $mg.kg^{-1}$
– fodder plants	MN4 – 5 $mg.kg^{-1}$	TO > 800 $mg.kg^{-1}$

In pot experiments the following mean and maximum (in parentheses) values were found:

– for radish 0.4 (3.0) $mg.kg^{-1}$ (extreme values > 30 $mg.kg^{-1}$ in a Fluvisol)

– for triticale 0.6 (2.0) $mg.kg^{-1}$ (extreme 15 $mg.kg^{-1}$)

In soils there were found the following mean maximum and extreme contents: TO 64 (231–2700), ED 36 (159–1334) and MN 0.12 (1.0–3.3) $mg.kg^{-1}$. The mere plant and soil contents within the examinated set show that even when we accept the strictest critical Pb plant loadings (5 $mg.kg^{-1}$) only extreme contents and solubilities (Fluvisols) can bring on their exceeding.

The more complicated interrelations between TO – pH, TO – clay, TO – humus confirm entirely these facts. The most important critical soil loadings, leading to the hazardous transfer into plants can be derived from relations in which the mobile species manifests itself (MN). Figure 11 proves how high should be the critical content of a mobile species (MN) even at pH 3–4 in relation to generic limiting values. The relation between the total Pb content and the content of the mobile species (MN), leading to the critical plant load proves (Figure 12), that at common total contents (100 $mg.kg^{-1}$) of Pb the critical content of the mobile species come close to the generic transfer value (3.5 $mg.kg^{-1}$).

The more complicated relation (Figure 13) also proves, that the critical transfer rate could by exceeded at high Pb contents and increased solubilities, accompanied by low content of the mobile species even at low ED contents (solubilities). The critical transfers at low total contents need unlikely high contents of mobile species. This follows also from Figure 14, that gives evidence on the extreme conditions of pH and the total Pb contents at which a higher content of the mobile species of Pb can occur in soils.

These facts are proved by studies of the extremes from the neighborhood of Příbram. They give evidence (Table 1) that up to the total (TO) contents 200 $mg.kg^{-1}$, potentially mobilizable content (ED) 150 $mg.kg^{-1}$ and mobile species (MN) 1.0 $mg.kg^{-1}$ the critical content was not exceeded. It happened only at the extreme Pb content exceeding 1200 $mg.kg^{-1}$, potentially mobilizable species above 800 $mg.kg^{-1}$ (solubility > 70%) and the content of the mobile species (MN) higher than 1.8 $mg.kg^{-1}$ in soils with a high anthropogenic loads.

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ABSTRAKT

Predikce transferu stopových prvků z půdy do rostlin

V příspěvku je charakterizována transferová cesta půda – rostlina. Pro stanovení kritických hodnot celkových obsahů stopových prvků, jejich mobilních specií a podmínek jejich mobilit v půdě je použito transferových funkcí. Jsou odvozovány pomocí vícenásobné regresní analýzy. Kritické hodnoty pro půdy jsou získány dosazením hodnot pícninářských standardů do predikčních rovnic. Výrazné vztahy mohly být nalezeny pouze pomocí nádobových pokusů. Příspěvek se zabývá stopovými prvky Cd, Tl a Pb, které patří k nejdůležitějším v půdě z ekotoxikologického hlediska. Velmi mobilní Cd a málo mobilní Pb jsou zahrnuty ve všech pícninářských normách. Byly odvozeny zkušební hodnoty kritických obsahů a mobilit Cd v poměru k dalším půdním vlastnostem. Pro Pb byly odvozeny hodnoty, které svědčí o tom, že pouze zřídka se vyskytující celkové obsahy Pb a jeho mobilní specie mohou vyvolat kritický transfer do rostlin, maximální hodnoty zabezpečují bezrizikovost stopového prvku.

Klíčová slova: rostliny; stopové prvky Cd, Tl, Pb; vícenásobná regresní analýza; transferové funkce půda – rostlina

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The transfer of less hazardous trace elements with a high mobility from soils into plants

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ABSTRACT

The paper characterizes transfer functions soil – plant of Zn, Ni, Mn and Co. Common features of these elements are their phytotoxicity. These trace elements have a high up to very high indirectly pH-dependent mobility. Zn has higher transfer quotients than Mn, Ni and Co. But common features of all mentioned trace elements is that in spite of their mobility only extreme contents or higher solubility manifest themselves in critical plant loads, inducing phytotoxicity.

Keywords: trace elements Zn, Ni, Mn, Co; transfer functions soil – plant; critical plant loads; phytotoxicity

The investigation of realistic trace elements (TEs) mobilities in soils and their uptake by plants enable us to come forward with the solution of critical plant loads from the viewpoint of food chain and phytotoxicity protection.

Realistic relations (equations) are being derived, based on confrontation of values from pot experiments, field observations and plant background values in relation to food and fodder plant hygiene standards (Podlešáková et al. 2001).

The previous paper (Němeček et al. 2001) was dedicated to the general principles of the procedure in the assessment of critical values of soil loads in relation to the pathway soil – crop. The principle attention was focused on the deducing of values of critical soil loads for trace elements (TEs) that are included into all fodder and food plant standards – Cd (Tl) and Pb. Both Cd and Pb are characterized by high zoo- and humanotoxicity.

This contribution turns attention to a group of TEs Zn, Ni, Mn and Co. Their mobility and transfer quotients are very high (Zn) or high enough (Mn, Ni, Co). They are characterized by phytotoxicity.

MATERIAL AND METHODS

The methodology was described in three previous papers (Němeček and Podlešáková 2001, Podlešáková and Němeček 2001).

RESULTS AND DISCUSSION

Zinc

Zinc is a trace element with a high mobility in soils and a high transfer into plants. The risk of Zn concerns the phytotoxicity. But the critical values in plants linked to the phytotoxicity are very high. These facts decrease the hazard that follows from the high inversely pH-dependent mobility and a high transfer quotient.

The value 250 $mg.kg^{-1}$ d.w. of fodder plants is generally taken for critical. Making use of this value results in the conclusion that the critical values have not been surpassed in the set under study. Therefore the critical value of plants was reduced to 150 $mg.kg^{-1}$ d.w. Even after substitution of this value for the plant content in the prediction equations, we arrive to the very high critical contents of the total Zn content exceeding the total content of Zn 5000 $mg.kg^{-1}$, the content of the mobile species (MN) 1000 $mg.kg^{-1}$, critical pH 2 and clay content 1%. These critical values (* significance at 95%) can be derived from some equations of the following design ($n = 97$):

– for triticale $\ln T = 0.131 \ln MN^{*} + 3.656^{*}$
– for radish $\ln R = 0.165 \ln MN^{*} + 3.801^{*}$
– for fodder plants $\ln F = 0.130 \ln MN^{*} + 3.649^{*}$
$\ln F = 0.368 \ln TO^{*} + 1.781$

Previous to the presented a more complicated relation that does not reflect only extreme values of critical plant loads we refer to the mean and maximum (in parentheses) Zn contents in plants and Zn contents and mobilities in soils ($mg.kg^{-1}$):

plants			soils		
triticale	36	(115)	TO	151	(736)
radish	43	(299)	ED	25	(421)
fodder plants	34	(363)	MN	0.6	(14.5)

Figure 1 proves that the critical transfer value (into triticale) is acquired at very high Zn contents not only at the most common pH values, but also at the low pH 3–4. Already at the pH 4.0 is the critical Zn content in soil close to 5000 $mg.kg^{-1}$. Even at the high total Zn content (Figure 2) is the critical content of the mobile species (MN) extremely high.

Figures 3a, b indicate relations in which total content of Zn and its solubility (ED/TO) manifest themselves at different pH values in critical transfer conditions. It shows

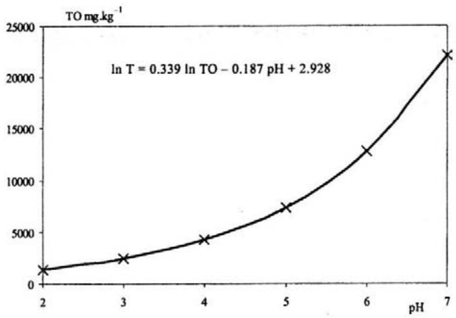


Figure 1. Dependence of critical transfer values of Zn into triticale upon the total content (TO) of Zn and pH in soil

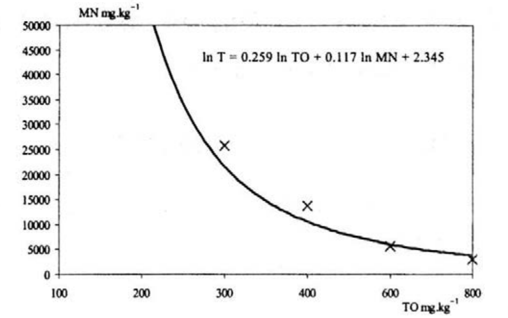


Figure 2. Dependence of critical transfer values of Zn into triticale upont the total content (TO) of Zn and the content of the mobile species (MN) in soils

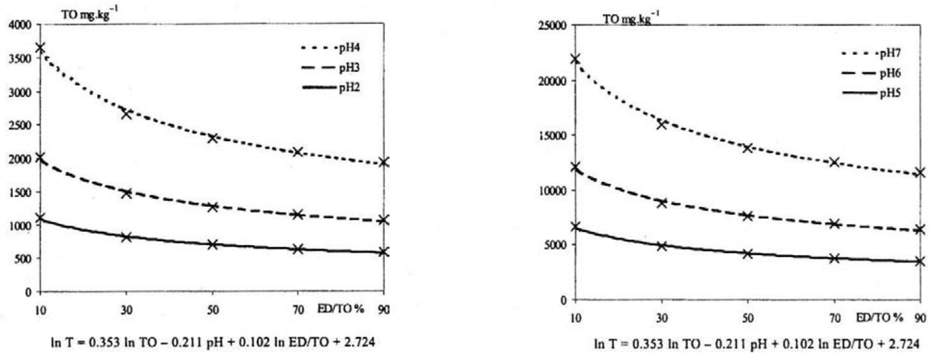


Figure 3. Dependence of critical transfer values of Zn into triticale upont the total content (TO) of Zn and its solubility (ED/TO × 100) in soils at different pH levels

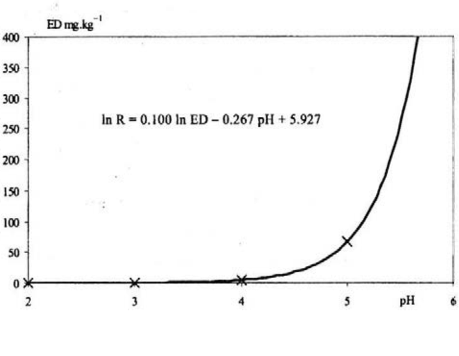


Figure 4. Dependence of critical transfer values of Zn into radish on the potentially mobilizable species (ED) and pH in soils

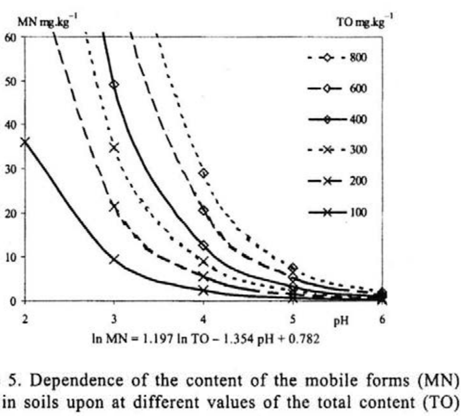


Figure 5. Dependence of the content of the mobile forms (MN) of Zn in soils upon at different values of the total content (TO) in soils

extremes under which Zn could be hazardous from the viewpoint of the phytotoxicity. The critical value of the total Zn content lies just above 1000 $mg.kg^{-1}$ even at pH 3 and the 90% solubility and is close to 5000 $mg.kg^{-1}$ at pH 5 and common solubility (3500 $mg.kg^{-1}$ at 90% solubility).

The very strictly calculated criteria show (Figure 4) that at mean values of ED (25 $mg.kg^{-1}$) the critical value could be surpassed only at pH < 4.5 (at 20% solubility).

It is evident from Figure 5 that the maximum content of the mobile species (MN) in the set under study (15 $mg.kg^{-1}$) is attained at pH 4, only if the total content is > 400 $mg.kg^{-1}$ and at pH 5 if the total Zn content is more than 800 $mg.kg^{-1}$.

We can conclude from the mentioned relations that the phytotoxicity level can be got only at a high anthropogenic soil load that is linked with the high relative solubility (ED/TO × 100), with a lesser probability at extreme geogenic contents in very acid soils. The analysis of extreme values (Table 1) testified that only anthropogenic fluvial loads, characterized by mobile (MN) Zn concen-

Table 1. Transfers of trace elements into plants from soils characterized by increased up to extreme contents of elements (mg.kg^{-1} d.w.)

Element	Kind of extremes	TO	ED	MN	ED/TO × 100 %	MN/TO × 100 %	pH	Radish	Triticale	Critical referent values	
										value	exceeding
Zn	AcG	400	13.5	3.20	3.4	0.80	4.8	32	35	150–250	–
	F	551	345	2.16	62.6	0.39	6.4	54	61		–
	AcG	303	48	8.41	15.8	2.78	4.8	123	109		–
	An	**356**	72	27.1	**20.2**	7.61	5.0	**498**	122		(+)
	AnF	**5451**	3029	522	**55.6**	9.58	5.5	**1495**	**1441**		+
Ni	Gb	**2900**	133	1.80	4.6	0.062	6.2	**12.3**	**6.9**	5–10	+
	Gb	920	31	0.16	3.4	0.017	6.8	4.3	1.2		–
	Ac	49	15	3.95	**31**	8.060	**4.8**	**8.82**	**12.1**		+
	F	72	31	0.44	43	0.610	6.6	1.15	1.0		–
	F	325	110	3.45	34	1.060	6.3	3.96	**4.78**		–
Mn	F	1259	719	10	56.4	0.79	6.7	10	67	250–500	
	F	739	329	124	44.5	16.8	4.8	179	**490**		(+)
	G	1645	265	20	16.1	1.21	4.9	45	159		–
	G	1476	199	83	13.5	5.6	4.5	90	**755**		+
	AcG	**4125**	1365	**203**	33.1	4.9	4.8	329	**1633**		+
	An	**6187**	1394	**122**	22.5	2.0	5.5	**1184**	**1694**		+
Co	G	55	5.6	0.10	10.2	0.18	4.9	0.54	0.30	6	–
	F	15	4.6	0.013	30.7	0.09	6.4	0.06	0.11		–
	G	103	62	0.03	60.2	0.03	6.2	1.96	0.45		–
	AcG	**175**	68	4.66	38.8	2.16	4.8	4.97	**19.11**		+

Ac = very acid oils, An = anthropogenic loads, F = fluvial loads, G = geogenic extremes, AcG = very acid soils with geogenic loads, AnF = anthropogenic and fluvial loads
bold numeric data = exceeding of critical plant and soil loadings

trations 27–522 mg.kg^{-1} and solubility 20–55% resulted in the excessive exceeding of the plant critical values (150 and also 250 mg.kg^{-1}) at the levels of the total Zn content > 300 mg.kg^{-1}.

We can recommend to take the contents > 30 mg.kg^{-1} of the mobile Zn species (MN) for values which call for attention.

Nickel

Nickel is a phytotoxic trace element with an increased mobility, except the often occurring geochemical loads (in transported weathering products of ultramafic and mafic rocks), but with a lower transfer quotient. We have taken for a critical plant load 5 mg.kg^{-1} d.w.

The simplest relations are represented by the following prediction equations:

– triticale $\ln T = 0.304 \ln MN^{*} + 0.430^{*}$
(the whole set, $n = 97$)
$\ln T = 0.333 \ln MN^{*} + 0.450^{*}$
(set lacking geochemical extremes, $n = 81$)

– radish $\ln R = 0.354 \ln MN^{*} + 0.854^{*}$
(the whole set)
$\ln R = 0.340 \ln MN^{*} + 0.739^{*}$
(set lacking geochemical extremes)

The following critical values were derived in pot trials from the above mentioned equations:

– for radish MN 6–8 mg.kg^{-1}
– for triticale MN 30 mg.kg^{-1}
– for fodder plants total content 210 mg.kg^{-1} (whole set, $n = 107$), 180 mg.kg^{-1} (set lacking geogenic loads, $n = 85$)

We can compare these data with the contents found in plants and in soils of the set under study. Triticale is characterized by average and maximum (in parentheses) values: 0.7 (6.0) mg.kg^{-1} d.w., radish 0.8 (12) mg.kg^{-1} d.w. The following total contents of Ni and its mobile forms were found: TO 28 (2955), ED 4.3 (157), MN 0.06 (4.8) mg.kg^{-1}.

From all figures that express the optimized solution of critical values by means of prediction equations with more variables it can be deduced (in relation to the realistic estimated plant and soil loads), that the critical pollution with Ni can take place only exceptionally.

The dependence of the critical transfer values into fodder plants on the total content of Ni (Figure 6) and pH proves that up to the background reference values of Ni (70 mg.kg^{-1}) the soil should have pH < 4.5 to induce the hazardous plant uptake. Figure 7 shows that critical transfer values concerning triticale can be surpassed at contents of ED up to 100 mg.kg^{-1} only if the mobile species (MN) exceeds 20 mg.kg^{-1}, the transfer into radish at

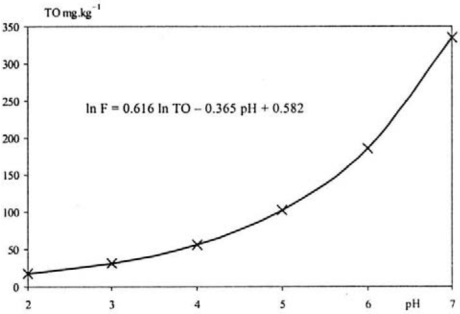


Figure 6. Dependence of critical transfer values of Ni into fodder plants upon the total content (TO) of Ni and pH in soils

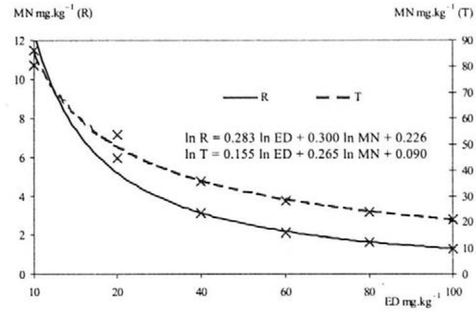
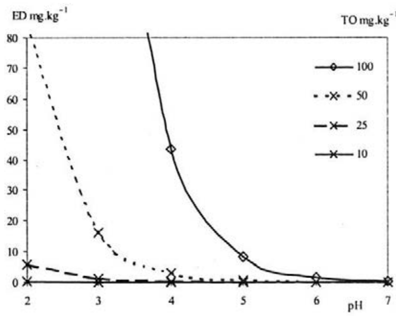
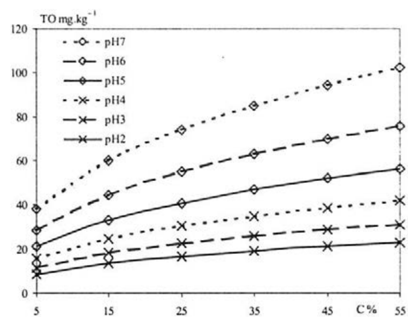


Figure 7. Dependence of critical transfer values of Ni into radish and triticale on the potentially mobilizable (ED) and mobile (MN) forms of Ni in soils



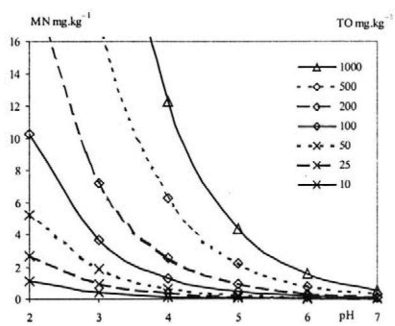
ln F = 0.825 ln TO – 0.215 ln ED – 0.357 pH + 0.049

Figure 8. Dependence of critical transfer values of Ni into fodder crops on the potentially mobilizable (ED) species and total con-



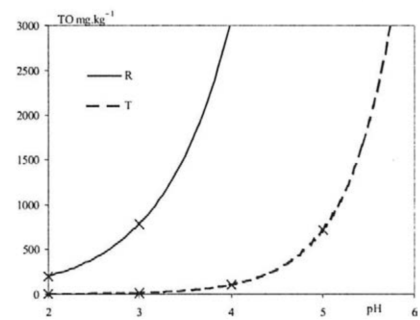
ln F = 0.676 ln TO – 0.311 pH – 0.428 ln C + 1.043

Figure 9. Dependence of critical transfer values of Ni into fodder plants on the total content (TO) of Ni and clay content in soils at different levels of the soil pH



ln MN = 0.980 ln TO – 1.038 pH – 0.108

Figure 10. Dependence of the content of the mobile forms (MN) of Ni in soils upon the pH at different total soil contents (TO)



ln R = 0.588 ln TO – 0.800 pH + 4.001
ln T = 0.335 ln TO – 0.648 pH + 6.560

Figure 11. Dependence of critical transfer values of Mn into radish and triticale on the total Mn content (TO) and the pH in soils

the content of the mobile species exceeding 1–2 mg.kg^{-1}. The strictest transfer limits of mobile species (MN) are 1 mg.kg^{-1}. Figure 8 demonstrates that critical transfer values can be exceeded only at low pH values and high Ni contents and increasing ED values, indicating the solubility. The influence of the total Ni and clay content at different pH levels on the critical Ni transfer into plants (Figure 9) proves that the increasing tendency of the transfer due to the total content and low pH is compensated by the clay increase.

Figure 10 shows that increasing contents of the mobile species (MN) of Ni is linked to the increasing are of soil acidity and total content.

The analysis of the extreme values confirms that the exceeding of the critical plant values 5 mg.kg^{-1} Ni can be attained only in the following cases:

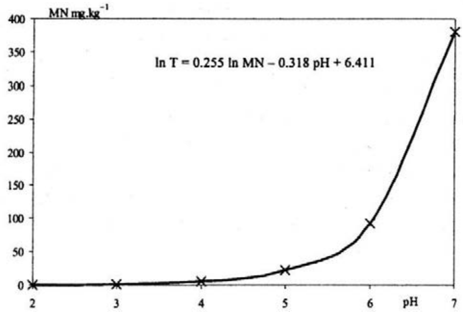


Figure 12. Dependence of critical transfer values of Mn into triticale on the content of mobile Mn species (MN) and pH in soils

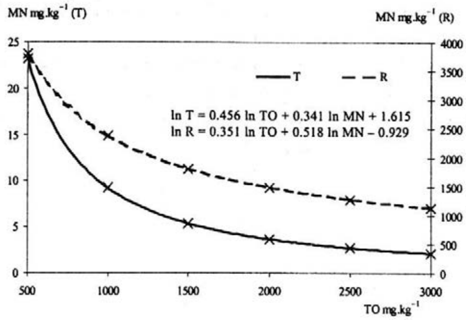


Figure 13. Dependence of critical transfer values of Mn into triticale and radish on the mobile species (MN) and total content (TO) of Mn in soils

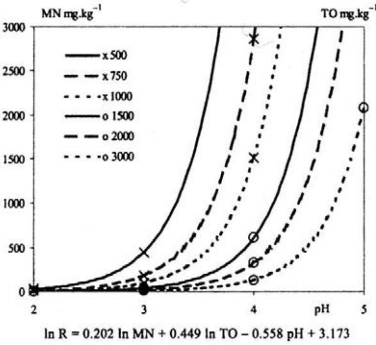


Figure 14. Dependence of critical transfer values of Mn into radish on the mobile species (MN) of Mn and pH at different levels of the total content (TO) of Mn in soils

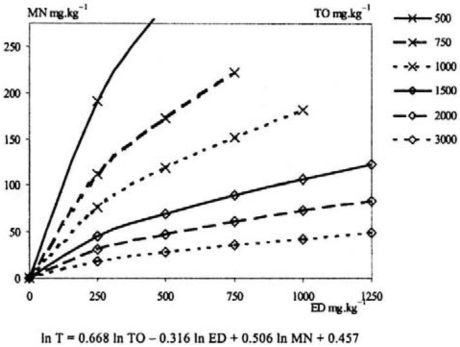


Figure 15. Dependence of the critical transfer values of Mn into triticale on the content of the mobile (MN) and potentially mobilizable species (ED) at different levels of the total content (TO) of Mn in soils

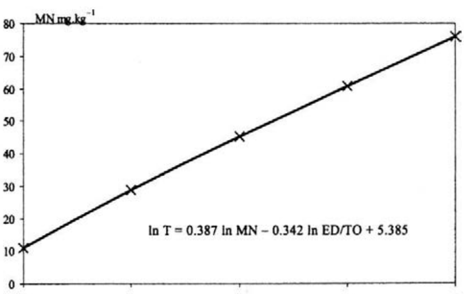


Figure 16. Dependence of the critical transfer values of Mn into triticale on the solubility of Mn (ED/TO × 100) and the mobile species (MN) content in soils

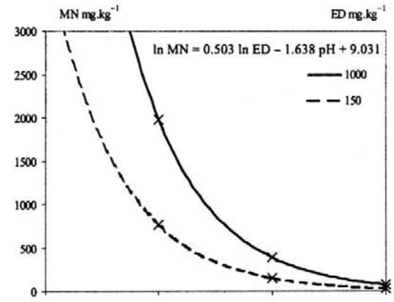


Figure 17. Dependence of the content of the mobile species (MN) of Mn in soils on the pH and the content of the potentially mobilizable (ED) species

– at extreme geochemical contents (> 1000 mg.kg^{-1})
– at low (< pH 4.5) acidity and higher (> 50–70 mg.kg^{-1}) Ni content
– at the high content (> 100 mg.kg^{-1}) of Ni
– an increased (> 20%) solubility in anthropogenically polluted soils, even in nearly neutral soils

In accordance with the very rigid statistical processing contents of the mobile species > 1 mg.kg^{-1} MN at common Ni total contents (30 mg.kg^{-1}) and ED contents up to 5 mg.kg^{-1} must be carefully examined.

Manganese

Manganese is an element on the boundary between trace elements and macroelements, with a high pH (and redox potential)-dependent mobility, but with a limited transfer quotient soil – plant.

High pH-dependent mobility testifies the fact that mobile species (MN) and pH are dominants in all relations concerning Mn. What concerns simple relations, we present the following equations:

a) for relations to the mobile species

– triticale $\ln T = 0.448 \ln MN^{*} + 4.135^{*}$ (the whole set, $n = 97$)
$\ln T = 0.444 \ln MN^{*} + 4.196^{*}$ (set lacking geogenic extremes, $n = 81$)

– radish $\ln R = 0.525 \ln MN^{*} + 2.246^{*}$ (the whole set)
$\ln R = 0.577 \ln MN^{*} + 2.109^{*}$ (set lacking geogenic extremes)

b) for relations to the pH

– triticale $\ln T = -0.643\ pH^{*} + 8.769^{*}$ (the whole set, $n = 107$)
$\ln T = -0.797\ pH^{*} + 7.907^{*}$

Accepting the lowest critical plant load 250 mg.kg^{-1}, we derived the following critical values:

– for radish mobile species (MN) 290–500 mg.kg^{-1}, pH < 3.6–3.2

– for triticale mobile species (MN) 14–22 mg.kg^{-1}, pH 5.4–5.2

The mean and maximum (in parentheses) values within the set are for radish 169 (1913), triticale 31 (400), fodder plants 75 (652) mg.kg^{-1} d.w., in soils TO 782 (4250), ED 212 (1433), MN 10 (219).

From the graphical presentation (Figure 11) follows that common total Mn contents in soils can result in critical triticale loadings at pH < 5, radish loads at < 3.5. We find a quickly ascending critical total content between pH 5 and 6 (650–3000 or more).

We can conclude from the relations between pH and the content of the mobile species (Figure 12) that the critical transfer value of MN becomes strict at pH values below 5, but expressively mitigates with increasing pH.

The affecting of critical transfer relations between the total content and the content of the mobile species (MN) is reflected (Figure 13) in triticale in the decline of the critical transfer values from the values close to average soil MN contents to very low concentrations at high total contents.

From the more complicated (TO, MN, pH) relation (Figure 14) follows the prevailing influence of the low pH on the transfer, especially at lower and common total and mobile species contents. Rising the pH values is accompanied by the rapid increase of the mobile species critical transfer values up to extreme values. Critical transfer values manifest themselves in mild plant accumulators only at pH 5 when total Mn contents are high and at pH < 4.5 at common Mn contents. The other complicated relation (TO, ED, MN) displayed in Figure 15 shows the expressive dependence of the critical transfer (into triticale) upon the content of the mobile species (> 300 mg.kg^{-1}) and upon the low total contents of Mn when the values of potentially mobilizable species increase and indicate the rising solubility. These trends are declining at high Mn contents. Synoptical presentation holds for the dependence of the critical transfer into triticale on the Mn solubility and mobile species content (Figure 16).

A rapid increase of the mobile species (MN) following the decline of pH, supported by increase of the potentially mobilizable species is shown in Figure 17.

The analysis of extremes indicates that also in case of manganese manifest itself the low solubilitiy of extreme geogenic loads and on the contrary, increased solubility of the extreme anthropogenic contamination.

Cobalt

Cobalt is a trace element with pH-dependent increased mobility, but with a low transfer quotient. The data concerning the phyto- and zootoxicity differ. Critical plant loads that occur sporadically in the literature show the values 5–10 mg.kg^{-1}.

Making use critical plant value 6 mg.kg^{-1} d.w. following critical total soil contents were derived:

– radish 80 (100–70) mg.kg^{-1}

– triticale 10 (15–9) mg.kg^{-1}

They were derived from these equations:

– triticale $\ln T = 0.642 \ln MN^{*} + 0.055^{*}$ (the whole set)
$\ln T = 0.696 \ln MN^{*} + 0.236^{*}$ (set lacking geogenic extremes)

– radish $\ln R = 0.393 \ln MN^{*} - 0.089^{*}$ (the whole set)
$\ln R = 0.440 \ln MN^{*} - 0.102^{*}$ (set lacking geogenic extremes)

We can compare the critical values with mean and maximum (in parentheses) values of the set:

plants			soils		
triticale	0.24	(12.9)	TO	11.0	(192)
radish	0.15	(21.0)	ED	3.2	(74)
fodder plants	0.11	(5.2)	MN	0.05	(3.6)

The exceeding of critical values can be expected only exceptionally.

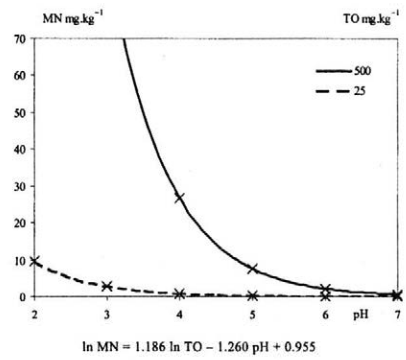


Figure 18. Dependence of the content of the mobile species (MN) of Co in soils on the total content (TO) of Co and pH in soils

Under the strictest conditions the exceeding of critical transfer values at lower ED and TO values should be accompanied by contents of the mobile species > 1–2 mg.kg^{-1}.

From Figure 18 follows that the mentioned content (1–2 mg.kg^{-1}) of the mobile species can be obtained only at a very acid conditions and high Co contents.

Exceptionality of the exceeding of critical values in plants is proved by the analysis of extreme values. From Table 1 it is clear that only at high total content values (175 mg.kg^{-1}) high acidity and mobile species contents close to 5 mg.kg^{-1}, the Co content in triticale was surpassed.

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ABSTRAKT

Transfer méně rizikových stopových prvků s vysokou mobilitou z půdy do rostlin

Příspěvek charakterizuje transferové funkce stopových prvků Zn, Ni, Mn a Co pro transferovou funkci půda – rostlina. Společnými znaky těchto prvků je jejich fytotoxicita. Jsou charakterizovány vysokou či zvýšenou, na pH nepřímo závislou mobilitou. Zn má výrazně vyšší transferový kvocient než Mn, Ni a Co. Společným rysem všech těchto stopových prvků je, že i přes jejich mobilitu mohou být zvýšené zátěže rostlin vyvolávající fytotoxicitu způsobeny pouze vysokými až extrémními obsahy nebo zvýšenou rozpustností.

Klíčová slova: stopové prvky Zn, Ni, Mn, Co; transferové funkce půda – rostlina; kritické zátěže rostlin; fytotoxicita

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Magnesium content in individual parts of *Avena sativa* L. plant as related to magnesium nutrition

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ABSTRACT

In the pot experiment of *Avena sativa* L. the influence of Mg rates and P nutrition grown by degrees upon Mg, Ca and K content in panicle, stem and in green upper and yellow lower leaves was studied. The content of cations significantly changed in individual parts of the plant. The highest content of magnesium was found within the dry matter of upper green leaves (0.13–0.23%). A lower content of Mg in the lower yellow leaves (0.09–0.11%) was also found. Compared with upper photosynthetically active leaves, it indicates a possibility of reutilization, which can be, when compared with potassium, lower in order. The effects of Mg doses were significantly revealed in its higher content mainly in functionally active leaves (for 80%). The decrease in Mg content (especially in leaves) was observed with the variant of P nutrition absence (for 44%).

Keywords: oat (*Avena sativa* L.); plant nutrition; magnesium; potassium; calcium; translocation

Recently, the problem of magnesium has arisen the interest of researchers. Subsequently, magnesium deficit in various soils, manifests itself in plants, farm animals and man, the final link of the food chain. Within plants, it is becoming the limiting factor for crop yield, numbers of livestock, especially in herbage breeding (whereby metabolic disorders and decrease of utility have occurred) and for man. An increase of cardiovascular system diseases was observed as well as an increased occurrence of allergies, tiredness and weakening of the immunity system (Grunes and Welch 1989).

Plants take magnesium in a passive way as seen in cation Mg^{2+}. In its input to plasmalema of root hairs participates above all the flow of the soil solution and in minor scale the growth of the roots themselves. From these characteristics it is clear to be similar to calcium. On the other side, with potassium there is significant above all the diffusion (Bergmann and Neubert 1976, Barber 1984). On the inner part of root cells, or plasmalema, there prevails a negative charge caused by the active work of the proton pump. This negative charge enables passive cation intake mediated by means of specific ion channels. If any cation is taken preferentially, it could non-specifically inhibit the uptake of other cations (Epstain 1972, Engels and Marschner 1993). Cation uptake is dependent upon its concentration, upon the chemical activity in the soil solution and upon the specific permeability of the cell membrane for individual cations. The transport rate of magnesium through cell membranes are strongly suppressed, especially by K and NH_4^+, and followed by Mn^{2+}. In specific cases it can be caused by Ca^{2+}. In the acid environment its uptake is limited by H^+ or by H_3O^+. It is also limited by Fe^{3+} and Al^{3+}. Anions affect the transport rate of magnesium synergically (i.c. nitrate and phosphate) (Mengel and Kirkby 1987).

Magnesium in plants is transported mainly by an ascendant flow of xylem. The fully photosynthesising leaves demand a continuous supply of Mg^{2+} from the soil. There does not exist a unified flow of magnesium mobility in phloem within literary reviews. According to the latest information, magnesium is placed to cations with good translocation and reutilization in plants. This fact is supported by its concentration in phloem and by the values of the concentration phloem/xylem rate. Furthermore, symptoms of deficiency show up first in older leaves. When compared with potassium, the amount of translocated magnesium is much lower in order (Hocking 1980). Other authors point out little possibility of reutilization. They explain primary symptoms of deficit on older leaves. Those leaves show great demand for magnesium supply for chlorophyll resynthesis. Younger leaves show much lower consumption of Mg and therefore in the case of Mg deficit, they are affected later (Matula 1987).

Magnesium in plants occurs in the following forms: as a salt (Mg-oxalate, phytin), as sorption ally fixed ion, in chelate link and in chlorophyll. More than 70% of Mg in this total content is in diffusible form and in link with inorganic and organic anions. Distribution of this form of magnesium is: vacuole 85%, chloroplast, cytosol and cell wall – each 5% (Leigh and Wyn Jones 1986). This distribution is in relation to physiological function of magnesium: magnesium controls and strongly supports almost 20% of enzymatic reactions that are in progress within the cell (e.g. phosphate transmission, -COOH transmission). In the reactions it is preferentially linked to nitrogen and phosphate. In this way it works like link component between ATP and enzyme, such as ATPase. Also ATP synthesis – photophosphorylation demands magnesium as a link component between ADP and enzyme (Rea and Sanders 1987). By virtue of its strong electrophilic characters it attracts oxocomplexes or phosphate. This causes the creation of suitable dimensional distribution particularly for the joint of enzyme and substrate. An example of this is the distribution of the centre of ribuloso-bisphosphate carboxylase (Hall and Rao 1999). This particular example is the most important enzyme on the Earth, activated by magnesium. From the rank of other important enzymes that are localized in chloroplasts and activated by magnesium, there are e.g. fructosabisphosphatase and glutaminsynthase (Kruger et al. 1999). Magnesium significantly influences the whole process of proteosynthesis. In this process, it affects the DNA chains by connecting and neutralization acid proteins in the nucleus, it controls the RNA polymerase while the RNA forms in nucleus, it influences the connecting of ribosome subunits (which dissociate by shortage of Mg) and it influences enzymatic disconnection of polypeptide chains from ribosome (Mengel and Kirkby 1987) etc.

The aim of this work was to study the dependence of magnesium content in individual parts of the oat plant upon gradated doses of Mg and upon P nutrition.

MATERIAL AND METHODS

The research was conducted in the form of a pot experiment. The experimental plant was oat (*Avena sativa* L.), Auron cultivars. The experimental pots were polyethylene bags with a perforated bottom placed into trays with circular pads of plastic foam. Placed into each experimental pot there were 10 kg of dry soil, including a dose of fertilizers. Agrochemical characteristics of the used soil are presented in Table 1. In the experiment five variants of fertilization in four repetitions were found. The scheme of the experiment and doses of fertilizer per pot are given in Table 2.

The experiment was performed under standard light conditions with optimal water regimen. The harvest passed through in the phase of milk ripeness. We harvested eight plants from each experimental pot. The plants were divided by panicle, stalks, upper green leaves and lower yellow leaves. Individual parts were separated and analyzed for content of Mg, Ca and K. There was realized mineralization – charge of dry matter 2 g (Ministry of Agriculture 1986). The content of cations in the solution after digestion was set by means of atomic absorption. Results were processed statistically by means of variance analysis.

Table 1. Agrochemical characteristics of used soil

Soil type	Luvisols
pH/KCl	6.9
P ($mg.kg^{-1}$)	117
K ($mg.kg^{-1}$)	551
Mg ($mg.kg^{-1}$)	279
Ca ($mg.kg^{-1}$)	3377
CEC mmol (+).kg^{-1}	165
Rate Mg/K in sorption complex	1.19

Eluate by Mehlich 2 (Mehlich 1978)

Table 2. Scheme of experiment

Variant No.	Fertilized	Chemicals (g/pot)		
		NH_4NO_3	$Ca(H_2PO_4)_2$	$MgSO_4$
1.	N, P	1.9	0.204	0
2.	N, P, Mg_{50}	1.9	0.204	1.032
3.	N, P, Mg_{100}	1.9	0.204	2.063
4.	N, P, Mg_{200}	1.9	0.204	4.127
5.	N, Mg_{200}	1.9	0	4.127

RESULTS

The content of magnesium within the dry matter of the individual parts of the oat plant is demonstrated in Figure 1. It should be clear from this figure that Mg content significantly differed within individual parts of the plant. The highest content was found in the dry matter of upper green leaves where it ranged from 0.13 to 0.23% of dry matter. In the lower yellow leaves was also found a high content of Mg (it oscillated within the interval 0.09–0.11% of dry matter). Nearly at the same level of oscillated Mg content was found in the panicle and the lowest level was found in the stalk.

The influence of gradated doses of Mg was significant in the upper green leaves. When the dose of magnesium was increased, the content in the leaves followed by a slight increase. This is evident in variant 4 with the highest dose of magnesium. There was observed up to 80% growth of magnesium at variant 1 without magnesium nutrition. Phosphorus nutrition absence with variant 5 displayed a significantly decreased content of Mg in the upper green leaves by 44% and in the lower yellow leaves by 27% with variant 4, where the same dose of magnesium was used. On the other hand, gradated doses

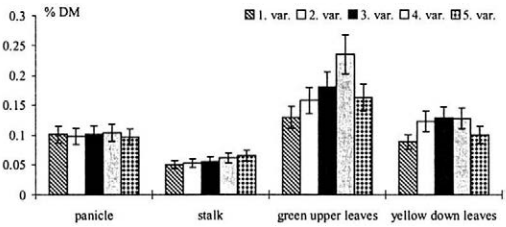

Figure 1. Content of Mg in dry matter of individual parts of *Avena sativa* L.

of Mg did not significantly change the Mg content in the panicle or stalk. There was noted merely a negligible increase.

Figure 2 demonstrates the relative representation of studied cations in the dry matter of individual parts of the oat plant. At first perception, there are palpable significant differences within the potassium content of individual parts of the plant. More than twice the content was recorded in the stalk as compared with the leaves. On the other hand, the content of magnesium and calcium was in the stalk and compared with other parts of the plant was the lowest. Calcium was the largest scale of change and represented in lower yellow leaves where the values of its content overtopped content of both potassium and magnesium. Compared with the content of studied elements in upper green and lower yellow leaves, there is a palpable significant decrease of values especially with potassium on average for 96% and with magnesium for 40%. The values of calcium remained approximately the same.

DISCUSSION

The greatest changes of magnesium content, in dependence upon its nutrition occur in places with the highest demand for magnesium supply – in functional photosynthetically active leaves. By means of a phloem flow, which permanently passes through a supply of magnesium, that participates in construction and regeneration of assimilatory apparatus, biosynthetically processes and in transport of assimilates. Most of this element is probably accumulated in vacuole and in the case of metabolic demand it is released little by little (Leigh and Wyn Jones 1986).

The absence of phosphorous nutrition within variant 5 and displayed in the Mg content of photosynthetically active leaves as well as in the lower yellow leaves. This is in accordance with a number of publications, which found a positive correlation between phosphorous and magnesium uptake (Matula and Tůma 1994). It is probably related to the function of phosphorus in energetic metabolism (esterification into ATP) and magnesium, as a link component between ATP and enzymes, or between ADP and ATP-synthase. Insignificant changes of magnesium content in the panicle correspond with a number of publications. These publications found that magnesium content within generative organs is actually quite stable. Although the lower magnesium content in lower yellow leaves compared with upper photosynthetically active leaves signalises certain possibility of reutilization, which is, compared to potassium, lower in order. It is in accord with the latest literary data (Hocking 1980).

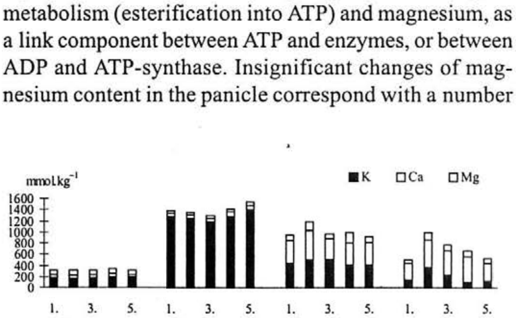

Figure 2. Rate of representation K, Ca and Mg in dry matter of individual parts of *Avena sativa* L. (x axis: variants)

Very high representation of potassium in the stalk and subsequently low representation of magnesium and calcium is probably related with the function of potassium in transport processes in plant and its easy translocation among individual parts of the plant.

In reviews is often described K/nitrate, malate etc. It follows from literary sources, that potassium disposes of several types. Potassium disposes of several possibilities of transport through cell membranes (Epstain 1972), this advantage potassium to other cations, above all Mg^{2+} and Ca^{2+} and in such a way that it can express their transport. This non-specific blockage can come to light at various levels, not only with uptake by root hairs cells but also with xylem filling or with uptake by leaf mezophyle etc. (Marschner 1997).

High content of calcium in lower yellow leaves is related with its bad reutilization and in fact disability of phloem transport. Accumulation of calcium in cells and tissues, mostly in the form of oxalate or other hardly soluble salts, is the symptom of plant senescence, too (Marschner 1997).

It also follows from the results, that obtaining of demanded content of magnesium in the plant and in its individual organs depends not only upon sufficient representation of magnesium in nutritive medium, but it considerably depends upon concentration and activity of potassium in nutritive medium. With its high concentration occurs the so-called luxury potassium consumption, which can then repress uptake and transport of other nutrients including magnesium at all levels (Tůma 1992, Tůma and Matula 1995, Tůma 1997).

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ABSTRAKT

Obsah hořčíku v jednotlivých částech rostliny *Avena sativa* L. v závislosti na hořečnaté výživě

V nádobovém pokusu s *Avena sativa* L. byl sledován vliv stupňované dávky Mg a výživy P na obsah Mg, Ca a K v latě, stonku a v zelených horních a žloutnoucích dolních listech. Obsah kationtů se významně měnil v jednotlivých částech rostliny. Mg byl nejvíce zastoupen v horních zelených listech (0,13–0,23 %). Nižší obsah Mg ve spodních žloutnoucích listech (0,09–0,11 %) ve srovnání s horními fotosynteticky aktivními listy naznačuje jistou možnost reutilizace, která je však v porovnání s K řádově nižší. Stupňovaná dávka Mg se signifikantně promítla v jeho vyšším obsahu, hlavně ve funkčně činných listech (o 80 %). Při absenci výživy P bylo pozorováno snížení obsahu Mg, zejména v listech (o 44 %).

Klíčová slova: oves setý (*Avena sativa* L.); výživa rostlin; hořčík; draslík; vápník; translokace

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Salicylic acid versus salinity-drought-induced stress on wheat seedlings

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ABSTRACT

The rise of NaCl level and drought treatment, generally, exhibited an inhibitory effect on the growth rate, leaf area and transpiration rate of wheat seedlings. The water content of either shoots or roots was mostly unchanged except in shoots of 70% and roots of 30% droughted plant, where it decreased at increased salinity. On the contrary, the chlorophyll and carotenoid contents, net photosynthetic rate and dark respiration rate were raised in plants subjected to both salinity and drought. Soaking of wheat grains for 6 h in 100 ppm salicylic acid before sowing was generally effective in antagonizing partially or completely the stressing effects of NaCl (40, 80, 120 and 160 mM) and drought (70, 50 and 30% field capacity) on growth rate, leaf area and transpiration rate. On the other side, salicylic acid enhanced the stimulatory effect of NaCl-drought on photosynthetic pigments, net photosynthesis and dark respiration of seedlings (30-day-old). Soaking of wheat grains in salicylic acid exhibited a favorable effect on the accumulation of some ions and antagonized or ameliorated the inhibitory effect of salt-drought stress on some others.

Keywords: dark respiration; NaCl-drought; net photosynthesis; salicylic acid

Plants in nature may be exposed during their ontogeny to a variety of environmental stresses, two of which are closely interrelated: water deficiency or water stress, and salt excess or salt stress. The interrelation between these two stress factors is of particular significance for irrigated crops. These two stressing factors are the most impedance factors affecting the rate of growth in plants.

Salicylic acid, an ubiquitous plant phenolic, was recognized as an endogenous regulator in plants after the finding that it is involved in many plant physiological processes. In an extensive screening program using modern analytical techniques, salicylic acid was detected in the leaves and reproductive organs of 34 agronomically important species (Raskin et al. 1990).

One of the most studied functions of salicylic acid is that it is associated with its involvement in plant resistance response to different pathogen attacks (Yalpani and Raskin 1993). It was also reported that salicylic acid accumulates during exposure to ozone or UV light (Sharma et al. 1996). In this respect salicylic acid treatment was found to improve the chilling tolerance of maize (Janda et al. 1997, 1999), the heat-shock tolerance of mustard (Dat et al. 1998) and drought tolerance of wheat plants (Hamada 1998).

Considering the potential value of preconditioning seeds to increase seedling growth, the present work was conducted to study the response of salicylic acid-treated wheat grains to various levels of salinity-drought. The interactive effects of salinity-drought and grain soaking presowing in salicylic acid (sodium salt) on transpiration, growth criteria, pigment contents, net photosynthetic, dark respiration and mineral composition of the test plants was also considered in the current study.

MATERIAL AND METHODS

Plastic pots (11.5 in diameter and 10 cm long) lined with polyethylene bags and containing soil composed of clay and sand (1:1) by volume were used. The grains of wheat before sowing were soaked for 6 h in solutions containing 100 ppm of sodium salt of salicylic acid and the other grains soaked for 6 h in distilled water (regarded as control). After sowing grains (5 g in each pot), the plastic pots were then irrigated with the different saline solutions to reach the desired salinization levels (40, 80, 120 and 160 mM NaCl) by adjustment the water content of the soil regularly near to the field capacity and the plants were left for 15 days. Thereafter, the pots were watered to the desired soil moisture content and salinity (70% field capacity and 40, 80, 120 and 160 mM NaCl, 50% field capacity and 40, 80, 120 and 160 mM NaCl and 30% field capacity and 40, 80, 120 and 160 mM NaCl). Some pots were left untreated (100% field capacity and 0.0 salicylic acid) and regarded as absolute control. On the other side, salinized-droughted plants but non-treated with salicylic acid were regarded as reference control. At the end of the experimental period (30 days) fresh shoots and roots were then dried in an aerated oven at 70°C. Transpiration rate was measured as described by Bozcuk (1975). The content of chlorophylls a, b and carotenoids was determined spectrophotometrically (Metzner et al. 1965). Net photosynthetic rate (oxygen evolution) and dark respiration rate (oxygen consumption) were determined manometrically using disks (diameter 16 mm) of leaf tissue exposed at 25°C, irradiance of 12 Wm^{-2} (40 W GEF lamps) using the Warburg buffer No. 2961 type VL 85 (Umbreit et al. 1959). Sodium and potassium were determined by flame photometer method (Williams and Twine 1960), calcium and magnesium by the versene titration method (Schwarzenbach and Biedermann 1948).

The results are the means of four measurements and were statistically evaluated using the standard deviation (*SD*) and *t*-test methods.

RESULTS AND DISCUSSION

The growth criteria (fresh and dry matter yield as well as leaf area) of wheat plants were markedly attenuated by salinization and drought stress and they were lowered gradually with the rise of salinity level and soil moisture level (Figures 1, 2 and 4). The reduction in growth could be attributed to the reduction in cell division and/or in cell enlargement (Terry et al. 1971). Also Schwarz (1985) stated that reduced plant growth under water stress conditions has been considered to result from various factors, the most important of which are physiological drought, induced by the low water potential of the soil solution and osmotic adjustment in plants as a result of increased ionic concentration in their cells. The effect of this stressing agent could be exhibited in deformation of macromolecules by disrupting their shell of bound water.

Soaking of wheat grains in salicylic acid did not only alleviate the inhibitory effects of salinity-drought-stress but also was of stimulatory effects, where the fresh and dry matter gain in shoots and roots as well as leaf area showed a marked increase (Figures 1, 2 and 4). It is well known that some stress factors are able to reduce the effects of other stresses (Sánchez-Diaz et al. 1993). However, in untreated plant salicylic acid reduced shoot and root fresh-and-dry-weight accumulation. These phenomena are probably due to mechanisms, which are not specific, but common to a wide range of stresses. Salicylic acid is known to be a signal molecule in acquired resistance to pathogens in several plant species (Raskin 1992). Also, salicylic acid treatment improved the drought-tolerance of wheat (Hamada 1998) and the chilling tolerance of maize plants (Janda et al. 1999).

The results presented in Figure 4 reveal that the transpiration rate of the experimental plants was markedly affected by the salinization and drought level is a manner that it decreased gradually as salinity-drought increased. In this context, Behboudian et al. (1986) indicated that the reduction in transpiration in the salt affected plants is due to stomatal closure. For other plant species, the inhibited transpiration activity with salt stress was attributed to a reduction in leaf area (West et al. 1979) and/or ascribed in the first place to impairment of water uptake by roots (Hagemeyer and Waisel 1989) and consequently, the transpiration capacity is altered (Kaplan and Gale 1972). In this respect, Camacho et al. (1974) suggested that species differ in their strategy, some sharply close their stomata in dry air to conserve water at the expense of photosynthesis, others exhibit only moderate humidity response and maintain high photosynthesis in dry air at the expense of high water use.

Salicylic acid treatment was capable in mitigating partially the depressive effect of salinity-drought on transpiration capacity of the test plants (Figure 4). The mitigative effects of grain soaking in salicylic acid on the inhibited transpiration capacity of the test salinized-droughted plants may be one aspect of the role of phenolic compound, which was recognized as an endogenous regular (Yalpani and Raskin 1993), in hairy root growth

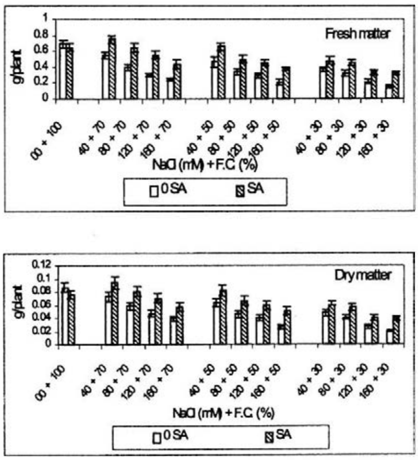

Figure 1. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on fresh matter and dry matter of shoots of wheat plants; values in parentheses represent ± *SD*

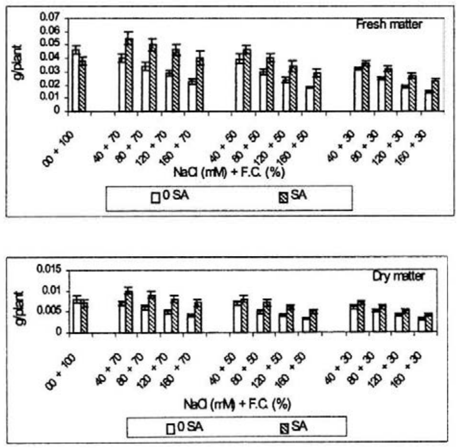

Figure 2. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on fresh matter and dry matter of roots of wheat plants; values in parentheses represent ± *SD*

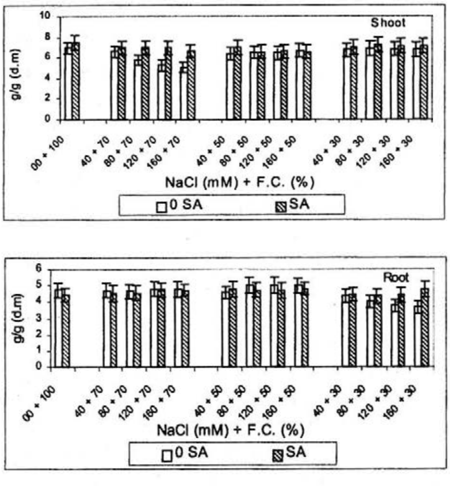

Figure 3. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on water content of shoots and roots of wheat plants; values in parentheses represent ± *SD*

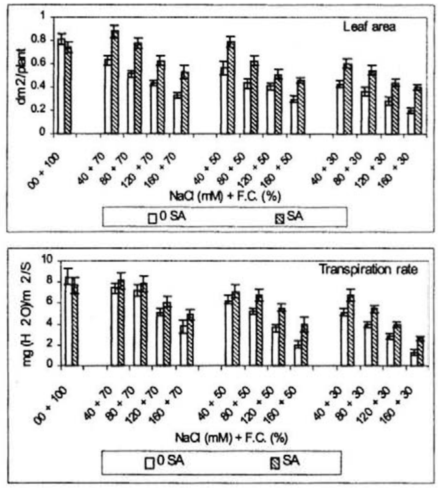

Figure 4. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on leaf area and transpiration rate of wheat plants; values in parentheses represent ± *SD*

which should be considered helpful in water uptake and concomitant less water loss via transpiration. Evidence to support this suggestion can be obtained from the data herein obtained, which indicated that grain soaking presowing in salicylic acid activated the dry matter accumulation in the different organs of the salinized-droughted plants and completely or partially alleviated the inhibitory effect of salt-drought stress on fresh and dry matter yields. Also in this respect, exogenously applied salicylic acid at a concentration of 100 ppm was found (Hamada 1998) to increase root fresh weight and transpiration rate of droughted wheat plants.

The effect of NaCl supply and lower soil moisture content on the biosynthesis of photosynthetically active pigments (chlorophylls a, b and carotenoids) as well as

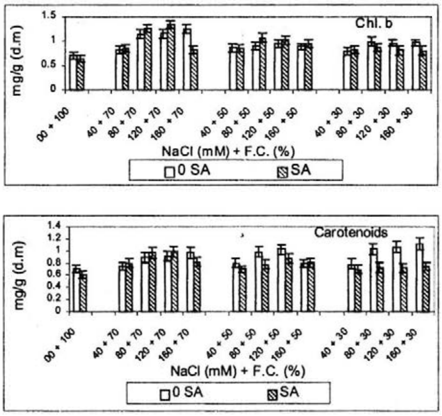

Figure 5. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on photosynthetic pigments (chlorophylls a, b and carotenoids) of wheat plants; values in parentheses represent ± *SD*

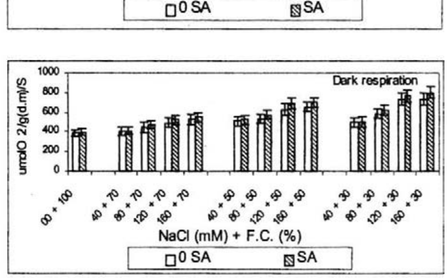

Figure 6. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70–30% field capacity) on net photosynthesis and dark respiration of wheat plants; values in parentheses represent ± *SD*

Table 1. The action of salicylic acid (SA) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 70% field capacity) on Na, K, Ca and Mg of shoots and roots of wheat plants

NaCl-drought-SA (mM-%FC-ppm)	Shoot (mg/g dry matter)				Root (mg/g dry matter)			
	Na	K	Ca	Mg	Na	K	Ca	Mg
0 + 100 + 0	14.84	39.22	15.46	7.24	26.83	10.82	12.60	6.79
40 + 70 + 0	25.10**	31.20**	18.55**	6.99	34.09**	9.73*	17.46**	6.44
80 + 70 + 0	41.23**	25.99**	19.17**	5.36**	50.60**	7.45**	18.95**	4.42**
120 + 70 + 0	52.73**	20.45**	20.23**	5.81*	59.16**	6.36**	21.12**	3.35**
160 + 70 + 0	61.53**	16.63**	24.65**	3.20**	69.82**	4.59**	22.85**	3.08**
0 + 100 + 100	13.98	28.30**	17.99**	7.19	22.46*	8.39**	11.42	6.84
40 + 70 + 100	20.66**	32.55**	20.46**	8.01	28.92	9.81*	16.99**	6.92
80 + 70 + 100	31.40**	34.60**	22.52**	7.28	39.30**	8.92**	19.97**	6.80
120 + 70 + 100	42.13**	36.33**	26.86**	6.68	45.93**	7.91**	22.33**	5.48**
160 + 70 + 100	54.36**	25.77**	29.03**	5.76*	59.16**	6.76**	24.26**	4.52**
LSD at 5%	2.947	1.956	1.589	1.114	3.251	0.979	1.747	0.492
LSD at 1%	4.192	2.782	2.261	1.585	4.625	1.392	2.485	0.700

* significant ($P = 0.05$), ** highly significant ($P = 0.01$) as compared with control

net photosynthetic rate in the leaves of salt-drought-stressed wheat plants, in addition to interactive effects of salinity-drought and salicylic acid, are shown in Figures 5 and 6. Opposite to expectations, salinity-drought levels, with or without salicylic acid treatment, were of stimulatory effects on the biosynthesis of photosynthetically active pigments and also net photosynthetic rate in wheat leaves. In this context, Hamada (1996, 1998) indicated that wheat plants tolerated water stress and exhibited higher pigment content compared with those of control plants. This observation is in accordance with the findings of Kulshrehtha et al. (1987) using two wheat genotypes of differing drought tolerance. In this regard, it is interesting to note that it has been proposed (Mayoral et al. 1981), that chlorophyll stability during drought may be one of the characteristics of drought-tolerant plants, and may therefore be used to differentiate between drought resistant and drought susceptible plants. Rawson (1986) reported that wheat leaves have shown an increase in net photosynthetic rate for a given rise in stomatal conductance under salinity as compared with non-saline conditions. These results suggested that net photosynthetic rate was less sensitive to salinity than transpiration. The increase in net photosynthetic rate at low salinity levels can also be attributed to an increase in chlorophyll contents per unit leaf area (Plaut et al. 1990).

Table 2. The action of salicylic acid (S.A) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 50% field capacity) on Na, K, Ca and Mg of shoots and roots of wheat plants

NaCl-drought-SA (mM-%FC-ppm)	Shoot (mg/g dry matter)				Root (mg/g dry matter)			
	Na	K	Ca	Mg	Na	K	Ca	Mg
0 + 100 + 0	14.84	39.22	15.46	7.24	26.83	10.82	12.60	6.79
40 + 50 + 0	30.10**	28.60**	17.20*	7.02	38.51**	9.08**	15.98**	5.89*
80 + 50 + 0	46.74**	22.04**	19.11**	6.17*	59.95**	8.19**	18.36**	4.18**
120 + 50 + 0	60.30**	19.64**	19.86**	5.93**	69.14**	6.02**	22.10**	3.73**
160 + 50 + 0	69.24**	15.29**	22.18**	4.65**	75.00**	4.18**	23.59**	3.11**
0 + 100 + 100	13.98	28.30**	17.99**	7.19	22.46**	8.39**	11.42	6.84
40 + 50 + 100	25.47**	31.67**	19.89**	7.46	29.32	9.92*	18.45**	6.18
80 + 50 + 100	37.99**	27.18**	23.02**	7.30	42.49**	9.04**	19.84**	5.84**
120 + 50 + 100	48.80**	23.12**	25.52**	6.84	52.68**	7.22**	21.80**	4.79**
160 + 50 + 100	51.16**	20.27**	28.77**	6.19*	60.18**	5.89**	23.76**	4.39**
LSD at 5%	2.501	2.330	1.569	0.905	2.733	0.686	1.204	0.666
LSD at 1%	3.558	3.315	2.232	1.287	3.887	0.976	1.713	0.948

* significant ($P = 0.05$), ** highly significant ($P = 0.01$) as compared with control

Table 3. The action of salicylic acid (S.A) treatment in ameliorating the adverse effects of NaCl-drought stress (40–160 mM NaCl and 30% field capacity) on Na, K, Ca and Mg of shoots and roots of wheat plants

NaCl-drought-SA (mM-%FC-ppm)	Shoot (mg/g dry matter)				Root (mg/g dry matter)			
	Na	K	Ca	Mg	Na	K	Ca	Mg
0 + 100 + 0	14.84	39.22	15.46	7.24	26.83	10.82	12.60	6.79
40 + 30 + 0	38.47**	25.10**	19.22**	6.18	46.74**	8.74*	16.89**	5.18*
80 + 30 + 0	49.16**	23.30**	19.64**	5.96*	65.51**	7.18**	17.84**	4.68**
120 + 30 + 0	66.51**	18.86**	18.19*	5.02**	77.68**	5.86**	20.14**	4.62**
160 + 30 + 0	74.80**	15.46**	20.49**	3.89**	83.82**	3.87**	22.45**	3.12**
0 + 100 + 100	13.98	28.30**	17.99*	7.19	22.46	8.39**	11.42	6.84
40 + 30 + 100	30.01**	28.74**	20.02**	7.99	35.14*	9.01*	17.18**	6.54
80 + 30 + 100	39.98**	26.52**	21.24**	6.52	49.86**	8.85*	19.79**	5.18*
120 + 30 + 100	50.19**	23.02**	26.49**	6.19	62.22**	6.88**	21.86**	4.86**
160 + 30 + 100	59.49**	18.88**	28.84**	5.77*	69.18**	5.16**	24.18**	4.22**
LSD at 5%	4.293	2.733	1.921	1.201	5.855	1.590	2.290	1.204
LSD at 1%	6.107	3.887	2.732	1.708	8.328	2.261	3.257	1.713

* significant (P = 0.05), ** highly significant (P = 0.01) as compared with control

Also, marked increases in anthocyanins and chlorophyll contents in salicylic acid treated *Spirodela* were observed (Khurana and Maheshwari 1980).

There is a considerable amount of evidence (Huq and Palmer 1978), that drought stress can generate the superoxide radical (O_2) in plant tissues which is converted to hydrogen peroxid (H_2O_2) by superoxide dismutase. The increasing level of H_2O_2 in water stressed tissue has been found to be a function of increasing magnitude of water stress (Mukherjee and Choudhuri 1985). H_2O_2 strongly inhibits CO_2 fixation, possibly by inactivating transketolase (Kaiser 1976) or by inactivating several Calvin cycle enzymes upon reaction with essential sulfhydryl groups (Smirnoff and Colombé 1988). In this context, the drought-tolerant cultivars are capable of maintaining higher net photosynthetic rate (Van Resburg and Krüger 1993). On the other side, Janda et al. (1999) using maize plants assumed that due to a decrease in catalase activity after 1 day of salicylic acid pre-treatment under normal growth conditions (22/20°C) an increase in the H_2O_2 level may occur, which can cause an increase in the activity of other antioxidant enzymes (i.e. peroxidase and gluthione reductase) leading to increased chilling tolerance.

On the other side, a stimulatory effect on the dark respiration rate (Figure 6) was recorded in wheat plants with the rise of salinity-drought level which could be regarded as a repairing system for the cellular damage (Thomas and Kirst 1991) linked in some way to the suppression of growth (Lambers 1979). It is also repeatedly mentioned that growth reduction is a consequence of a more or less energy diversion for synthesis and accumulation of compatible solutes to reach suitable osmotic adjustment (Fortmeier and Schubert 1995).

Soaking wheat grains in salicylic acid enhanced the stimulatory effect of salinity-drought-stress on dark respiration of seedlings. These increased values of dark respiration rate indicated that salicylic acid could provoke alterations very often associated with plant responses to stressful conditions. Some evidence for the involvement of salicylic acid in induction of an alternative respiratory pathway (Elthon et al. 1989) and expression of a nuclear gene encoding the alternative oxidase protein (Rhoads and McIntosh 1991) has been presented.

Significant response in connection with the interaction of salinity-drought and salicylic acid treatments were manifested in the present investigation with respect to ionic balance which is considered as one of the most complicated and integral parts of plant activities. The cation imbalance in one of the most basic disorders due to salt-drought-stress. The results of the present work (Tables 1, 2 and 3) reveal unequivocally that the applied salt-drought stress was effectual in producing Na^+ accumulation in the different organs of wheat plants, the highest Na^+ accumulation was consistently displayed in plants subjected to the highest salinity-drought level. Serrano and Goxiala (1994) reported that the high concentrations of Na^+ negatively affected the intercellular K^+ accumulation, presumably either by competing for sites through which influx of both cations occurs (Jeschke and Wolf 1988) or affecting membrane stability causing leakage of K^+ (Watad et al. 1991). The alterations in distribution and accumulation of mono-and divalent cations in the different organs of salt-drought stressed plants may be an indication of the role of these cations in regulating the physiological activities of these plants (Benzioni et al. 1992). The accumulation of K^+ and Mg^{2+} decreased gradually with the rise of salinity level and this trend was generally accompanied by reciprocal variations in the concentration of calcium. However, in wheat plants the extent of sodium accumulation varied in shoots and roots in a manner that the roots generally accumulated more sodium than the shoots. This is in conformity with the results obtained by Lahaye and Epstein (1969) who found that in many glycophytes relatively small amounts of sodium were retained in the aerial parts, while most of it was retained in roots. Also, the data herein clearly demonstrated that salicylic acid treatment generally exerted a favorable effect on the concentration of K^+, Ca^{2+} and Mg^{2+} cations in different organs (shoot, root) of the salinized-droughted wheat plants; a response which could be attributed to a number of functional changes in the different phases of metabolism.

Soaking of grains presowing in salicylic acid induced on the other hand a significant decrease in the accumulation of sodium. This response may be involved in the maintenance of the ions in adequate amounts to enhance the metabolic processes. These nutrients may also lead to consider that the soaking in salicylic acid could play an important role in osmoregulation which could probably increase the efficiency of utilization of water under stress conditions maintaining salt-drought tolerance of the experimental plants.

CONCLUSION

In conclusion, this study shows that salicylic acid pretreatment induces protection against NaCl-drought stress in wheat plants, probably due to an increased of net photosynthetic rate, decreased accumulation of sodium and increased accumulation of K^+, Ca^{2+} and Mg^{2+}, also due to increased antioxidant activity, as peroxidase and glutathione reductase.

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ABSTRAKT

Vliv kyseliny salicylové na stres mladých rostlin pšenice vyvolaný zasolením půdy a přísuškem

Zvýšení obsahu NaCl a přísušek měly zpravidla inhibiční účinky na rychlost růstu, listovou plochu a rychlost transpirace u mladých rostlin pšenice. Ke změnám obsahu vody v nadzemních částech a kořenech většinou nedocházelo, s výjimkou nadzemních částí u varianty 70 % a kořenů u varianty 30 % rostlin vystavených přísušku, kdy tento obsah klesal s rostoucím zasolením. Naproti tomu se v rostlinách vystavených jak zasolení, tak přísušku zvyšoval obsah chlorofylu a karotenoidů, rychlost čisté fotosyntézy a rychlost respirace ve tmě. Máčení obilek pšenice po dobu 6 h v 100 ppm kyseliny salicylové před výsevem bylo zpravidla účinným opatřením vyrovnávajícím částečně nebo zcela stresující vlivy NaCl (40, 80, 120 a 160 mM) a přísušku (70, 50 a 30 % polní kapacity) na rychlost růstu, listovou plochu a rychlost transpirace. Naproti tomu použití kyseliny salicylové zvyšovalo stimulační účinky NaCl přísušku na tvorbu fotosyntetických pigmentů, na čistou fotosyntézu a respiraci mladých (třicetidenních) rostlin ve tmě. Máčení obilek pšenice v kyselině salicylové mělo příznivý vliv na akumulaci některých iontů a omezovalo nebo snižovalo inhibiční účinek stresu zasolením přísušku na některé jiné parametry.

Klíčová slova: respirace ve tmě; NaCl přísušek; čistá fotosyntéza; kyselina salicylová

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Weight and stratification of root biomass in selected turf cultivars

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ABSTRACT

The total weight of dry root biomass occurring in the depth of 200 mm and stratification of root biomass of turf cultivars of grasses (*Poa pratensis*, *Agrostis tenuis*, *Deschampsia caespitosa*, *Festuca arundinacea*) were evaluated in polyfactorial field trials within the period of 1997–1999. In all experimental years, *Poa pratensis* produced the highest amounts of root biomass (1333.50 $g.m^{-2}$) while *Agrostis tenuis* the lowest ones (906.96 $g.m^{-2}$). The following descending sequence in production of total dry root biomass was found out after a comparison of some turf grass species: *Poa pratensis*, *Deschampsia caespitosa*, *Festuca arundinacea* and *Agrostis tenuis*. Using variance analysis and Tukey's test for a statistic evaluation of obtained results a significant difference ($P = 95\%$) was found out between the total weights of root biomass of *Poa pratensis* and *Agrostis tenuis*. After spring and autumn sampling, the weight of root biomass was significantly ($P = 99.9\%$) different in all turf cultivars of grasses.

Keywords: root biomass; turf; *Poa pratensis*; *Agrostis tenuis*; *Deschampsia caespitosa*; *Festuca arundinacea*

From the viewpoint of species composition, lawns represent usually very simple associations consisting of a limited number of species the selection and proportions of which are determined by the type of use of a concrete sward. The simplicity of these associations is, however, the main cause of their decreased stability. For that reason it is necessary to pay great attention to detailed studies on properties of individual species. Respecting of these properties is reflected individual caespetechnical measures and results in a top-quality sward – the final objective of our efforts. This paper deals with problems of root biomass and stratification of some turf cultivars of grasses.

Root biomass represents 60–90% of net primary production of grass ecosystems (Stanton 1988). Production of a greater amount of active roots (including a higher amount of reserve substances) means also a higher resistance of these stands to changes in environmental conditions and to stress factors (Straka and Hrabě 2000). Duration of roots, depth of rooting as well as mass and stratification of the root system show considerable interspecific and even inter-varietal differences that can be modified by environmental factors, standard of grassland management, and stress effects. The deeper root system, the better its capacity to uptake moisture and to resist stress induced by draught. Besides the depth of the root system also the density of root biomass per unit of soil volume is an important criterion that has been studied intensively especially in recent years.

MATERIAL AND METHODS

In June 1996, a polyfactorial field experiment has been established using a randomized method with two replications at the Grassland Research Station Vatín in the Českomoravská vrchovina Highlands at the altitude of 530 m. The experiment involved 8 grass species with altogether 17 cultivars. From the pedological point of view the soil of this site was characterized as a typical, acid, sandy-loamy cambisol developing on biotic gneiss.

Using four cultivars of turf grasses, the following parameters were evaluated within the period of 1997–1999:
- total weight of all dry root biomass occurring in the depth of 200 mm
- stratification of root biomass, i.e. its amounts in depths of 0–20 mm and 21–200 mm as well as their proportions (in %)

Evaluated were the following species: *Poa pratensis* L., cv. Bohemia; *Agrostis tenuis* Sibth., cv. Bardot; *Deschampsia caespitosa* (L.) P. Beauv., cv. Kometa; *Festuca arundinacea* Schreb., cv. Koreta.

In spring, the grass stand was mowed every week in the height of 35 mm above soil surface using a rotary grassland mower BRILL equipped with an aerating cylinder, after 15 June this mowing interval was prolonged to 9–12 days. The last mowing was carried out in the first half of October. In 1998, the treatment with the aeration cylinder was performed to the end of growing season in the last decade of September. In 1999, this intervention was carried out two times during the growing season with the objective to remove grass felt. This intervention should reduce infestation with fungal diseases and assure a better over-wintering of individual grass species.

Total dry root biomass and its stratification were estimated using the method of soil monoliths (Fiala 1987). Measuring was carried out twice a year, in the spring and in the autumn (i.e. at the beginning and after the end of growing season). At each sampling term soil the monoliths were sampled on 3 sites so that the total number of obtained samples (pseudoreplications) was 6 on the plot. Soil was sampled using a steel cylinder 200 mm long and the obtained monolith was thereafter separated into two parts (i.e. 0–20 mm and 21–200 mm). Samples were

Table 1. Stratification of dry root biomass in selected turf cultivars

Species and cultivar	Layer (mm)	Stratification of dry root biomass (g.m^{-2})											
		1997				1998				1999			
		spring	%	autumn	%	spring	%	autumn	%	spring	%	autumn	%
P. pratensis L.	0–20	142.80	44.09	649.40	75.94	1271.60	89.53	1025.10	75.56	1328.55	82.22	2037.45	83.87
cv. Bohemia	20–200	181.05	55.91	205.70	24.06	148.75	10.47	331.50	24.44	287.30	17.78	391.85	16.13
	Σ	323.85	100.00	855.10	100.00	1420.35	100.00	1356.60	100.00	1615.85	100.00	2429.30	100.00
A. tenuis Sibth.	0–20	193.80	41.30	336.60	60.64	544.85	67.76	855.95	67.22	597.55	62.32	1038.70	75.20
cv. Bardot	20–200	275.40	58.70	218.45	39.36	259.25	32.24	417.35	32.78	361.25	37.68	342.55	24.80
	Σ	469.20	100.00	555.05	100.00	804.10	100.00	1273.30	100.00	958.80	100.00	1381.25	100.00
D. caespitosa L.	0–20	283.05	52.69	307.70	47.26	799.85	68.29	968.15	65.88	868.70	71.17	1018.30	76.94
cv. Kometa	20–200	254.15	47.31	343.40	52.74	371.45	31.71	501.50	34.12	351.90	28.83	305.15	23.06
	Σ	537.20	100.00	651.10	100.00	1171.30	100.00	1469.65	100.00	1220.60	100.00	1323.45	100.00
F. arundinacea	0–20	164..90	41.81	401.20	52.80	941.80	81.77	913.75	72.29	745.45	77.41	1380.40	78.99
Schreb.	20–200	229.50	58.19	358.70	47.20	209.95	18.23	350.20	27.71	217.60	22.59	367.20	21.01
cv. Koreta	Σ	394.40	100.00	759.90	100.00	1151.75	100.00	1263.95	100.00	963.05	100.00	1747.60	100.00

washed off using nets with mesh sieve of 0.5 mm and the obtained root biomass was dried in a natural way.

Results obtained were statistically processed using the method of variance analysis and Tukey's test. The method of correlation analysis was used for the evaluation of relationships existing among individual layers of root biomass.

RESULTS AND DISCUSSION

Differences in stratification of turf cultivars of grasses under study after the spring and autumn samplings performed within the period of 1997–1999 are presented in Table 1. In the layer of 0–20 mm, the average weight of root biomass ranged from 594.58–1075.82 g.m^{-2} (in *Agrostis tenuis* and *Poa pratensis*, respectively) (Table 3). In the layer of 21–200 g.m^{-2}, the corresponding range was 257.69–354.59 g.m^{-2} (in *Poa pratensis* and *Deschampsia caespitosa*, respectively).

The highest proportion of root biomass (an average of spring and autumn samplings) was found in the layer of

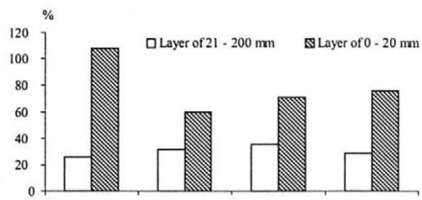

Figure 1. A relative comparison of stratification of dry root biomass

0–20 mm in case of *Poa pratensis*. In stands of *Festuca arundinacea*, *Deschampsia caespitosa* and *Agrostis tenuis*, the proportions of root biomass (also an average of spring and autumn samplings) in the layer of 0–20 mm were 72.4, 66.6 and 65.6%, respectively (Figure 1). In an experiment where similar methodology was applied, Bäuerle and Schulz (1993) report a relative proportion of root biomass in the depth of 0–20 mm of intensive turf corresponding to 93.8–98% of the total root biomass weight in the depth of 0–250 mm, depending on the date of sampling, the dosage of N, the type of fertiliser, and the type of split dosage of N. The higher proportion of the root biomass in the depth of 0–20 mm corresponds with Rieder's data (1983), which show that there are up to 90% of grassland roots in the soil layer of 0–50 mm.

When evaluating dynamics of production of root biomass in individual turf cultivars it was found out that, as compared with spring of 1997, *Poa pratensis* increased the total weight of its dry roots by 338.58 and 398.95% in the spring of 1998 and 1999, respectively (Table 2). When comparing results of autumn samplings, this increase was only 58.65 and 184.10% in 1998 and 1999, respectively. In case of *Agrostis tenuis*, production of dry root biomass increased only by 71.38 and 104.35%, respectively. In the autumn of 1998 and 1999, the corresponding increase in the total weight of dry root biomass was 129.40 and 148.85%, respectively.

When comparing relative increases in total root biomass in 1998 and 1999 with the results obtained in 1997, the measured results ranged from 203.26–227.22% (*Deschampsia caespitosa*) and from 166.33–292.03% (*Festuca arundinacea*), respectively (Table 2).

The total weight of root biomass (mean value of spring and autumn samplings) found in the layer of 0–200 mm ranged from 906.96 g.m^{-2} (*Agrostis tenuis*) to 1333.50 g.m^{-2}

Table 2. Dynamics of dry root biomass in selected turf cultivars in individual years

Species and cultivar	Total weight of dry root biomass (g.m^{-2})											
	1997				1998				1999			
	spring	%	autumn	%	spring	%	autumn	%	spring	%	autumn	%
P. pratensis cv. Bohemia	323.85	100.00	855.10	100.00	1420.35	438.58	1356.60	158.65	1615.85	498.95	2429.30	284.10
A. tenuis cv. Bardot	469.20	100.00	555.05	100.00	804.10	171.38	1273.30	229.40	958.80	204.35	1381.25	248.85
D. caespitosa cv. Kometa	537.20	100.00	651.10	100.00	1171.30	218.04	1469.65	225.72	1220.60	227.22	1323.45	203.26
F. arundinacea cv. Koreta	394.40	100.00	759.90	100.00	1151.75	292.03	1263.95	166.33	963.05	244.18	1747.60	229.98

Table 3. Weights of dry root biomass of selected turf cultivars (means of years 1997–1999)

Layer (mm)	Season	*P. pratensis*	*A. tenuis*	*D. caespitosa*	*F. arundinacea*
		cv. Bohemia	cv. Bardot	cv. Kometa	cv. Koreta
0–20	spring	914.32	445.40	650.53	617.38
	autumn	1237.32	743.75	764.72	898.45
	mean	1075.82	594.58	707.63	757.92
21–200	spring	205.70	298.63	325.83	219.02
	autumn	309.68	326.12	383.35	358.70
	mean	257.69	312.38	354.59	288.86
0–200	spring	1120.02	744.03	976.36	836.40
	autumn	1547.00	1069.87	1148.07	1257.15
	mean	1333.51	906.96	1062.22	1046.78

(*Poa pratensis*) (Table 3). In all experimental years, *Poa pratensis* produced the highest amounts of root biomass while *Agrostis tenuis* the lowest ones (Figure 2). Similar results were published by Gandert and Bureš (1991) who observed that in *Poa pratensis* roots continued to grow in unfrozen soil both in winter and at temperatures above 27°C when other grass species significantly reduce their growth. For growth of roots, optimum temperature range is 10–18°C. However, as mentioned by Beard (1973) and Skirde (1980), optimum temperatures of air above sward ranged from 16–24°C. Boeker (1974), as well, found that in a stand of *Poa pratensis* mowed to the height of 30 mm the total weight of root biomass in the soil layer of 0–200 mm was 1113.68 g.m^{-2} while in stands of *Agrostis capillaris* and *Lolium perenne* the corresponding values were only 670.63 and 710.73 g.m^{-2}, respectively.

After autumn sampling, the total weight of root biomass was always higher than in the spring (Table 1, Figure 3). Only in case of *Poa pratensis* a slighter reduction of root biomass was observed as compared with spring sampling. In the layer of 0–200 mm, the weight of root biomass increased in the years 1997 and 1998. As com-

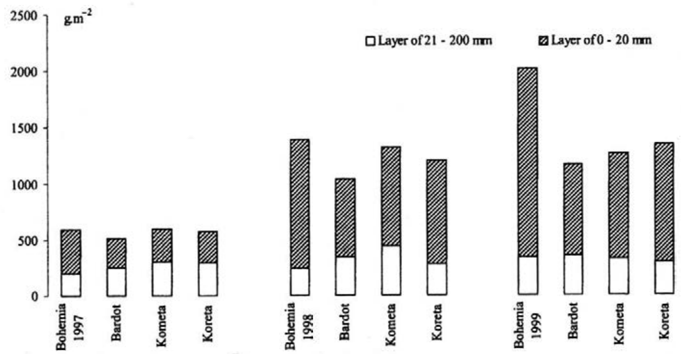

Figure 2. Weight and stratification of dry root biomass in selected turf cultivars (mean of spring and of autumn)

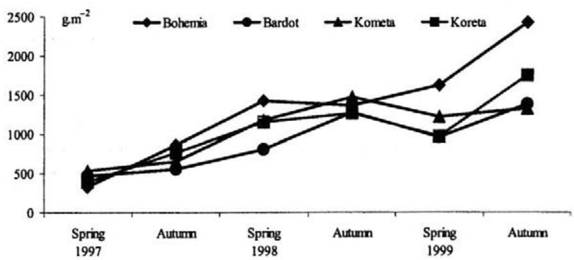

Figure 3. Effect of year and date of sampling on the weight of dry root biomass in soil layer of 0–200 mm

pared with the autumn of 1998, a marked decrease in the amount of root biomass was recorded in case of *Agrostis tenuis*, *Deschampsia caespitosa* and *Festuca arundinacea* in the spring of 1999 (Figure 3). This can be explained by the fact that the root biomass responded to the aeration of sward performed in the autumn of the previous year (see Material and Methods). This intervention reduced the amount of above-ground biomass and induced in plants a stress response. This stress was manifested, among others, also in a reduced growth of roots. The fact that in *Poa pratensis* roots are produced all-year-round and its root system survives for several years (Gandert and Bureš 1991, Fischer 2000) explains why the weight of total root biomass was, in contradistinction to other grass species, decreased in the spring of 1999. This means that roots of *Poa pratensis* responded in a better manner to the stress caused by sward aeration because of reasons mentioned above. Other grass species (e.g. *Lolium perenne* or *Agrostis tenuis*) have annual root system and for that reason their roots are newly produced every year so that they temporarily are short and thin (Fischer 2000). Fiala (2000) found out that when meadow stands are used extensively, the total weight of root biomass in the depth of 0–150 mm accounted for 3.670 g.m^{-2} in the Czech Moravian Highlands, while in the Beskydy mountains it accounted for 3.300 g.m^{-2} in the depth of 0–200 mm. The above values are 2.8 and 2.5 times higher than the maximal value that had been found out in the monitored/observed varieties. The root biomass weight in the intensively used meadow stand in Kameničky in the Czech Moravian Highlands was 3.3310 g.m^{-2} in the depth of 0–150 mm, and in the newly founded stand on the identical site it totalled 2.290 g.m^{-2} in the same depth (Fiala 1993).

Using variance analysis and Tukey's test for a statistic evaluation of obtained results (Table 4) a significant difference (P = 95%) was found out between the total weights of root biomass of *Poa pratensis* and *Agrostis tenuis*. After spring and autumn sampling, the weight of root biomass was significantly (P = 99.9%) different in all turf cultivars. When comparing weights of dry root biomass in soil layers of 0–20 mm and 21–200 mm, significant differences were found out in all turf cultivars as well (P = 99.9%).

Correlation analysis of weights of root biomass of selected turf grass species in individual soil layers revealed also significant differences in traits under study (Table 5). The closest statistically significant dependence (P = 99.9%) was determined between the total root weight in the depth of 0–200 mm and the root weight in the depth of 0–20 mm.

The following descending sequence in production of total root biomass was found out after a comparison of

Table 4. Result of variance analysis – classic experiment

Source of variability	Sum of squares	Degrees of freedom	Mean square	F	P
Main effects	48042619.0	11	4367510.8	118.2	0.0000
Species	3330556.2	7	475793.7	12.8	0.0000
Year	17291629.2	2	8645814.6	234.0	0.0000
Season	2836066.5	1	2836066.5	76.7	0.0000
Layer	24584367.0	1	24584367.0	665.6	0.0000
Interactions of the 2nd degree	23643966.4	33	716483.8	19.4	0.0000
Species × year	1799626.2	14	128544.7	3.4	0.0000
Species × season	500774.0	7	71539.1	1.9	0.0618
Species × layer	4181504.1	7	597357.7	16.1	0.0000
Year × season	816188.4	2	408094.2	11.0	0.0000
Year × layer	15714583.7	2	7857291.8	212.7	0.0000
Term × layer	631289.8	1	631289.8	17.0	0.0000
Explained	71686585.4	44	1629240.5	44.1	0.0000
Error	19611066.3	531	36932.3		
Total	91297651.8	575	158778.5		

Table 5. Matrix of correlation coefficients expressing the relationship between the weight of individual layers of dry root biomass

	Species	Weight of roots in the layer 0–20 mm	Weight of roots in the layer 21–200 mm
Weight of roots in the layer 0–200 mm	*Poa pratensis* L.	0.988***	0.604***
	Agrostis tenuis Sibth.	0.971***	0.961***
	Deschampsia caespitosa L.	0.968***	0.629***
	Festuca arundinacea Schreb.	0.977***	0.437**
Weight of roots in the layer 21–200 mm	*Poa pratensis* L.	0.472**	
	Agrostis tenuis Sibth.	0.963***	
	Deschampsia caespitosa L.	0.413*	
	Festuca arundinacea Schreb.	–	

* significance at $P_{0.95}$ level, ** significance at $P_{0.99}$ level, *** significance at $P_{0.999}$ level

some grass species: *Poa pratensis*, *Deschampsia caespitosa*, *Festuca arundinacea* and *Agrostis tenuis*.

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ABSTRAKT

Hmotnost a stratifikace kořenové biomasy vybraných trávníkových odrůd trav

V polyfaktoriálním pokusu byla v letech 1997 až 1999 sledována celková hmotnost a stratifikace kořenové biomasy v půdní vrstvě 0 až 200 mm u čtyř trávníkových odrůd trav (*Poa pratensis*, *Agrostis tenuis*, *Deschampsia caespitosa*, *Festuca arundinacea*). Ve všech sledovaných letech dosahovala nejvyšších hodnot celkové hmotnosti kořenové biomasy v suchém stavu *Poa pratensis* (1333,50 g.m^{-2}) a nejnižších hodnot *Agrostis tenuis* (906,96 g.m^{-2}). Při vzájemném porovnání vybraných druhů ve vztahu k celkové produkci kořenové biomasy bylo zjištěno toto pořadí (od nejvyšší k nejnižší): *Poa pratensis*, *Deschampsia caespitosa*, *Festuca arundinacea* a *Agrostis tenuis*. Při statistickém hodnocení dosažených výsledků analýzou variance a následném testování Tukeyovým testem byl zjištěn statisticky významný rozdíl (P = 95 %) mezi celkovou hmotností kořenové biomasy mezi *Poa pratensis* a *Agrostis tenuis*. Velmi vysoce průkazně (P = 99.9 %) se u všech trávníkových odrůd lišila hmotnost kořenové biomasy při jarním a podzimním termínu odběru kořenů.

Klíčová slova: kořenová biomasa; trávník; *Poa pratensis*; *Agrostis tenuis*; *Deschampsia caespitosa*; *Festuca arundinacea*

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The effect of variety and site of cultivation on the content of starch in wheat

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ABSTRACT

A great development of production of wheat starch puts great demands on starch-making material. Its quality is restricted above all by a variety, which provides a required yield as well as the quality of starch, given by a high percentage of great starch grain of category A. In the three-year period we evaluated a selected set of varieties of winter wheat of domestic and foreign provenance in view of suitability and efficiency for starch-making purposes. The aim of the research was to judge the effect of variety and cultivation locality on the content of starch and other indicators of technological quality and to pay an attention particularly to the possibilities of cultivation of starch-making wheat in marginal regions. The variety Contra excelled by the highest content of starch in grain in the evaluated set followed by the varieties Siria, Estica, Šárka, Samara and Versailles. These varieties were also marked by the satisfying content and good washing out of gluten, what is another factor that should be taken into account. An important fact with respect to the aims of research is suitability of all the above-mentioned varieties into the so-called marginal or submarginal regions, respectively (cereal-, potato- and forage-growing regions). Except suitable varieties in distribution of starch-making wheat production capacity of cultivation localities and hence yield capacities of wheat and starch production of starch per 1 hectare should be taken into account. This is economically acceptable in regions with a production potential of soil above 55–60 points in cereal- and potato-growing region. Good yields can be obtained by the proposed varieties in these conditions.

Keywords: wheat for starch production; varieties; starch content; cultivation locality

The starch is qualified as one of the strategic materials of the future. Its consumption is growing each year both in food industry and in non-food utilisation. In recent years, the interest in the use of wheat has been increasing in Europe as a starch-making material, and what is more, as it follows from the experience of German starch factories, the choice of a suitable variety for starch-making processing brings a marked increase in the profit. Formulation of quality criteria for starch-making wheat and characterisation of starch-making wheat varieties in the Czech Republic is still in the phases at the beginning.

The aim of our study, financed by the grant from the Grant Agency for Agricultural Research of the Ministry of Agriculture of the Czech Republic No. 7222 *Wheat in marginal regions for starch production* and by the research project of the Czech University of Agriculture in Prague MSM 412100002 was to evaluate the set of winter wheat varieties of domestic and foreign provenance in view of its suitability and usability for starch-making purposes, to assess as locality affected the starch content and other indicators of technological quality and to pay an attention particularly to the possibilities of wheat cultivation for starch-making purposes in marginal regions.

The possibilities to use the starch have no competitions compared with other materials. Starch consumption is growing fast particularly in industrial processing where its annual increment amounts to as much as 6.5%. The greatest utilisation of starch is in paper, textile and chemical industries, where it serves for production of numerous products. Modification is needed to recognise its polymeric qualities, which can be reached by chemical or physical methods (Lillford and Morrison 1997).

A wide use of modified starches in industry of synthetic polymers is expected, what will allow their decomposability (Munck et al. 1988). It is also associated with a main commercial attention, which studies the possibility of substitution of petrochemical products. Doane (1989) reported that starch could be used from technological aspect as a material for production of any chemical product obtained from crude oil till now. This does for starch an ecological and renewable material from the starch and the starch production, from starch-bearing crops in agriculture will develop further with this prospective as a perspective utility orientation.

Existing main starch-bearing crops are starch-bearing grain crops, potatoes and tapioca. In the world-wide sense the most important source of starch is maize, where the percentage of maize starch is 50%, in Europe these are potatoes (approximately 25%) and wheat – also 25%. More dynamic development can be seen in production of wheat starch, what has been confirmed by Bergthaller et al. (1998) and their data on extending capacities of starch factories in France and Germany. In the European Union during the last five years the production of wheat starch rose by 30%. Reasons for utilisation of wheat for starch production consist in favourable weather conditions for starch production, high yields of wheat varieties as well as intensity of its cultivation. Existing over-production of wheat is solving too, and it is not necessary to import expensive maize. Vital gluten is also extracted from wheat beside the starch, that is much valued on the world market and quasi waste-free technology during wheat production can be marked here (Anonym 2000).

Food wheat has been particularly used for starch production till now. Flour for starch-making purposes is prepared by ordinary milling process, e.g. in Germany it is flour T550 with ash content 0.6%.

Kodet and Babor (1991) reported average values of processed flour in starch factories: 0.6% of ash, starch content 68.5% and protein content 13.5% (high quality food varieties prevailed in those times).

German authors Lindhauer and Zwingelberg (1997) considered wheat with lower content of proteins in dry matter as a suitable for starch-making process, in grain they report 12–12.5% and in flour 11–11.5%. These authors also recorded that wheat varieties for starch production should have a low durability of endosperm, low content of pentosans and in addition, a good quality of starch – higher falling number and higher values of amylographic maximum.

MATERIAL AND METHODS

Based on the preliminary, orientation analyses which were carried out in 1996, a set of winter wheat varieties was chosen, that was analysed in detail in the years 1997–1999.

The selected set of wheat varieties comes from different localities of the Czech Republic, representing cereal-, potato-, forage- and sugar beet-growing regions. Wheat grain samples used for laboratory evaluation were obtained from variety test stations of the Central Institute for Supervising and Testing (ÚKZÚZ) Domanínek on the Českomoravská vysočina (Highlands), Hradec nad Svitavou, Lípa near Havlíčkův Brod, Trutnov, Nechanice near Hradec Králové and Stachy in the Šumava Mountains. Soil and climatic characteristics of these locations are presented in Table 1.

Treated seed, nitrogen fertilization 80–100 kg $N.ha^{-1}$, in addition 60 kg of $K_2O.ha^{-1}$, 60 kg of $P_2O_5.ha^{-1}$ were used in the variety trials. Herbicide was applied during the growing season.

The following varieties were studied in 1997 – Hana, Samanta, Siria, Estica, Samara, Sida, Versailles, Contra, in 1998 – Hana, Samanta, Siria, Estica, Samara, Versailles, Contra, Šárka, and in 1999 – Samanta, Siria, Estica, Samara, Versailles, Contra, Šárka.

After the harvest of wheat in evaluated localities about 2 kg of grain sample were taken from four repetitions, which were sent to the Department of Plant Production, Faculty of Agronomy, Czech University of Agriculture in Prague for laboratory evaluation.

The grain was purified and ground on the mill falling number. The starch content in dry matter (%) – the Czechoslovak Standard ČSN 56 0512-16 (the method after Ewers) was detected in the produced meal. Polamate A was used to determine analyte, in addition wet gluten content in dry matter (%) was determined – ČSN 56 0512-10 (Glutomatic was used for determination).

Beside the starch content and wet gluten other indicators of technological quality [crude protein content in dry matter (%) – ČSN 56 0512-12, falling number (s) – ČSN 46 1018, *SDS*-test (ml) – ČSN 46 1021] were evaluated in the studied wheat varieties to judge the wheat quality as a complex.

The starch content one-way variance analysis was used for statistical evaluation. Homogenous groups among varieties and localities were tested using the Scheffe test on the level of probability $\alpha = 0.05$.

RESULTS

The effect of variety on the starch content

The results of the starch content in grain of different wheat varieties of different cultivation localities are presented in Figures 1–3, average values of the starch content and wet gluten in evaluated varieties are in Figures 4–6. Results of statistical evaluation in the starch content among varieties are presented in Table 2.

In 1997 the highest starch content on average of evaluated varieties was reached by the variety Contra (68.82%), however, it was evaluated only on three localities (Domanínek, Trutnov and Chrastava). The variety

Table 1. Characteristics of conditions (localities) of which originated the evaluated wheat varieties

Locality	District	Growing region	Altitude (m)	Great soil group	Soil texture	$\bar{x}$ (°C)	Σ (mm)	P
Domanínek	TR	potato	565	cambisol	sandy loam	6.4	602	47.0
Hradec/S.	SV	potato	450	luvisol	sandy loam	6.5	624	67.1
Chrastava	LI	cereal	345	albic luvisol	loam	7.1	798	62.8
Lípa	HB	cereal	505	albic-gleyic cambisol	sandy loam	7.7	632	55.0
Nechanice	HK	sugar beet	235	luvisol	loam	8.1	582	70.6
Stachy	PT	forage	860	podzolic cambisol	loam-clay	6.3	755	34.8
Trutnov	TU	potato	437	cambisol	sandy loam	6.8	778	67.1

$\bar{x}$ = average annual temperature, Σ = average sum of precipitation, P = production potential of soil

Siria was the second one (on average 68.20% of starch) – the highest starch content obtained at Domanínek and Stachy, the lowest one in Trutnov and Chrastava. The lowest average starch content (Figures 1 and 4) was recorded in the varieties Hana and Samanta (Hana 65.91%, Samanta 66.50%).

The varieties Hana and Samanta and Contra were statistically significantly different among them and with each other varieties in the starch content. On the other hand, statistically significant differences were not among the varieties Siria and Versailles, Estica and Sida, Samara and Versailles (Table 2).

The content of wet gluten in grain dry matter was studied as a supplementary indicator in evaluated varieties (Figure 4). It is evident from the results that higher starch content is connected with lower content of wet gluten in grain. The highest content of wet gluten was reached by the varieties Hana and Samanta (on average of regions 36.31% and 32.60%). The lowest content of gluten was recorded in the variety Contra (28.73%), followed by the varieties Versailles (29.64%) and Sida (31.07%).

In 1998 the highest starch content on average of the varieties (67.13%) that reached the highest starch content at Domanínek, Stachy and Hradec was predominated by the variety Siria. They were followed by the varieties Estica (66.90%), Contra (66.82%) and Versailles (66.71%). The lowest starch content was (Figures 2 and 4), like in the previous year, found with the varieties Hana and Samanta (62.93% and 64.43%), but also with the variety Šárka (63.10%).

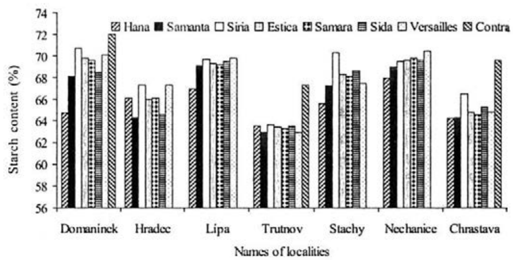

Figure 1. Starch content in grain of selected wheat varieties from different cultivation localities (harvest of 1997)

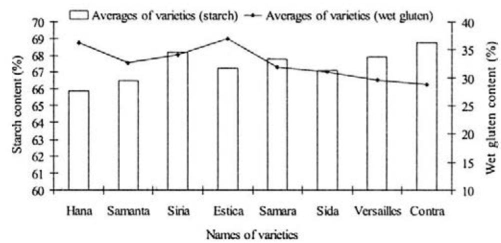

Figure 4. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of varieties (harvest of 1997)

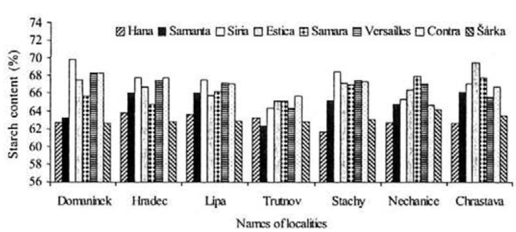

Figure 2. Starch content in grain of selected wheat varieties from different cultivation localities (harvest of 1998)

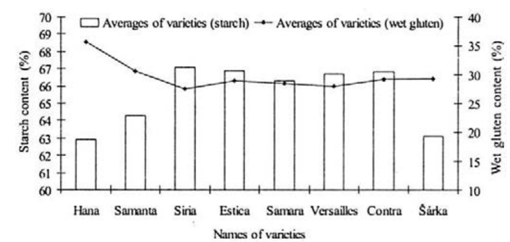

Figure 5. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of varieties (harvest of 1998)

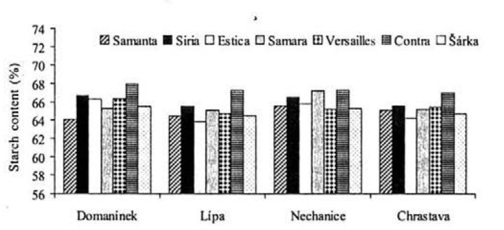

Figure 3. Starch content in grain of selected wheat varieties from different cultivation localities (harvest of 1999)

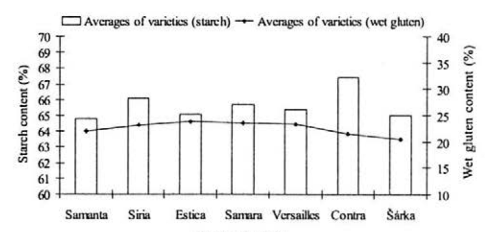

Figure 6. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of varieties (harvest of 1999)

Table 2. One-way analysis of variance and homogenous groups in the starch content among varieties (Scheffe, $\alpha = 0.05$)

Year	1997				1998				1999			
Locality	$\bar{x}$ (%)	*MS*	*F*-ratio	HG	$\bar{x}$ (%)	*MS*	*F*-ratio	HG	$\bar{x}$ (%)	*MS*	*F*-ratio	HG
Hana	65.91	3.446[a]	213.42	A	62.93	13.469[a]	468.48	A	–	3.169[a]	255.97	–
Samanta	66.50	0.020[b]		B	64.34	0.029[b]		B	64.80	0.012[b]		A
Siria	68.20			C	67.13			C	66.14			B
Estica	67.32			D	66.90			C	65.11			C
Samara	67.80			E	66.33			D	65.73			D
Sida	67.24			D	–			–	–			–
Versailles	67.91			CE	66.71			CD	65.45			D
Contra	68.82			F	66.82			CD	67.42			E
Šárka	–			–	63.10			A	65.08			AC

$\bar{x}$ = average content of starch in grain, *MS* = mean square ([a]between groups, [b]within groups), HG = homogenous groups

Variety Samanta was statistically significantly different with each other varieties in the starch content. On the contrary, there were no statistically significant differences among the varieties Hana and Šárka, among the varieties Siria, Estica, Versailles and Contra and among the varieties Samara, Versailles and Contra (Table 2).

Similarly to the previous year, the highest content of wet gluten was recorded in the varieties Hana (35.62%) and Samanta (30.60%). Wet gluten content was balanced in the remaining varieties and ranged between 27 and 29%.

In 1999 the highest starch content was recorded in the varieties Contra (97.42%) and Siria (66.14%). They reached the highest starch content at Domanínek and Nechanice. They were followed by the varieties Samara and Versailles.

The varieties Siria and Contra were statistically significantly different among them and with each other varieties in the starch content. On the other hand, there were no statistically significant differences among the varieties Hana – Šárka, Estica – Šárka and Samara – Versailles (Figures 3 and 6, Table 2).

Content of wet gluten ranged between 21 and 24% on average in evaluated varieties.

The effect of cultivation locality on the starch content

The results of evaluation of the effect of cultivation locality on the starch content are presented in Figures 7–9, the results of statistical evaluation in the starch content among different localities are presented in Table 3.

In the year 1997 the highest average starch content was recorded in evaluated localities at Nechanice (69.40%), Lípa (69.12%) and Domanínek (68.80%). The lowest average starch content was recorded at Chrastava (64.91%) and Trutnov (63.33) (Figure 7).

With exception Lípa and Nechanice, there were among the each other tested localities statistically significant differences in the starch content.

The highest average content of wet gluten was found in 1997 at Trutnov (35.92%) and Chrastava (35.90%), the lowest one at Stachy (23.41%) and Lípa (26.73%).

In 1998 the highest average starch content was recorded at Chrastava (66.15%) and Domanínek (66.03%), the lowest at Trutnov (64.11%). It is evident from the results, that in this year average starch content in different localities was much balanced compared with the year 1997 what is confirmed also by the results of statistical evalu-

Table 3. One-way analysis of variance and homogenous groups in the starch content among localities (Scheffe, $\alpha = 0.05$)

Year	1997				1998				1999			
Locality	$\bar{x}$ (%)	*MS*	*F*-ratio	HG	$\bar{x}$ (%)	*MS*	*F*-ratio	HG	$\bar{x}$ (%)	*MS*	*F*-ratio	HG
Domanínek	68.80	21.801[a]	999.99	A	66.03	2.066[a]	151.88	AB	66.26	1.428[a]	122.43	A
Trutnov	63.33	0.012[b]		B	64.11	0.014[b]		C	–	0.012[b]		–
Nechanice	69.40			C	65.35			D	66.12			A
Hradec	66.21			D	65.90			AB	–			–
Lípa	69.12			C	65.82			A	65.05			B
Stachy	67.90			E	65.94			AB	–			–
Chrastava	64.91			F	66.15			B	65.30			C

$\bar{x}$ = average content of starch in grain, *MS* = mean square ([a]between groups, [b]within groups), HG = homogenous groups ation when were not found statistically significant differences in the starch content among the localities Lípa – Hradec, Lípa – Stachy, Lípa – Domanínek, Hradec – Stachy, Hradec – Domanínek and Hradec – Chrastava (Figure 7, Table 3).

The highest average content of wet gluten in 1998 was recorded at Nechanice (34.10%) and at Trutnov (31.51%), the lowest one at Stachy (22.73%) and at Hradec (26.81%).

In 1999, where only four localities were evaluated, the highest average starch content was reached at Domanínek (66.26%) and Nechanice (66.12%) – there were no statistically significant differences between these localities (Figure 9). Average content of wet gluten was relatively balanced in all evaluated localities – it ranged between 20 and 23%.

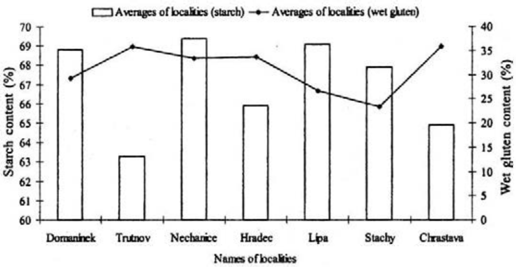

Figure 7. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of localities (harvest of 1997)

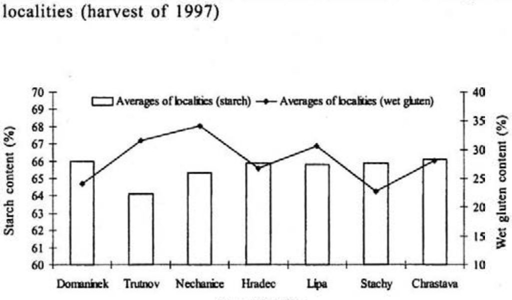

Figure 8. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of localities (harvest of 1998)

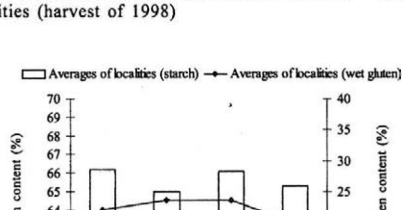

Figure 9. The content of starch and wet gluten in grain of selected wheat varieties from different cultivation localities – averages of localities (harvest of 1999)

DISCUSSION

From the results of three-year analyses on the starch content of the selected set of winter wheat varieties cultivated in different soil-climatic conditions of the Czech Republic, we can mention the varieties with the highest starch content in grain dry matter. The highest starch content was marked by the variety Contra, followed by the varieties Siria, Samara, Estica, Šárka and Versailles.

To recommend the varieties to be used for starch production, however, we have to consider also other properties, among other things – a good washing out of gluten (Kodet 1999). For these reasons, the variety Trane, which was studied within sub-selection of the set of varieties in 1996, cannot be recommended. This variety was, however, marked by high starch content, but its gluten was of extra low quality, strongly dissolving and it could not be washed out; therefore this variety was eliminated from further investigation.

Another marked criterion is a percentage of size categories of starch grains. Lindhauer and Zwingelberg (1997) studied the suitability of varieties in Germany. They paid their attention in evaluation of varieties to yield capacity of the starch of category A. The best was the variety Contra according to their results, which in our trials predominates as a starch-making variety, the variety Soisson too had the favourable values. However, this variety was not registered in the Czech Republic for its low frost-hardiness. Survey of varieties of suitable according to our results for starch production is given in Table 4.

An important fact with respect to the aim of the study is suitability of all above-mentioned varieties into the so-called marginal regions (cereal, potato and forage regions) where are the highest yields. For example, the above-mentioned varieties had the highest yields in the potato-growing region: Versailles 122%, Estica 118%, Siria 116%, Samara 115%. In the forage-growing region these varieties had the following yields to the standard variety: Versailles 111%, Estica 110%, Siria 108%, Samara 103%. In the cereal-growing region the variety Versailles reached 118%, Estica 116% and Samara 114% (Jurečka and Beneš 2000).

We studied also a possible production of starch-making wheat in the regions of distribution of processing industry. Yet in the first experimental year the prerequisite, that higher starch content will be in cooler and less fertile regions with lower production and biological potential, has been confirmed. It can be explained by the fact that the production of supply substances of saccharide character is less demanding for plants for energy compared with the production of proteins or fats (Kincl and Krpeš 2000).

In 1997 the highest starch content was from Nechanice, what we consider as an exception, given by location of the trial on the plots not typical for this region. In addition, very high starch content had the varieties from Lípa and Domanínek. In 1998 the highest starch content was recorded in the studied varieties from the stations

Table 4. Survey of varieties of suitable according to our results for starch production

Variety	Year of approval	Quality group	Classification into region	Properties
Siria	1994	B	potato and cereal growing regions	late, good health condition
Estica	1995	C	into all regions	late high-yielding variety
Versailles	1997	C	all regions, especially marginal ones	semi-late intensive variety
Contra	1998	C	central site of cereal and potato growing regions	semi-late yield-stable variety
Samara	1995	C	colder potato growing region	semi-late yielding variety
Šárka	1997	B	sugar beet, cereal and potato growing regions	semi-early, good health condition

Chrastava, Domanínek, Stachy, Hradec nad Svitavou and Lípa. In 1999 the highest starch content was reported from the station Domanínek. However, we have to take into account the production capacities of these localities. Just at the station Domanínek, which is situated in the potato-growing region with production potential of soil 44–50 points, average yield of the studied set of wheat varieties was 3.7 $t.ha^{-1}$, while in cereal-growing region, where the station Lípa is located, the average yield of the same set of varieties was 6.42 $t.ha^{-1}$. At the same time, also this site is situated where processing industry is placed. With respect to the relatively small differences in average starch content, it will be necessary to assess the distribution of cultivation of starch-making wheat regarding the starch production per 1 hectare.

In the case of concern of starch factories to obtain main production in gluten (vital gluten), other variety should be chosen from the quality groups E and A, and to apply nitrogen doses approximately 110 kg $N.ha^{-1}$. We recommend the variety Hana among the varieties which beside higher gluten content has greater percentage of starch grains of category A. However, new varieties were introduced into the practice which should be tested from this aspect.

One of the aims of the research was to formulate complexly quality criteria of wheat varieties for starch-making processing. An extensive set of the results of analyses of indicators in varieties that were demonstrated as suitable for starch production allows us to formulate the general criteria for starch-making wheat varieties.

Moisture, admixtures and impurities identical like for food wheat:

Bulk density ($g.h^{-1}$)	760–780
Grain hardness (B.U.)	100–150
Starch content in grain dry matter (%)	>67
Crude protein content (N×5.75) in grain dry matter (%)	11–12
Percentage of starch grains of category A (> 10 μm) (%)	>60
As lowest as possible percentage of starch grain of category B (< 10 μm)	
Falling number (s)	250–300
SDS test (ml)	40–42
Gluten index	>50
Wet gluten content in grain dry matter (%)	26–29

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ABSTRAKT

Vliv odrůdy a místa pěstování na obsah škrobu u pšenice

Velký rozvoj produkce pšeničného škrobu klade nové nároky na škrobárenskou surovinu. Její jakost je vymezena především odrůdou, která zaručuje požadovanou výtěžnost a též kvalitu škrobu, danou vysokým podílem velkých škrobových zrn kategorie A. V tříletém období jsme hodnotili vybraný soubor odrůd ozimé pšenice tuzemské i zahraniční provenience z hlediska vhodnosti a využitelnosti pro škrobárenské účely. Cílem výzkumu bylo posoudit vliv odrůdy a pěstitelské lokality na obsah škrobu a další ukazatele technologické jakosti a věnovat pozornost zejména možnostem pěstování škrobárenské pšenice v marginálních oblastech. Nejvyšším obsahem škrobu v zrnu vynikala z hodnoceného souboru odrůda Contra, následovaly odrůdy Siria, Estica, Šárka, Samara a Versailles. Tyto odrůdy se též vyznačovaly uspokojivým obsahem a dobrou vypíratelností lepku, což je další faktor, který je třeba brát v úvahu. Důležitou skutečností s ohledem na cíle výzkumu je vhodnost všech výše uvedených odrůd do tzv. marginálních, resp. submarginálních oblastí (obilnářské, bramborářské a pícninářské). Kromě vhodných odrůd je však třeba při rajonizaci škrobárenské pšenice brát v úvahu produkční schopnost pěstitelských lokalit, a tím výnosové možnosti pšenice a produkci škrobu na 1 ha, která je ekonomicky přijatelná v oblastech s produkčním potenciálem půdy nad 55 až 60 bodů v obilnářské a bramborářské oblasti. V těchto podmínkách také navržené odrůdy poskytují dobré výnosy.

Klíčová slova: pšenice pro produkci škrobu; odrůdy, obsah škrobu; pěstitelská lokalita

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INFORMACE

Porovnání metod stanovení pH půd

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ABSTRAKT

Na reprezentativním souboru 1181 půdních vzorků byl porovnán stávající postup stanovení pH používaný v rámci Agrochemického zkoušení zemědělských půd ČR (0,2M KCl) se dvěma postupy zahrnutými do normy ISO 10390 (stanovení pH půd v 1M KCl a v 0,01M $CaCl_2$). Rozdíly mezi postupy se týkaly odlišného složení extrakčního roztoku, různé doby kontaktu půdy s roztokem a různého míchání půdní suspenze v průběhu měření. Mezi metodami byl zjištěn statisticky průkazný rozdíl. Z regresních závislostí vyplynulo, že všechny sledované postupy stanovení pH jsou si velmi blízké. Využití postupu podle ISO 10390 s 0,01M $CaCl_2$ pro stanovení pH půd místo dosud používaného roztoku 0,2M KCl se ukazuje jako nejvhodnější. Mezi těmito postupy jsou jen velmi malé rozdíly stanovovaných hodnot v celém rozsahu pH. Pro celý soubor sledovaných půd byl rozdíl mezi těmito metodami –0,03 jednotek pH. Pro všechny kyselé půdy to bylo –0,12, pro neutrální a alkalické půdy +0,03 a pro alkalické a silně alkalické půdy +0,10 jednotek pH.

Klíčová slova: analýzy půd; pH; porovnání metod

Stanovení pH patří k základním požadavkům pro zjištění kvality půdy, protože hodnota pH má vliv na většinu chemických a biologických procesů v půdě. Příjem živin rostlinami, resp. přechod cizorodých látek do rostlin je zpravidla vysoce závislý na pH půdy. Problém vlivu pH půdy na rostliny podrobně diskutují Mengel a Kirgby (1987). Popis zdrojů H^+ iontů v půdě, ovlivnění pH půd a způsoby měření popisují Scheffer a Schachtschabel (1992). Vlastní měření pH skleněnou elektrodou v oblasti pH 3–9 je ovlivňováno nejen aktivitou H^+ iontů, které jsou ve styku s vnější membránou elektrody, ale i difuzním potenciálem, parciálním tlakem oxidu uhličitého a v půdních suspenzích např. i sorpcí vysokomolekulárních látek na skleněnou membránu (Meier et al. 1989). Pro potlačení vlivu difuzního potenciálu byla pro stanovení pH půdních suspenzí dávána přednost roztokům solí, především KCl o koncentraci 0,1–1 mol.l^{-1} případně 0,01M roztoku chloridu vápenatého. Conyers a Davey (1988) porovnávali stanovení pH půdní suspenze pro 0,1M KCl, vodu a 0,01M $CaCl_2$. Sledovali vliv poměru půdy k přidanému roztoku od 2:1 až po 10:1. Zjistili, že koncentrace uvolněných H^+ iontů závisela lineárně na tomto poměru. Dále zjistili, že delší kontakt půdy s roztokem vede ke kolísání získaných výsledků. Vztah mezi jednotlivými postupy zkoumali např. Brennan a Bolland (1998) pro stanovení pH ve vodě a v 0,01M $CaCl_2$. Na souboru 236 západoaustralských půd odvodili lineární vztah mezi těmito postupy ($r^2 = 0,94$). Ponnamperuna et al. (1966) podrobně prozkoumali vliv redoxního potenciálu půdy a parciálního tlaku oxidu uhličitého na hodnoty pH u zaplavovaných půd. Zjistili, že za uvedených podmínek pH alkalických a karbonátových půd klesalo, zatímco pH půd kyselých stoupalo. Obdobné závěry vyplývají i z měření pH v půdních suspenzích v závislosti na době kontaktu půdy a roztoku (Sterckeman et al. 1997). Podrobné posouzení vlivu délky kontaktu půdy s extrakčním roztokem na změnu měřeného pH bylo provedeno na souboru deseti půd z ČR o pH 5,1–8,1. Bylo zjištěno, že pH kyselých půd se s dobou kontaktu zvyšuje a pH půd alkalických naopak snižuje. Pokud však doba kontaktu půdy s roztokem nepřesáhne 4 h, jsou změny zanedbatelné (Sterckeman et al. 2000). Bylo také zjištěno, že vliv doby kontaktu půdy s roztokem je obecný a není závislý na složení roztoku.

Cílem práce bylo ověřit rozdíly mezi metodou stanovení pH podle Jednotných pracovních postupů ÚKZÚZ (Zbíral 1995) a stanovením podle revidované ISO 10390, která předpokládá omezení doby kontaktu půdy s roztokem, používá jiné složení roztoků a nepřipouští míchání proudem vzduchu v průběhu měření. Celý tento komplex vlivů byl posuzován současně jako rozdíl stanovené hodnoty pH.

MATERIÁL A METODY

Byla použita rotační třepačka na 100 míst (ÚKZÚZ), pH-metr Multical pH 526 (WTW, SRN). Všechny chemikálie byly čistoty p.a. (Lachema Brno, Merck Darmstadt). Pro přípravu roztoků byla používána demineralizovaná voda. pH upravených vzorků půd bylo stanoveno podle Jednotných pracovních postupů ÚKZÚZ (Zbíral 1995) a podle revidovaného znění ISO 10390. Pro statistické zpracování výsledků byl využit program Excel 97 (Micro-

Tab. 1. Popisná statistika; hodnoty stanovené v extraktu podle Mehlicha III – Descriptive statistics; results in Mehlich III soil extracts (n = 1181)

Parametr[1]	AP	MED	MAX	MIN	LQ	UQ
K	342	275	1627	39	193	405
P	120	100	834	0	60	154
Mg	205	183	1247	31	123	254
Ca	5800	3422	42510	221	2192	7829
S	30,2	22,9	1427	2,7	17,5	29,2
Cu	4,71	3,59	67,10	0,26	2,62	4,99
Zn	6,50	5,39	92,5	0,53	3,76	7,44
Mn	142	137	403	12	99	182
Fe	300	326	889	32	148	423
Al	687	733	1664	1,9	489	894
pH/KCl (JPP)	6,80	7,05	7,90	3,80	6,22	7,47
Karbonáty[2] (%)	8,6	4,3	55,6	0	1,35	12,9

AP = aritmetický průměr – arithmetic mean, MED = medián – median, LQ = dolní kvartil – lower quartile, UQ = horní kvartil – upper quartile; údaje v $mg.kg^{-1}$ – data in $mg.kg^{-1}$
[1]parameter, [2]carbonates

soft, Redmont, USA). Přístroj pro měření pH byl kalibrován za pomoci certifikovaných pufrů (Hanna Instr., Itálie). Rutinní nastavení pH-metru bylo prováděno podle normy ISO 10390.

Vzorky půd

Vzorky pro porovnání byly vybrány ze dvou zdrojů, jednak vzorky Bazálního monitoringu půd ČR (Sáňka et al. 1998) a dále vzorky ze speciálního odběru. Celý soubor se skládal ze 157 lehkých, 968 středních a 56 těžkých půd. Popisná statistika souboru je uvedena v tab. 1. Vzorky byly vysušeny na vzduchu a upraveny speciální půdní prosévačkou (bez drcení skeletu) na jemnost < 2 mm.

Pracovní postup

JPP ÚKZÚZ (0,2M KCl): k 20,0 g upraveného vzorku půdy se dávkovalo 50 ml 0,2M roztoku KCl (60,0 g KCl se rozpustilo v demineralizované vodě a objem se upravil na 4000 ml). Po promíchání se nechala suspenze stát 16–24 h. Po této době se suspenze nejprve mechanicky promíchala a za stálého míchání proudem vzduchu byla stanovena hodnota pH skleněnou elektrodou.

ISO 10390 (revidovaný postup, 1M KCl a 0,01M $CaCl_2$): k 10 g upraveného vzorku půdy se dávkovalo 50 ml 1M roztoku KCl (745 g KCl v 10 l roztoku) nebo 50 ml 0,01M roztoku $CaCl_2$ (21,9 g hexahydrátu chloridu vápenatého v 10 l roztoku). Suspenze se po 60 min protřepávání v rotační třepačce nechala 1 h stát a po této době se mechanicky promíchala a stanovila se hodnota pH skleněnou elektrodou bez míchání suspenze. Měření proběhlo nejpozději do 3 h po extrakci. Norma předpokládá objemové odměřování půdy místo navažování. Vzhledem k vyšší přesnosti navažování byl v tomto bodě postup modifikován. Norma dále doporučuje míchání i v průběhu měření. Vzhledem k omezením (nelze použít proud vzduchu ani míchací zařízení, které svým elektromagnetickým polem ovlivňuje měření) byly vzorky promíchány těsně před měřením a vlastní měření probíhalo bez míchání. Změny způsobené touto úpravou jsou zanedbatelné.

VÝSLEDKY A DISKUSE

Korelace mezi metodami

Korelační analýza udává těsnost lineárního vztahu mezi jednotlivými metodami. Korelační koeficienty v tab. 2 odpovídají hodnotám Pearsonových korelačních koeficientů.

Regresní analýza

Regrese byla vypočítána pro celý soubor měřených hodnot a pro všechny sledované postupy. Výsledky uvádí tab. 3 a obr. 1 a 2. Z tab. 3 je zřejmé, že metody se na použité hladině významnosti od sebe statisticky významně liší. Hodnoty koeficientu a jsou vždy odlišné od nuly a koeficientu b od jedné. Z hodnot koeficientů determinace vyplývá, že vztahy mezi metodami jsou velmi těsné.

Tab. 2. Pearsonovy korelační koeficienty pro celý soubor dat – Pearson correlation coefficients for all samples (n = 1181)

	1M KCl	0,2M KCl	0,01M $CaCl_2$
1M KCl	1	0,9767	0,9858
0,2M KCl		1	0,9718
0,01M $CaCl_2$			1

Tab. 3. Lineární regrese – Linear regression ($y = a + bx$, n = 1181)

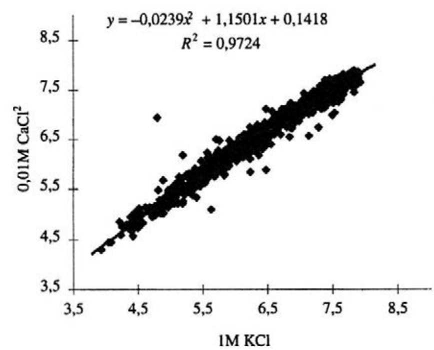
x	y	R^2	a	a min	a max	b	b min	b max
1M KCl	0,01M CaCl	0,972	1,0745	1,0198	1,1291	0,8482	0,8400	0,8565
1M KCl	0,2M KCl	0,954	1,4975	1,4318	1,5631	0,7891	0,7792	0,7990
0,01M $CaCl_2$	0,2M KCl	0,945	0,6157	0,5312	0,7003	0,9126	0,8999	0,9252

Využití nelineárních vztahů zvýšilo poněkud hodnoty koeficientů determinace. Pro 0,2M KCl a 0,01M $CaCl_2$ z 0,945 na 0,957.

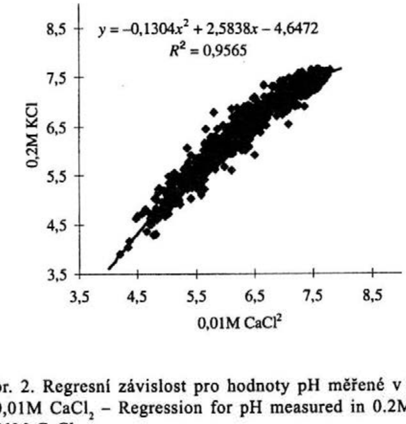
ZÁVĚR

Navrhovaná změna postupu stanovení pH půd je významná především proto, že odstraňuje vlivy, které způsobovaly zvýšený rozptyl měření. Omezení doby kontaktu půdy a roztoku eliminuje nežádoucí změny pH, které u kyselých půd znamenají mírné zvýšení měřených hodnot a u půd alkalických mírné snížení. Přínosem je také odstranění míchání proudem vzduchu. Místo dosud používaného roztoku 0,2M KCl se ukazuje jako nejvhodnější použití 0,01M $CaCl_2$. Mezi těmito roztoky jsou velmi malé rozdíly v celém rozsahu pH. Z vyhodnocení středních hodnot jednotlivých podsouborů je možné konstatovat, že pro celý soubor půd bude rozdíl –0,03 jednotky pH. Pro všechny kyselé půdy to bude –0,12, pro neutrální a alkalické půdy +0,03 a pro alkalické a silně alkalické půdy +0,10. Tyto rozdíly však nejsou z hlediska rozdělení půd do kategorií a z hlediska povolené tolerance měření významné.

Přechod na stanovení pH podle revize normy ISO přinese správnější výsledky, které se budou poměrně málo odchylovat od dosavadních výsledků. Významným přínosem bude zvýšená porovnatelnost a přenositelnost výsledků na mezinárodní úrovni, včetně možnosti účastnit se mezinárodních kruhových testů, které tento postup využívají.



Obr. 1. Regresní závislost pro hodnoty pH měřené v 1M KCl a 0,01M $CaCl_2$ – Regression for pH measured in 1M KCl and 0.01M $CaCl_2$



Obr. 2. Regresní závislost pro hodnoty pH měřené v 0,2M KCl a 0,01M $CaCl_2$ – Regression for pH measured in 0.2M KCl and 0.01M $CaCl_2$

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ABSTRACT

Comparison of methods for soil pH determination

The method of pH determination used in the State Soil Testing Programme in the Czech Republic and the two methods included into the revised version of ISO 10390 were compared. 1181 agriculture soil samples were collected for the comparison. The soil samples represented all major soil types, climatic regions and proportions of agronomic cultures in the Czech Republic. Method using 0.01M $CaCl_2$ according to ISO 10390 was found to be the most suitable for the pH determination since the differences between the present method (0.2M KCl) and this method were relatively small. For all measured samples the difference was only –0.03 pH units. For acid soils –0.12, for neutral and alkaline soils +0.03 and for alkaline and strongly alkaline soils +0.10 pH units.

Keywords: soil analysis; pH; comparison of methods

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Poznámka redakce:

Komise výživy rostlin doporučila používat v rámci agrochemického zkoušení půd od roku 2001 jako základní metodu stanovení pH půd ve výluhu (suspenzi) 0,01M $CaCl_2$.

RECENZE

Wheat ecology and physiology of yield determination
Ekologická a fyziologická podmíněnost výnosu pšenice

E.H. Satorre, G.A. Slafer

Food Products Press, Imprint of The Haworth Press Inc., New York, London, Oxford 2000. 503 s., 8 tab., 49 obr.

Pod autorským vedením profesorů Emilio H. Satorre a Gustavo A. Slafera (University of Buenos Aires, Argentina) byla vytvořena významná publikace zaměřená komplexně na veškerou problematiku, zabývající se tvorbou výnosu u pšenice. Kniha byla vydána vydavatelstvím Food Products Press, které působí v New Yorku, Londýně a Oxfordu. Tvoří ji čtyři hlavní tematické části – fyziologie, ekologie, produkční systémy a šlechtění pro další zvyšování výnosů. Vydavatelé kladli velký důraz na vyváženost a komplexnost prezentovaných poznatků a na srozumitelnost textu. Autoři jednotlivých kapitol pocházejí především z Jižní Ameriky, USA, Oceánie a Afriky, méně jsou zastoupeni autoři z Evropy.

Všeobecný význam knihy podtrhuje skutečnost, že pšenice je co do rozšíření a produkce nejvýznamnější plodinou, sloužící jako zdroj obživy pro 35 % světové populace. Vzhledem k neustále se zvyšujícímu počtu obyvatel na Zemi, stabilizaci pěstebních ploch přibližně na 223 milionech hektarů (průměr za období 1986–1995) a k roční produkci přibližně 545 milionů tun (údaje FAO 1998–1995) musí být očekávaný nárůst potřeby pšenice zabezpečován především cestou zvyšování hektarových výnosů. Podle analýz samotných autorů knihy vývoj trendů výnosů u pšenice již není tak strmý, jako tomu bylo v období 1950–1980. V tomto kontextu vyvstala právě nyní nutnost analyzovat fyziologicko-ekologické procesy na úrovni plodin a prostředí. Tyto analýzy umožní odhalit reálné možnosti dalšího šlechtitelského zdokonalování pšenice a jejího pěstitelského využívání. Z globálního pohledu je třeba dosáhnout do roku 2020 (kdy se očekává dosažení osmi miliard počtu obyvatel Země) přibližně jedné miliardy tun roční produkce pšenice. Při současném průměrném výnosu pšenice ve světě (podle FAO bylo dosaženo v roce 2000 průměrného výnosu 2,7 $t.ha^{-1}$ z plochy 214 milionů hektarů) jde o téměř nereálný požadavek, který musí být nezbytně řešen na mezinárodní úrovni.

První tematická část knihy (120 s.), orientovaná na fyziologii rostlin, sleduje v pěti dílčích kapitolách problematiku analýz výnosových trendů a výnosového potenciálu pšenice v hlavních producentských oblastech, ontogenetický vývoj rostlin ve vztahu k tvorbě výnosových prvků, význam dusíkatého hnojení a zásobenost vody a fyziologické vlivy působící na kvalitu bílkovinné a nebílkovinné složky zrna. Druhá část (140 s.), zabývající se ekologickými aspekty ve vztahu k výnosu, se v šesti kapitolách orientuje na možnosti optimalizace termínu výsevu a velikosti výsevního množství v jednotlivých regionech pěstování, na význam hustoty porostů, dopady negativního působení plevelů, škůdců a chorob a na možnosti jejich eliminace, osevní sledy a perspektivu pěstování pšenice v odrůdových směsích. Ve třetí části (88 s.), zaměřené na charakteristiku a uplatnění produkčních systémů, jsou ve čtyřech kapitolách podrobně uvedeny používané pěstitelské postupy v klimaticky odlišných podmínkách – na velkých prériích Severní Ameriky, v Austrálii, v oblastech mírného klimatu a na pampách Jižní Ameriky. Zvláštní zřetel je věnován produkčním systémům, low-input systému a systému pro dosahování vysoké kvality produkce. Čtvrtá část (106 s.), zabývající se významem šlechtění pro další zvyšování výnosů, je rozdělena do čtyř kapitol, analyzujících trendy růstu genetického zisku výnosu v různých oblastech světa, ke kterým došlo vlivem intenzivní šlechtitelské činnosti během 20. století. Jsou zde objasněny fyziologické a morfologické změny u nejdůležitějších znaků, které se rozhodujícím způsobem podílely na zvyšování výnosového potenciálu. Dále je věnována pozornost perspektivám šlechtění hybridní pšenice pro podmínky s nízkou úrovní agrofonu a současným aktuálně využitelným možnostem uplatnění biotechnologických metod ve šlechtění.

Všechny kapitoly obsahují černobílé obrázky a přehled citací. V závěru knihy je uveden autorský (24 s.) a jmenný (18 s.) rejstřík. Kniha velmi dobře a srozumitelně charakterizuje problematiku tvorby výnosu. Stává se tak vhodnou příručkou pro výzkumné pracovníky a šlechtitele i pro studenty. Je zdařilým aktualizovaným pokračováním světově významných monografií napsaných na toto téma v minulých letech (např. E.G. Heyne: Wheat and wheat improvement, 2. vyd., ASA-CSSA-SSSA, Madison 1987).

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RECENZE

Heterosis and hybrid seed production in agronomic crops

Heteroze a produkce hybridního osiva u zemědělských plodin

A.S. Basra

Food Products Press, Imprint of The Haworth Press Inc., New York, London, Oxford 2000. 269 s.

Kniha, jejímž vydavatelem a spoluautorem je Amarjit S. Basra, profesor na zemědělské universitě v indickém městě Ludhiana, se v osmi kapitolách věnuje heterozi a produkci hybridního osiva nejvýznamnějších zemědělských plodin – kukuřice, rýže, pšenice, čiroku, bavlníku, slunečnice a řepky. Představuje čtenáři hlavní úlohu heteroze, neboli hybridní zdatnosti, která spočívá ve zvýšení produktivity a zlepšení kvality polních plodin ve stále se zvyšující lidské populaci, a to především v rozvojových zemích světa. Autoři pocházejí hlavně z Asie (Indie a Čína), kapitoly zaměřené na pšenici a kukuřici sepsali autoři z evropských zemí, Francie a Řecka.

Úvodní kapitola je zaměřena na stručný přehled hybridního šlechtění polních plodin, zabývá se genetickými základy heteroze a hledáním nových paradigmat. Diskutována je problematika QTL markerů a jejich využití v hybridním šlechtění. *Produkce hybridního osiva kukuřice* je název druhé kapitoly knihy. Autor v jednotlivých podkapitolách sleduje historické aspekty hybridního šlechtění, zaměřuje se na postupy při tvorbě a produkci hybridní kukuřice, spočívající především ve výběru zárodečné plazmy a šlechtitelských postupů, v tvorbě inbredních linií, metodách hodnocení S-linií a v široké škále produkce hybridního osiva. Třetí kapitola se zabývá problematikou moderních postupů při tvorbě hybridního osiva rýže. Čínští autoři popisují faktory ovlivňující produkci hybridního osiva a seznamují čtenáře s výzkumem a praktickými metodami vedoucími ke zlepšení hybridní čistoty osiva rýže. Ve čtvrté kapitole nazvané *Možnosti produkce hybridního osiva u pšenice* autoři ve stručnosti shrnují dosavadní úspěchy i neúspěchy při tvorbě hybridní pšenice. Zaměřují se na metody získávání pylově sterilních mateřských rostlin cestou ruční kastrace, genetickými metodami – cytoplazmatickopylovou sterilitou (CMS) a jadernou pylovou sterilitou (NMS). Věnují se i chemickým metodám získávání pylově sterilních mateřských rostlin, a to aplikací chemických hybridizačních činidel nebo tzv. gametocidů. Zabývají se výběrem vhodných otcovských rodičů – opylovačů a vlivem biologických, klimatických a agronomických faktorů na produkci hybridního zrna pšenice. Pátá kapitola je zaměřena na produkci hybridního osiva u čiroku. Jednotlivé podkapitoly shrnují historii a globální trendy komerční produkce hybridního čiroku. Jsou zde objasněny metody produkce hybridního osiva, sklizně, výmlatu, skladování a certifikace osiva a nastíněny další možnosti produkce hybridů u této plodiny. Šestá kapitola je orientována na produkci hybridního osiva u bavlníku. Autoři se zabývají využitím heteroze a znaky hybridní zdatnosti u bavlníku. Popisují genetické základy projevu heteroze a seznamují čtenáře s metodou ruční kastrace s následným opylováním a technikou použití pylově sterilních linií. Zabývají se i využitím chemických hybridizačních činidel pro vyvolání pylové sterility. Heteroze a produkce hybridního osiva slunečnice je náplní sedmé kapitoly, jejíž autoři se věnují významným mezníkům v hybridním šlechtění této plodiny, studiu inbreedingu, heteroze a praktickým výsledkům při tvorbě hybridní slunečnice v Indii. Závěr kapitoly je zaměřen na pěstební technologie při produkci hybridního osiva a na potřeby pro správné udržování rodičovských linií. Závěrečná osmá kapitola je orientována na šlechtění hybridní řepky. V jednotlivých podkapitolách jsou objasněny základní principy produkce hybridního osiva z hlediska biologie kvetení, vedení rodičovských linií, klimatických podmínek a technologie pěstování hybridní řepky. Dále se autor zabývá popisem reprodukčních technologií cytoplazmatických pylově sterilních tříliniových hybridů, jaderných pylově sterilních dvouliniových hybridů a autoinkompatibilních liniových hybridů.

Jednotlivé kapitoly jsou doplněny řadou tabulek, grafů a fotografií a jsou zakončeny přehledem literárních odkazů. V závěru knihy je pak uveden věcný rejstřík. Publikace podává ucelený přehled o nejnovějších poznatcích, které byly dosaženy v oblasti hybridního šlechtění těchto polních plodin v minulých letech, a o perspektivách jejich dalšího využití. Pro komplexnost předkládaných poznatků a srozumitelnost textu bude kniha vhodným studijním materiálem jak pro šlechtitele a výzkumné pracovníky, tak i studenty vysokých škol.

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Ing. Zdeněk Nesvadba

POKYNY PRO AUTORY

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