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Differences in chlorophyll content in leaves of sugar beet (*Beta vulgaris* L.)

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ABSTRACT

In the course of vegetation in the years 1997–1999 changes in chlorophyll content in leaves of 21 select sugar beet varieties in small-plot trials at Sedlec u Prahy were measured by chlorophyllmeter. Chlorophyllmeter determines chlorophyll in leaves of plants directly in field, without damaging them. The measured chlorophyll units show the relative amount of chlorophyll present in leaves of plants. The assessment of individual values of chlorophyll content showed a correlation between individual times of measurements and between the total average chlorophyll content. The assessment of relationship between yield and chlorophyll content showed no stronger correlation. The statistical assessment showed no correlation between chlorophyll content and the efficiency type (sugar, normal and yield type) of variety. The trials confirmed different chlorophyll content in the surveyed varieties and, accordingly, the need for their classification into groups. The varieties were classified into groups by the index of chlorophyll content in sugar beet leaves in the whole course of vegetation. The values of percentage of index of chlorophyll content $\geq 102.5\%$, $97.5\text{--}102.5\%$ and $\leq 97.5\%$ were considered high, average and low, respectively. The overall highest chlorophyll content was found in Domino, Orion, Fox and Kaweduca varieties. The medium chlorophyll content group is most numerous. The low chlorophyll content group included four varieties, namely Madeira, Melina, Petra and Amelie. The low and high chlorophyll content groups were assessed as statistically significant, with 95% probability rate. The above mentioned findings may be used for the creation of methodics for optimisation of nitrogen nutrition of sugar beet.

Keywords: sugar beet; varieties; chlorophyll; sugar beet growth; chlorophyllmeter; changes in chlorophyll content; nitrogen fertilisation

The content and activity of pigments and their correlations depend on plant growth and development stage and react sensitively to the effects of changes in the outer environment (Stehlík 1982; Zalewski 1992; Švachula et al. 1996; Pačuta and Bajčí 1998; Pulkrábek 1998; Pulkrábek et al. 1999). A number of growing interventions in the technology of sugar beet growing has a significant influence on the chlorophyll content in leaves. The degree to which radiation is utilised depends on the concentration of chlorophyll or, more precisely, of photosynthetically active pigments. Plant pigments, in particular chlorophylls, reflect with sufficient exactness and visibly physiological changes and health condition of sugar beet. As such they were already used for the purposes of identification of diseases due to the deficit of some nutrients or virus diseases (Řimsa et al. 1978), observation of production processes by using distance methods in plant production (Griepentrog 1998) as well as in precision farming (Griepentrog 1998). Recently, they have also been used in the assessment of condition of stands (Justes et al. 1994; Guérif et al. 1995).

The absorption of dispersed light depends considerably on the colour of leaves and chlorophyll content. The increase in photosynthesis in dark green leaves exposed to light is rather steep while the photosynthesis curve in light green leaves grows more slowly (Šebánek et al. 1983). The intensity of photosynthesis in early morning is 1.5–2 times higher in dark green leaves

than in light green ones under the same conditions. The same relations in these forms appear also in daytime under low temperature and light intensity. On the contrary the benefits of dark green colour become hardly visible or completely disappear at noon in clear weather. A high intensity of photosynthesis is frequently visible in leaves with low chlorophyll content under such conditions (Rubin 1968).

Changes in chlorophyll content in sugar beet leaves may contribute to clarification of differences in yield and quality formation under different environmental conditions or serve as a basis for differentiation of growing interventions with respect to the required root quality. Guérif et al. (1995) show that the close correlation between chlorophyll content and concentration of nitrogenous substances in leaves enables to determine deficit nitrogen nutrition and the optimum dosing and time of fertilisation necessary for growing. In an attempt to contribute to clarification of the influence of some factors on the content of chlorophylls and to improvement or elaboration of new, possibly simple methods used in the assessment of chlorophyll content the chlorophyllmeter Minolta-SPAD 502 was examined at the Czech University of Agriculture in Prague. The present paper aims to assess the possibility of use of the above mentioned chlorophyllmeter for measurement of changes in chlorophyll content in sugar beet leaves in the course of vegetation; to find out the differences between sugar beet

varieties and the degree of correspondence between the measured content and the quantity and quality indices of harvested sugar beet roots.

MATERIAL AND METHODS

In the course of vegetation in the years 1997–1999 changes in chlorophyll content in leaves of 21 select sugar beet varieties were measured (Table 2). The chlorophyllmeter is a light compact device for determination of chlorophyll contained in plant leaves. The value measured by SPAD 502 provides data on the relative content of chlorophyll present in plant leaves. The chlorophyllmeter enables to measure chlorophyll in plant leaves directly in field, without damaging them (relative chlorophyll units – SPAD). The SPAD values as defined by Minolta determine the relative chlorophyll content in plant leaves. The measured area is 1×3 mm. The values are calculated on the basis of light transmitted through the leaf in two intervals of wave lengths of different chlorophyll absorption. The values measured by receiver (silicon photodiode) are further computer processed and displayed on the chlorophyllmeter display. The device calculates the average value of chlorophyll units, usually of 30 individual partial measurements. After their statistical evaluation and potential completion it provides the average determined chlorophyll units.

The measurement was made in small-plot trials established by the Union of Sugar Beet Growers for the system of joint variety trials in the Sedlec u Prahy station of ÚKZÚZ. The trial was established by the alpha design method. Each variety was established in three repetitions on plots sized 10 m^2 . The sowing was made by non-remainder sowing machines with manual singling to the required distance. Uniform commercial seed for standard growing was used. The plants were counted down before adjustment of the number to 90 pcs per plot. The harvest was made by using three-row harvesters. The roots of each variety and from each plot were weighed and 25 average roots were selected for laboratory determination of technological values. The mea-

sured values were determined by analysis of sugar beet pulp in automatic analyser.

The Sedlec u Prahy station of ÚKZÚZ is located in the north outskirts of Prague. The land located 300 m above the sea level is classified as sugar beet-barley production type. The geographic position is $50^\circ 12'$ of north latitude and $14^\circ 28'$ of east longitude. The topography is slightly undulating. The soil on the trial site is loamy, the soil type is black soil. The location belongs to climatic region T2 – warm, slightly dry. The annual mean air temperature is 8.2°C . The annual mean precipitation reaches 501 mm. The months of highest precipitation are June and July with the lowest precipitation occurring in January and February. Lang rain factor is 62. Table 1 shows the characteristics of weather in the years of the trial.

The values of chlorophyll content were measured in approximately fourteen-day intervals. Each measured value was the average of thirty statistically evaluated measurements. Two repetitions were measured twice in each variety. The chlorophyll measurement itself in the surveyed plants of sugar beet was based on the methods published by Pulkrábek (1998). The measured values were statistically evaluated. The linear regression and variance analysis of individual trials were calculated by using the Microsoft Excel.

RESULTS AND DISCUSSION

Selected for measurement in the involved sugar beet stands were fully created and sound leaves in accordance with our former recommendations. The youngest leaves as well as the old dying ones have lower values. The leaves most suitable for field measurement by chlorophyllmeter are considered to be fully developed, dark green leaves with visible lustre (of balanced colour corresponding with the predominant colour of the stand). It is necessary to avoid measurement of leaves in the middle (heart) and in the periphery of the leaf rosette as well as of those which are damaged or already yellowing and dying which would strongly influence the average of measured values.

Table 1. Characteristics of weather in the years of trial

Agrometeorological year		Assessment			
		Δt	temperature	%	precipitation
1996/1997	cold half-year	+0.2	normal	93	normal
	warm half-year	+0.2	normal	92	normal
	AMT 1996/1997	+0.2	normal	92	normal
1997/1998	cold half-year	+1.4	warm	87	normal
	warm half-year	+0.8	warm	78	dry
	AMT 1997/1998	+1.1	warm	81	dry
1998/1999	cold half-year	+0.4	normal	106	normal
	warm half-year	+1.3	very warm	70	dry
	AMT 1998/1999	+0.9	warm	81	dry

Table 2. Rating of the surveyed varieties by chlorophyll content in individual years of measurement and total average chlorophyll content for three years

Variety	1997		1998		1999		1997–1999 total		
	rating	index 1997	rating	index 1998	rating	index 1999	average	index	
Domino	1.	107.5	1.	107.4	1.	107.7	587.76	107.5	high
Orion	2.	107.0	3.	106.4	5.	103.8	577.77	105.8	
Fox	5.	102.2	5.	103.4	4.	105.0	566.31	103.5	
Kaweduca	8.	100.1	4.	103.8	3.	105.9	565.19	103.2	
Agrios	6.	102.1	14.	98.8	2.	106.4	560.04	102.4	average
Triumph	4.	102.2	8.	102.1	7.	102.0	558.22	102.1	
Eureka	7.	100.9	9.	102.1	6.	102.9	557.70	102.0	
Dunja	16.	98.5	2.	107.0	12.	99.0	555.42	101.5	
Vegas	18.	97.5	6.	103.3	11.	99.6	547.95	100.1	
Anca	13.	99.0	12.	99.8	8.	101.4	547.31	100.1	
Elan	15.	98.9	7.	102.5	15.	98.6	547.01	100.0	
Alice	10.	99.6	17.	97.6	9.	101.3	543.82	99.5	
Hana	3.	103.0	11.	100.3	19.	93.5	539.84	98.9	
Hilma	11.	99.5	13.	99.7	16.	97.3	540.01	98.8	
Format	9.	99.7	18.	94.8	10.	100.4	537.03	98.3	
Kristal	19.	96.9	15.	98.3	13.	98.9	536.36	98.1	
Sofie	12.	99.2	10.	101.2	20.	92.6	533.40	97.7	
Amelie	17.	97.7	16.	97.7	18.	95.2	529.31	96.9	low
Madeira	21.	95.7	20.	94.4	14.	98.8	526.44	96.3	
Melina	20.	96.6	19.	94.6	17.	95.3	521.86	95.5	
Petra	14.	99.0	21.	90.7	21.	92.5	513.08	94.1	
Average		100		100		100	542.77	100	
F-test		0.3198		1.8627		1.8599			
P-value		0.999		0.0148		0.0155			
Significance		no		yes		yes			

The calculation of average during vegetation (Table 2) used the partial averages (of 120 measurements) of individual (8–11) times of measurement (Figure 1). The minimum differences in the measured values with the standard deviation of the measured values in the interval of 14.1–16.6 appeared at the beginning of vegetation. The variance of values gradually increased in the course of vegetation with the maximum values in the interval of 26.6 (1997) to 50.4 (1999) reached in all measurements in the month of September. The values of variance were already lower and the total chlorophyll content was reduced in the October measurement.

The assessment of relationship between individual values of chlorophyll content showed a correlation between individual measurements and the total average chlorophyll content. The correlation of chlorophyll content gradually increased in the course of vegetation with a strong correlation already found in the second half. The assessment of relationship between yield indices and chlorophyll content did not show any stronger correlation. Some values of the correlation coefficient moved around 0.4–0.5 in case of some indices (sodium content) in individual times of measurement; 0.2–0.3 in case of sugar content and refined sugar yield; and around 0.1–0 in case of the other indices.

The statistical evaluation did not prove any correlation between chlorophyll content and the efficiency type (sugar, normal and yield type) of variety. This allows the conclusion that efficiency type has no relation to chlorophyll content. The curve of average content (Figure 2) and the equation of chlorophyll content in relation to the length of vegetation period: $y = -9E - 0.7x^4 + 0.0002x^3 - 0.009x^2 + 1.3148x + 425.7$ were calculated in the total evaluation of chlorophyll content in sugar beet leaves in the vegetation period.

The trials confirmed different chlorophyll content for the surveyed varieties and, accordingly, the need for their classification into groups (Table 2). The most appropriate simple method suitable also for newly licenced varieties was sought. The classification into groups is necessary to optimize the nitrogen dose for sugar beet fertilisation at the beginning of vegetation. The classification by the index of chlorophyll content measured in individual measurements or years proved to be the most suitable. To select the index which could be used for the best classification of varieties into several groups with respect to the uneven representation of varieties with different chlorophyll content. In accordance with these limitations the classification of varieties by the index of chlorophyll content in sugar beet leaves during the whole

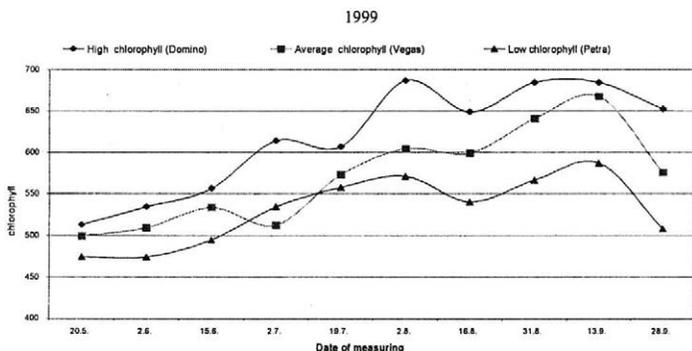
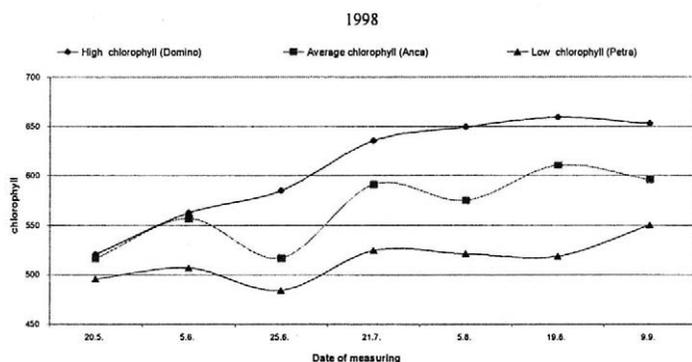
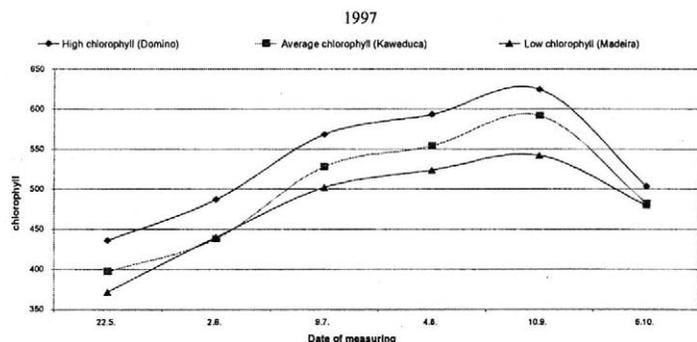


Figure 1. Comparison of average chlorophyll content for varieties of high, average and low number of chlorophyll units (Sedlec u Prahy)

vegetation in relation to the average of surveyed varieties was selected. The values of percentage of index of chlorophyll content $\geq 102.5\%$, $97.5-102.5\%$ and $\leq 97.5\%$ were considered high, average and low, respectively.

The overall highest chlorophyll content was found in Domino, Orion, Fox and Kaweduca varieties. The medium chlorophyll content group is most numerous. The low chlorophyll content group included four varieties, namely Madeira, Melina, Petra and Amelie. The low and high chlorophyll content groups were assessed as statistically significant, with 95% probability rate.

The results of Puršl (2000) concerning efficiency and uniformity of varieties under different conditions were confirmed. The chlorophyll content was approximately

the same for varieties in individual years of different growing conditions.

The values measured by chlorophyllmeter were compared with the chlorophyll content in sugar beet leaves determined by extraction method (Šesták and Ullmann 1964). The values of correlation and regression analysis [$y=100.81x+108.97$; $x=(y-108.97)/100.81$; and $R=0.8856$] were deduced from the measured values (the same leaf was measured by chlorophyllmeter and sampled for laboratory determination by extraction method). The observation measurements (Pulkrábek 1998) confirmed the suitability of using chlorophyllmeter for observation of changes in chlorophyll content in sugar beet leaves and comparability of values determined by standard extraction method.

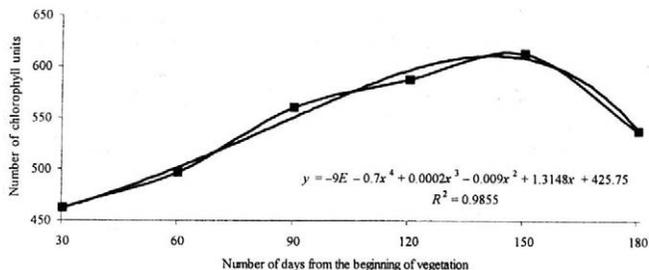


Figure 2. Average chlorophyll content in the course of vegetation by numbers of chlorophyll units measured in the vegetation periods of 1997–1999 (Sedlec u Prahy)

The aim of observation of chlorophyll content in sugar beet leaves is to obtain sufficient data for the creation of methodics for optimum fertilisation and observation of health and nutritive condition of stand and possibility of its operative solution. In the initial growing stage sugar beet reacts very sensitively to any fertilisation with a change in chlorophyll content. In the later vegetation stage sugar beet reacts only very slowly with the intake of nutrients from soil supply. The effect of this intake is that sugar beet shows only very little changes in the course of vegetation and that the change in chlorophyll content is only slow. The change is more influenced in the later stage by the weather course and sufficient precipitation enabling sufficient growth not only of root but also of photosynthetic apparatus which requires sufficient water supply for optimum activity. Variety has a significant influence on chlorophyll content. This knowledge is the key one for the creation of methodics for optimisation of nutrition of sugar beet and observation of its nutritive condition during vegetation.

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ABSTRAKT

Rozdíly v obsahu chlorofylu v listech řepy cukrovky (*Beta vulgaris* L.)

V průběhu vegetace v letech 1997 až 1999 byly v maloparcelkových pokusech v Sedleci u Prahy sledovány pomocí chlorofylmetru změny v obsahu chlorofylu v listech vybraných odrůd cukrovky. Chlorofylmetr stanovuje chlorofyl v listech rostlin přímo na poli, bez jejich poškození. Zjištěné chlorofylové jednotky udávají relativní množství chlorofylu přítomného v listech rostliny. Při hodnocení jednotlivých hodnot obsahu chlorofylu byla zjištěna korelační závislost jednotlivých termínů měření mezi sebou a celkovým průměrem obsahu chlorofylu. Při hodnocení závislosti výnosu na obsahu chlorofylu nebyla zjištěna silnější korelační závislost. Při statistickém hodnocení nebyla prokázána závislost obsahu chlorofylu na užitkovém typu odrůdy. V pokusech byl potvrzen rozdílný obsah chlorofylu u sledovaných odrůd, a tudíž i potřeba jejich

rozdělení do skupin. Odrůdy byly rozděleny do skupin podle indexu obsahu chlorofylu v listech cukrovky během celé vegetace. Za vysoký obsahu chlorofylu byly považovány hodnoty indexu obsahu chlorofylu v procentech $\geq 102,5$ %, za průměrný v rozmezí 97,5 až 102,5 % a za nízký $\leq 97,5$ %. Celkově nejvyšší obsah chlorofylu vykázaly odrůdy Domino, Orion, Fox a Kaweduca. Skupina se středním obsahem chlorofylu má nejvíce zástupců. Ve skupině s nízkým obsahem chlorofylu se umístily čtyři odrůdy: Madeira, Melina, Petra a Amelie. Při statistickém hodnocení se jako statisticky rozdílné s 95% pravděpodobností jevíly skupiny s nízkým a vysokým obsahem chlorofylu. Uvedená zjištění bude možno využít na vypracování metodiky pro optimalizaci výživy cukrovky dusíkem.

Klíčová slova: cukrovka; odrůdy; chlorofyl; růst cukrovky; chlorofylmetr; změny obsahu chlorofylu; hnojení dusíkem

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The biochemical adaptive strategies for drought-salt resistance of wheat plants

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ABSTRACT

Responses of wheat (*Triticum aestivum*, Giza 164) to various concentrations of NaCl and levels of drought were followed. With the rise of NaCl and drought together, pectin and lignin was retarded in shoot or root systems. Considerable variations in the content of hemicellulose or cellulose were induced by NaCl-drought treatments. Salinity-drought induced a considerable increase in soluble sugars, starch, soluble proteins and proline in shoots or roots of the test plants. Biphasic action of salinity-drought treatments involving activation of free amino acids at shoot system and inhibition at root system. Considerable variations in the content of Na⁺, K⁺, Ca²⁺ or Mg²⁺ were induced by NaCl-drought treatments.

Keywords: amino acids; cellulose; hemicellulose; lignin; pectin; proline; soluble sugars; soluble proteins; starch; Na/K and Ca/Mg

The effects of drought and salinity on plant growth represent two of the most important environmental stresses influencing the productivity of agricultural systems around the world. Transient water deficit is normal and universal experience for crop plants and most have evolved appropriate responses to cope with this stress. When the deficit is prolonged and occurs over large areas of agricultural land, yield losses occur which are a function of the timing and duration of the drought stress (McWilliam 1986).

Wheat (*Triticum aestivum* L.) is a major crop grown in large irrigated areas as well as in rainfed areas. However, with an increasing human population, particularly in developing countries, there is an urgent need for expanding its cultivation from irrigated or relatively high rainfall areas to non-irrigated low rainfall areas.

Thus, the main objective of this study is to investigate the biochemical adaptive strategies for drought-salt resistance of wheat plants that may be cultivated in the desert. The specific objectives are to assess cell wall components, soluble sugar, starch, soluble proteins, proline, other amino acids and mineral composition imposed by different levels of salinity and soil moisture contents in wheat plants.

MATERIAL AND METHODS

Wheat (*Triticum aestivum*, Giza 164) was grown in plastic pots (10 cm in diameter and 13.5 cm high) with clay and sand (2:1). Perforated plastic tubes (1.2 cm in diameter and 15.7 cm long) were inserted into the soil to help the distribution of water and nutrient solution. Five grains were sowed in each pot, the pots were then irrigated and the water content of the soil was adjusted regularly near to the field capacity and the plants were left to grow for 15 days. Thereafter, the pots (four replicate per treatment) were only watered to the desired soil moisture

content and salinity (70% field capacity and subjected to 40, 80, 120 and 160 mM NaCl, 50% field capacity and subjected to 40, 80, 120 and 160 mM NaCl and 30% field capacity and subjected to 40, 80, 120 and 160 mM NaCl). At the end of the experimental period (30 days) cell wall fractionation was conducted essentially according to Dever et al. (1968) and Galbraith and Shields (1981). Tissue powder samples were extracted twice in distilled water, twice in 80% ethanol to remove soluble metabolites. The precipitate was then extracted in 2 ml 0.5 N NaOH for starch, 0.5% ammonium oxalate-oxalic acids (90°C for 24 h) for pectin, 17.5% NaOH for hemicellulose and in 72% H₂SO₄ (with 15 min autoclaving) for cellulose extraction. After that, the remaining precipitate was ascribed to the lignin fraction according to Dever et al. (1968). Content of soluble sugars, starch and wall polysaccharides were determined by the anthrone sulphuric acid reagent using glucose as a standard (Fales 1951), free amino acids were determined according to Moore and Stein (1948), free proline according to Bates et al. (1973) and amount of protein according to Lowry et al. (1951). Sodium and potassium were determined by flame photometer method (Williams and Twine 1960), calcium and magnesium by the versene titration method (Schwarzenbach and Biederman 1948).

The results are the means of four measurements and were statistically evaluated using the standard deviation.

RESULTS AND DISCUSSION

Cell wall structure and properties determine, to a large extent, the magnitude of cell division and elongation, and hence plant growth. Therefore, cell wall components of the studied plants were estimated to evaluate how far they could have been affected by water stress. The accumulation of pectin fraction in wheat shoot and root cells was significantly lowered by combination of salin-

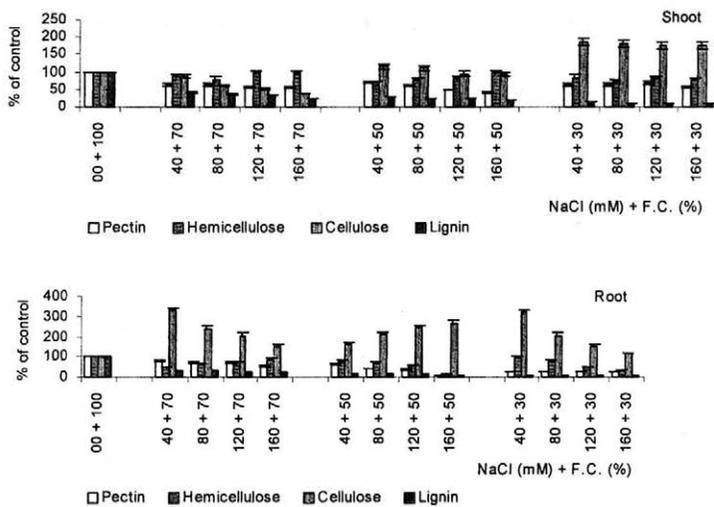


Figure 1. Effect of combination of NaCl (0–160 mM) and soil moisture content (70–30% field capacity) treatments on cell wall components of shoot and root of wheat plants; values in parentheses represent \pm SD

ity and drought stress (Figure 1). Hemicellulose fraction of wheat roots was significantly decreased by the exposure of plants to salinity and drought combination. While in case of wheat shoots, little variation in hemicellulose biosynthesis were obtained at the various investigated salt levels and drought levels. Considerable variations in the accumulation of cellulose were induced by the various levels of salt and drought. In case of 70% field capacity all the investigated salt levels induced an inhibitory effect on the accumulation of cellulose in shoot cells. Moreover, cellulose content in the shoot cells showed a tendency to decrease with the increase of the salt level in the culture medium. In 50% field capacity, there were more or less no appreciable differences in cellulose content in shoot between low (40 mM) and high (160 mM) NaCl levels. In 30% field capacity all NaCl

treatments were of stimulatory effect on the accumulation of cellulose in shoot cells. With respect to cellulose distribution in roots, it could be noticed that in the three drought levels, the various salt levels induced stimulatory effects on cellulose content. The data herein obtained (Figure 1) clearly demonstrate that lignin accumulation in shoots and roots of wheat plants was inhibited by water stress and lignin accumulation decrease gradually with the rise of salt level and decrease of soil moisture content. The possible mechanisms for the inhibitory effect of salinity stress on the incorporation of glucose into cell wall polysaccharides have been discussed (Hassan-Porath and Poljakoff-Mayber 1973). Al-Hakimi (1999) showed that wall components as pectin, cellulose and hemicellulose were drastically altered by drought stress. Also, Van Volkenburgh and Boyer

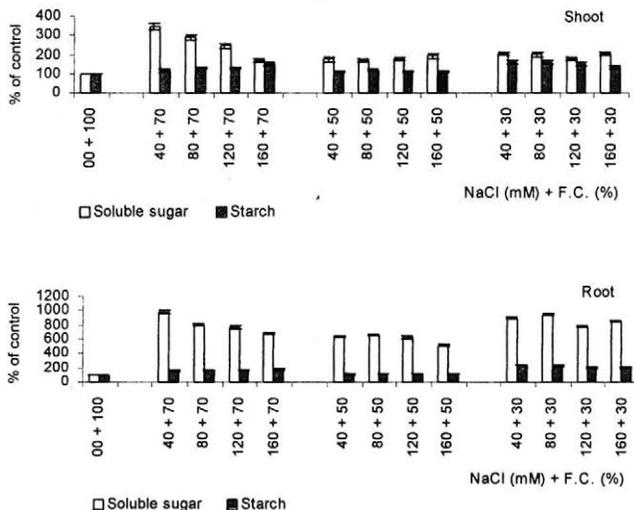


Figure 2. Effect of combination of NaCl (0–160 mM) and soil moisture content (70–30% field capacity) treatments on soluble sugars and starch contents in shoot and root of wheat plants; values in parentheses represent \pm SD

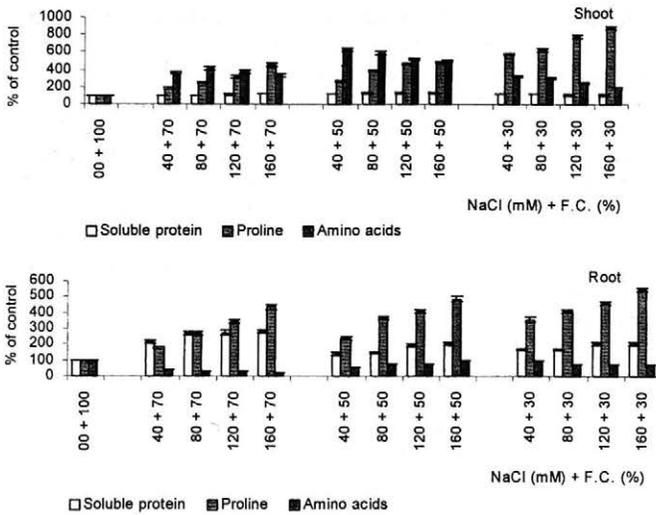


Figure 3. Effect of combination of NaCl (0–160 mM) and soil moisture content (70–30% field capacity) treatments on soluble proteins, proline and other free amino acids contents in shoot and root of wheat plants; values in parentheses represent \pm SD

(1985) found that osmotic stress modifies the biochemical changes taking place in the cell wall during growth and thus preventing their extension.

Further evidence of the role played by NaCl and drought combination as a trigger for a chain of metabolic changes that lead to growth interruption can be obtained from the data presented in Figure 2. The data herein obtained reveal that all the investigated salinization treatments and their interactive effects with drought treatments induced stimulatory effects on the production and accumulation of soluble sugars and starch in shoots and roots of wheat plants (Figure 2).

In the current studies the response of protein (soluble) biosynthesis to salinity and its interaction with drought was investigated (Figure 3). It is clear that most of the investigated salinity levels up to 160 mM with drought

treatment were of stimulatory effect on the production and accumulation of soluble proteins in wheat shoot and root. The activated soluble proteins accumulation induced by salt stress (40–160 mM NaCl) increased progressively with the increase of the salinization level. The data presented here and those obtained by other authors (Ramagopal 1988; Al-Hakimi 1999) on the effect of salt stress or drought stress on carbohydrate and protein biosynthesis clearly demonstrate, that it is somewhat difficult to follow the numerous and gross disturbance in the different facets of cellular metabolism induced by salinity stress or drought stress. The water stressed plants showed marked and various responses at various levels of the salinizing agent or soil moisture contents. The interpretation of these responses and the factors that determine their pattern and magnitude are of impor-

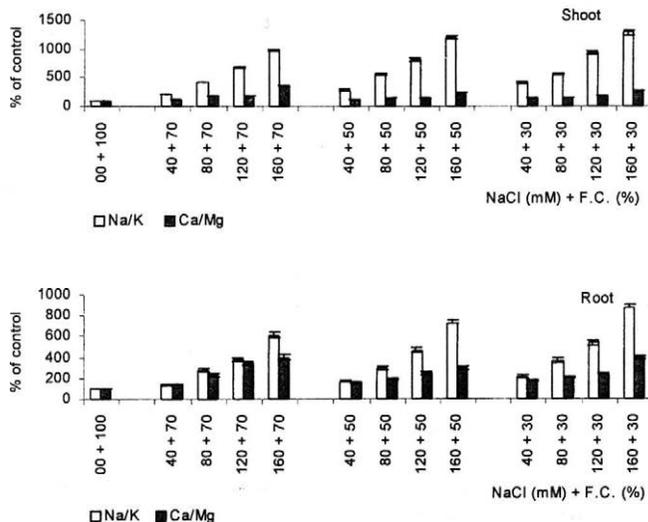


Figure 4. Effect of combination of NaCl (0–160 mM) and soil moisture content (70–30% field capacity) treatments on Na⁺/K⁺ and Ca²⁺/Mg²⁺ contents in shoot and root of wheat plants; values in parentheses represent \pm SD

tance in determining the mechanism controlling the salt or drought resistance plants. The notable sensitivity in the biosynthesis of carbohydrate and protein fractions in the different organs of the test plants, which was displayed in the presence of various salinization levels and soil moisture contents, may be taken as a further evidence of the role played by water stress in modifying the functional state at the sites of synthesis. Such modifications may contribute directly or indirectly to the enhancement or impairment of the functional state at the sites of synthesis, reflected in increased production. These results are in agreement with the results obtained by other authors (Venekamp et al. 1989; Hamada and Khulaf 1995). The increase in soluble components may play an important role in osmotic adjustment; a conclusion which is in accordance with the results obtained by Flowers et al. (1977) working with halophytic plants and Drossopoulos et al. (1987) working with glycophytic plants.

Also, the role played by NaCl and drought in modifying some other facets of metabolism to withstand water stress can be obtained from the data presented in this investigation on proline and other free amino acids accumulation in water stressed wheat plants (Figure 3). It appeared from wheat plants responses that, in the range studied, the increase in NaCl supply also drought levels generally had a significant stimulatory effect on the accumulation of proline in the different organs of the test plants. The highest proline concentration in shoots or roots of the test plants was consistently found in plants grown in the highest NaCl with low moisture content cultures.

The biphasic action of NaCl and drought treatments involving activation of free amino acids at shoot system and inhibition at root system. This biphasic action, involving stimulation of free amino acids accumulation in one organ (root) and inhibition in the other (shoot), clearly demonstrate the capability of NaCl and drought stress in playing a role in amino acids mobilization and organ adaptation mechanisms.

Proline accumulation is a well-known response to water deficit, it also occurs with salt stress and has a protective effect on seed germination in saline media (Bar-Nun and Poljakoff-Mayber 1977). Proline leads to the maintenance of membrane integrity (Van Rensburg et al. 1993). It has been reported that proline can protect pyruvate phosphate dikinase from maize against stress (Krall et al. 1989). It has been shown that plant membrane damage is related to the peroxidation of membrane lipid due to the stress-induced accumulation of free radicals (Van Rensburg and Krüger 1994). The major function of proline seems to be the protection of the cytoplasm against short-term (e.g. diurnal) fluctuations in leaf water potential. However, other cytosolutes, including sugar and sugar alcohol, probably provide greater protection against long-term effect imposed by high salt concentrations in the vacuoles (Bolarin et al. 1995).

Accumulation of compatible, low-molecular-weight osmolytes, such as sugar alcohol, special amino acids and glycine betaine, has been suggested as a major mechanism that may counteract salt stresses (Yancey et al. 1982).

Recently, several studies have demonstrated that genetic manipulation of the accumulation of low molecular-weight osmolytes resulted in increased tolerance to water or salt stress in transgenic plants (Saneoka et al. 1995).

In addition to metabolic changes and accumulation of low-molecular-weight protective compounds, a large set of plant genes is transcriptionally activated, which leads to accumulation of new proteins in vegetative tissue of plants under osmotic stress conditions (Xu et al. 1996). It is generally assumed that stress-induced proteins might play a role in tolerance, but direct evidence is still lacking, and the functions of many stress-responsive genes are unknown. It has been hypothesized, based on the correlation of late embryogenesis abundants (LEA) gene expression with physiological and environmental stresses and the prediction novel structure of the LEA proteins, that LEA protein may play a protective role in plant cells under various stress conditions. Moreover, this protective role may be essential for the survival of the plant under extreme stress conditions (Chandler and Robertson 1994).

Ionic balance and distribution of the studied plants exhibited variable changes in response to the imposed salinity-drought-stress (Figure 4). Variations in the concentration of Na⁺, K⁺, Ca²⁺ and Mg²⁺ in shoots and roots of test plants due to increased salinity-drought levels were generally accompanied by reciprocal variations in the concentration of other mono (Na⁺) and divalent (Ca²⁺) cations, i.e. Na⁺/K⁺ and Ca²⁺/Mg²⁺ ratios increase along with NaCl-drought level; a trend which is in accordance with some of the results of Garcia-Reina et al. (1988) and Torres-Schumann et al. (1989) using other plant tissues. Serrano and Gaxiola (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 1984) or affecting membrane stability causing leakage of K⁺ (Wadat et al. 1991). The alterations in distribution and accumulation of mono- and divalent cations in the different organs of salt stressed plants may be an indication of the role of these cations in regulating the physiological activities of these plants (Benzioni et al. 1992).

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ABSTRAKT

Biochemická adaptační strategie při rezistenci rostlin pšenice vůči přísušku a zasolení půdy

Sledovali jsme reakci pšenice (*Triticum aestivum*, Giza 164) na různé koncentrace NaCl a na různou intenzitu přísušku. Se zvyšováním koncentrace NaCl i přísušku se zpomalovala tvorba pektinů a ligninu v nadzemních částech rostlin i v kořenovém systému. Varianty koncentrace NaCl a přísušku navodily značné kolísání obsahu hemicelulózy nebo celulózy. Zasolení

půdy a přísušek vedly ke značnému zvýšení obsahu rozpustných cukrů, škrobu, rozpustných bílkovin a prolinu v nadzemních částech i v kořenech testovaných rostlin. Dvoufázové působení variant zasolení a přísušku způsobilo aktivaci volných aminokyselin v nadzemních částech rostlin a jejich inhibici v kořenovém systému. Varianty koncentrací NaCl a přísušku navodily značné kolísání obsahu Na⁺, K⁺, Ca²⁺ nebo Mg²⁺.

Klíčová slova: aminokyseliny; celulóza; hemicelulóza; lignin; pektin; prolin; rozpustné cukry; rozpustné bílkoviny; škrob; Na/K a Ca/Mg

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Estimation of winter wheat nitrogen stress using the CERES crop model

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ABSTRACT

Deterministic crop growth CERES-Wheat model was used to estimate the relation between the nitrogen stress and grain yield of winter wheat (Samanta variety). Climatological, pedological, physiological and management data measured during three year experiment (1996–1999) form the database which was used for calibration of the crop model. Its evaluation was done by grain yield, length of growing season and total amount of nitrogen in biomass. The nitrogen stress for five growth stages was modelled for two treatments differing in the previous growth crop (treatment A with spring barley, treatment B with alfalfa). These stress values were correlated with index of production (yield) potential Z, which is computed as a ratio between potential and stressed (nutrient and water limited) yield. Its lowest value reached 72.3% in 1997–1998 (treatment A), the highest value was 93.4% in 1998–1999 (treatment B). Their statistic response (the coefficients of determinance varied between 0.6007 to 0.9686) describes the size of nitrogen stress in respect to grain yield. The dividing of growth period to five stages enables to estimate the time of nitrogen stress occurrence.

Keywords: winter wheat; growth model; nitrogen stress; production potential

Simulation models of agricultural systems have a great potential for increasing the quality of agricultural research and development, when coupled with appropriate data sources. Within the agricultural disciplines, crop production involves a complexity of interactions between the crop genotype, the soil, the atmosphere and the management practices. One of the crucial production moments in the cereal growth and development is management of nitrogen fertilization. In modern agriculture systems nitrogen has to be applied frequently and in amounts which fit the crops demand as close as possible (Harre and White 1985). It is also the most limiting yield factor in many cases.

Many field trials have been done to optimize nitrogen or water supply in the conditions of sustainable agriculture. To save time and experimental costs, the crop growth models are used in various cases and studies. The most useful simulations are those concerning estimation of the nitrogen stress (Frissel and van Veen 1980) and nitrogen supplement distribution (Groot and van Keulen 1990). Knowledge of how much and when to apply nitrogen is essential not only because the nitrogen inputs are expensive, but also because they can be threat to the environment, if too much of nitrogen is applied.

Considerable research has been done on the various components of crop production and some of their interactions. Crop models are also used to evaluate nitrogen uptake and nitrogen leaching from soil. Some of these information are being used in models designed for specific questions, such as limits of crop growth by the water or nitrogen stress.

The crop models contained within the Decision Support System for Agrotechnology Transfer (DSSAT) Hoo-

genboom et al. (1994), which is used as a tool in this paper, attempt to meet these criteria and are designed for a wide applicability. The DSSAT models have common nitrogen balance and water balance routines and include crop growth and development routines that are specific to each crop.

It must be stressed at the beginning that simulation models are not usable as a substitute for standard testing and monitoring of the nitrogen behavior in soils and plants. Rather they provide a tool to extend the value of such measurements and to explain possible discrepancies in field trials.

One of the tasks of the project *Optimization of cereal crop nutrition for sustainable cropping systems* was to describe nitrogen stress during three growing seasons. Two treatments which differed in previous grown crop (spring barley = treatment A and alfalfa = treatment B) were analyzed during 1996–1999.

MATERIAL AND METHODS

Model description

The CERES-Models have been used for water and nitrogen stress evaluation. CERES-Wheat (Ritchie and Otter 1985) is running under DSSAT computer surroundings. The CERES (Crop Environment Resource Synthesis) model is a dynamic, specific, explanatory, deterministic, non ultimate model designed to simulate crop growth, soil, water, temperature and soil nitrogen dynamics at field scale for growing seasons in daily step.

More details and examples of the CERES-Wheat model use can be found, e.g. in Dhakhwa et al. (1997), Mearns et al. (1992, 1996, 1997) and Cuculeanu et al. (1999).

The CERES-Wheat model simulates most important processes, associated with both crop nitrogen demand and plant available nitrogen. It also simulates the availability of nitrogen from different N fertilizers as well as the decomposition of plant residue containing nitrogen. The capability to simulate the complex interactions of these major processes makes also possible to estimate the efficiency of different nitrogen sources and management practices.

The aim of the paper is to use the CERES-Wheat model for estimation of the nitrogen stress and its influences on the grain yield of winter wheat during various phenological stages.

Weather, pedological and management data

Observed weather data (daily series of *SRAD* – sum of global solar radiation, *TMAX* – maximum and *TMIN* – minimum air temperatures, and *RAIN* – precipitation amount), required for the crop model simulations were measured in Kroměříž climatological station, located approximately in 0.5 km distance from the experimental field.

The experimental field is located in the middle part of the Moravia region of the Czech Republic. Climatological (at the climatological station), pedological (taken by the soil pit), agrotechnological and plant parameters were measured at the experimental station of the Agricultural Research Institute Kroměříž, Ltd. (altitude 49°18' N, longitude 17°23' E and elevation 236 m above the sea level).

The experimental fields of the Institute are located in a southern part of the Hornomoravský (Upper-Moravian) Vale which is formed by neogene and quaternary sediments, among which minerals of the Czech massive arise as small enclaves. The soil type is Luvi-haplic Chernozem with the profile: Amp: 0–31 cm, Am (Bt): 32–68 cm, Cc: less under 68 cm.

The planting details, management factors and fertilization regime were set individually for each year. One dose of nitrogen fertilization was applied (the total amount of N was 40 kg ha⁻¹ only) before sowing. Details on the previous grown crop, residue, tillage, rotation and chemical application are discussed in the interim report Střalková et al. (1999) of NAZV (National Agency for Agriculture Research) project. No irrigation was applied.

Evaluation of crop models

The first condition in order to use crop model is its evaluation. Evaluation includes checking internal consistency and units used in a computer program, comparison of the model output with an independent data set of real world observations, uncertainty analysis, and judgement of utility.

The grain yield, period between planting and physiological maturity, total biomass, harvest index and leaf area

index are often used for model evaluation (Bacsi and Hunkár 1994; Iglesias 1995; Šťastná 1998; Alexandrov and Hoogenboom 1999; Žalud 1999). The grain yields and length of the growing periods, simulated by the crop growth model with use of measured pedological, physiological, cultivation and meteorological data were compared with observed grain yields in Table 1. The winter wheat variety Samanta was used.

Description of the nitrogen module

Nitrogen dynamics in the model include mineralization and/or immobilization of nitrogen associated with the decay of crop residues, nitrification, denitrification, urea hydrolysis, leaching of nitrate, and the uptake and use of nitrogen by the crop (Godwin et al. 1984). The nitrogen module uses the layered soil-water balance model described by Ritchie and Otter (1985) and the soil temperature component of the EPIC model (Williams et al. 1984).

The nitrogen module itself requires input data that describes the initial amount of mineral nitrogen in the soil profile and information that enables the estimation of how much nitrogen will be mineralized from soil organic matter, the potassium sulfate, extractable nitrate (NO₃⁻) and ammonium (NH₄⁺) in each of the layers. The soil bulk density is used in the calculation of nitrogen concentration from mass units. In the model, different horizontal layers in the root zone are distinguished, each with its own nitrogen concentration. The basic assumption of the uptake model is that the uptake rate is regulated by demand as long as the transport rate of nitrogen from bulk soil to the root surface exceeds the required rate given by plant demand.

The input data are completed by data specifying the dates, amounts and types of the used nitrogen and others fertilizer. The depths and degree of incorporation are also required inputs.

The nitrogen formulation in CERES-Wheat has also been tested in diverse environments (e.g. Kovacs et al. 1995; Semenov et al. 1996).

Relation of the nitrogen stress and grain yield

The CERES-Model estimates the nitrogen stress for five periods of crop development as described in Table 2. The 0–1 scale proposed by model developers was taken into account for the stress description. These values were correlated for each period using the index of the yield potential, computed by equation 1 to find out the significance of the relation between the nitrogen stress and grain yield for every stage. The value of the index *Z* (%) is defined as a ratio of the stressed (*Y_s*) and potential (*Y_p*) yields under given weather, pedological and management conditions:

$$Z(w, p, m) = Y_s(w, p, m) / Y_p(w, p, m) \cdot 100 \quad (1)$$

Table 1. Evaluation of the CERES-Wheat model by the yield and length of the growing period; the simulated potential yield is added

Year	Evaluation parameter	A (winter wheat after spring barley)			B (winter wheat after alfalfa)		
		observed	simulated		observed	simulated	
			real	potential		real	potential
1996/1997	yield (t.ha ⁻¹)	6.09	5.77	8.0	7.27	6.36	8.0
	growing period (day)	293	298		299	298	
1997/1998	yield (t.ha ⁻¹)	4.27	4.50	5.8	5.50	5.35	5.9
	growing period (day)	289	277		293	276	
1998/1999	yield (t.ha ⁻¹)	6.31	6.62	7.3	5.63	6.78	7.3
	growing period (day)	281	266		283	265	

This index may serve as a measure of the impacts of limiting factors on the grain yields. The value of *Z* is always greater than 0% and lower than 100%. The zero value of *Z* would mean that the stress totally inhibits the growth, *Z* = 100% would mean that no stress affects the yields.

RESULTS AND DISCUSSION

The first condition for a model use is its evaluation, as it was already mentioned above. The successful evaluation is a result of model calibration and parametrization. All necessary input data were measured or taken from literature (some special physiological data). Table 1 gives an example of CERES-Wheat evaluation for two treatments differing in the previous grown crop. The yield and length of the growing seasons were chosen as evaluation parameters.

The probability, of the differences between the predicted and observed yield are not more than 15%, should be at least 80% (Hunkár 1994) for most practical applications. The largest grain yield difference is overestimation by 17% in 1998/1999 (treatment B – wheat after alfalfa) in our case. The index of the production (yield) potential was computed as a ratio between the potential and stressed simulated yield and is presented in Table 2. The potential yield is defined as the total dry grain production of crops if the canopy is optimally supplied with water and all essential nutrient elements, and grows without interference from the weeds, the pests and the diseases, limiting factors such as temperature, radiation and crop genetic potential. The stressed (water and nutrient limited) yield is the crop yield obtained under real environmental conditions. In this case the yield reduction is caused by limiting factors such as e.g. water, nitrogen or other nutrients.

The best utilization of all factors influencing winter wheat growth and development was observed in the growing season 1998/1999. On the other hand, the various stress effects decreased the index of production potential by 27.7% in treatment A (wheat after spring barley) in 1996/1997.

As it was expected, the nitrogen stress is lower in wheat after alfalfa comparing the treatments in the same year. The highest simulated stress occurs regularly before the be-

ginning of the ear growth. In accordance to the results from Tables 2 and 3, the highest stress was reached in treatments when the lowest *Z* value was detected. Another model analysis as comparisons of leaching or testing nitrogen uptake confirm that the best utilization of nitrogen fertilization was in 1999 (Žalud and Stralková 1999).

In Figure 1 the relation between the nitrogen stress occurrence in development stage 1 (Zadocks 10–30) and the index of production potential *Z* (%) is analyzed. Correlation is done by six values (three years trial with two treatments). Occurrence of the nitrogen stress and its relation to index of production potential is shown in Figures 2–5 for other development stages described in Table 3 and again in Table 5. High values of the coefficient of determination (the lowest 0.6007 in stage 3, the highest 0.9686 in stage 2) could indicate the good ability for the nitrogen stress assessment by the crop models for all tested periods.

Evaluation of measured and simulated nitrogen amount for some phenological stages is presented in Table 4. The standard values vary in wide range depending on a test-

Table 2. Index of production potential *Z* (%) for three year experiment and two treatments (A and B) of winter wheat

Year	A	B
1996/1997	72.3	79.6
1997/1998	76.9	91.0
1998/1999	91.3	93.4

Table 3. Description of the winter wheat nitrogen stress; the value 0 means the lowest stress, number 1 is the highest stress

Stage DC	1996/1997		1997/1998		1998/1999	
	A	B	A	B	A	B
1 10–29	0.028	0.021	0.046	0.009	0.001	0.001
2 30–49	0.776	0.706	0.773	0.509	0.538	0.494
3 51–59	0.712	0.653	0.618	0.364	0.559	0.541
4 61–69	0.352	0.246	0.345	0.058	0.116	0.102
5 71–90	0.074	0.072	0.058	0.010	0.024	0.020

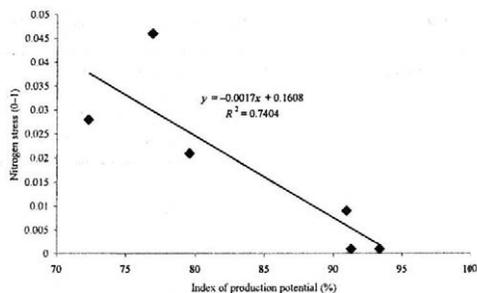


Figure 1. Relation between the nitrogen stress occurrence in stage 1 (emergence – term spikelets) and the index of production potential Z (%)

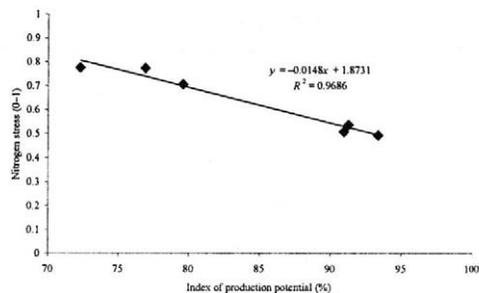


Figure 2. Relation between the nitrogen stress occurrence in stage 2 (end of vegetation – beginning of ear growth) and the index of production potential Z (%)

ed variety. The measured and simulated data are compared with standard data, published by Baier et al. (1988). The model mostly underestimated the nitrogen amount (overestimated the nitrogen stress) with exception of the beginning of 1999. This is in agreement with the results, shown in Table 1 when in 1996/1997 and 1997/1998 the simulated yield is lower than the observed yield (with an exception of the 1997/1998 treatment – winter wheat after spring barley).

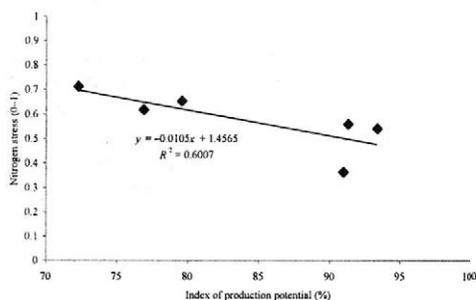


Figure 3. Relation between the nitrogen stress occurrence in stage 3 (beginning of ear growth – end of ear growth) and the index of production potential Z (%)

The nitrogen balance and stress is often coupled with the water balance and stress (Šřastná and Žalud 1999). To get a completely overview how the growth was stressed, the water values are added (Table 5), in which the water stress was described in the same way as by the nitrogen stress assessment. It seems that available water and the water stress was not crucial factor, which could limit yield. The detailed analysis of meteorological conditions (air temperature sums, lengths of the growing seasons, amount and distribution of precipitation, occurrence of dry spells and hot waves) is discussed in Střalková et al. (1999). The same report describes soil and plant contents of another nutrients as phosphorus, potassium and magnesium which, comparing with Baier et al. (1988), seem not to be limiting factors for yield formation.

CONCLUSIONS

The soil nitrogen and water content are mostly limiting growth factors in the studied region. A field experiment (winter wheat, two treatments differing in the previous grown crop) was carried out to optimize the nutrient technology of the winter wheat crop in conditions of sustainable agriculture. The evaluated crop model CERES-Wheat

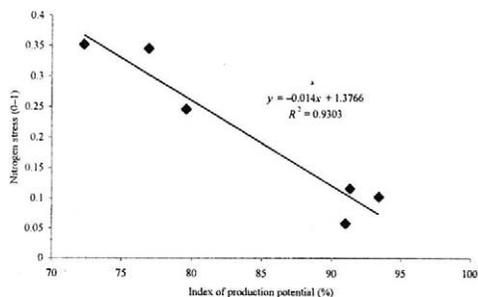


Figure 4. Relation between the nitrogen stress occurrence in stage 4 (end of ear growth – beginning of grain filling) and the index of production potential Z (%)

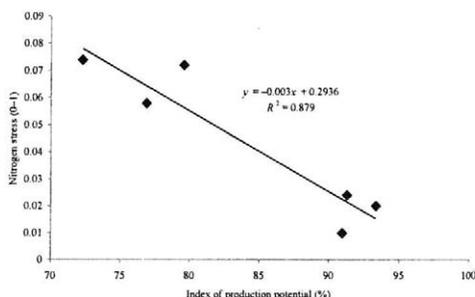


Figure 5. Relation between the nitrogen stress occurrence in stage 5 (linear grain filling phase) and the index of production potential Z (%)

Table 4. Comparison between the standard nitrogen amount (Baier et al. 1988), measured nitrogen by the Kjeldahl method and simulated nitrogen by the CERES-Wheat model during selected phenological stages

	DC	Treatment A nitrogen (%)			Treatment B nitrogen (%)				
		Julian day	standard	measured	simulated	Julian day	standard	measured	simulated
1996/1997	30	118		4.03	3.7	118		4.34	3.98
	31		2.49-4.92				2.49-4.92		
	33								
	50	146		1.93	1.8	147		3.39	3.1
	60	156	1.14-2.70	1.31	1.21	157	1.14-2.70	1.63	1.48
	70	175		1.05	0.97	177		1.01	0.75
	73	185		0.90	0.72	187		1.01	0.65
	83	195		0.94	0.69	197		1.02	0.63
	91	207	1.29-1.45	0.97	0.65	211	1.29-1.45	0.95	0.6
1997/1998	30	92		4.23	4.27	92		4.54	4.57
	31	102	2.49-4.92	5.01	4.40	102	2.49-4.92	4.40	4.00
	33	118		4.23	3.08	118		3.99	3.41
	50	138		2.80	2.44	138		2.84	2.19
	60	147	1.14-2.70	2.12	1.7	147	1.14-2.70	1.95	1.81
	70	159		1.36	1.11	159		1.36	1.22
	73	166		1.06	0.97	166		1.16	1.02
	83	187		1.06	0.87	187		1.20	0.9
	91	198	1.29-1.45	1.09	0.8	200	1.29-1.45	1.30	0.9
1998/1999	30	100				100			
	31	109	2.49-4.92	3.61	3.7	109	2.49-4.92	3.67	4.00
	33	119		3.50	3.41	119		3.30	3.42
	50	146		1.68	1.68	144		1.85	1.75
	60	151	1.14-2.70			151	1.14-2.70		
	70	159		1.30	1.22	159		1.29	1.1
	73	166				166			
	83	186		1.23	0.95	186		1.40	0.90
	91	197	1.29-1.45	1.09	0.65	197	1.29-1.45	1.16	0.69

was used as a tool for nitrogen stress estimations, related to its time of occurrence. The five phenological stages, originally recommended by the model developers were used to divide the growing season. Statistically significant relations were established for each of the five studied periods between the level of nitrogen stress (number between 0 = minimal stress and 1 = maximal stress) and

the Z value in % (the index of production potential computed as a ratio between the stressed and potential yield), which was estimated for every treatment. The real (Kjeldahl method) and modelled (simulated) nitrogen values are compared to estimate model performance in respect to the nitrogen stress simulation. The comparison with standard data are shown. The importance of the nitrogen stress as a yield limiting factor is emphasized by the results. There were only few insignificant water stress records during the experiment conductance (Table 5).

Table 5. Simulated water stress of winter wheat grown in the studied vegetative seasons; the stress factors during growing season are presented similar like in Table 3; the value 0 means the lowest stress, number 1 is the highest stress

Stage DC	1996/1997		1997/1998		1998/1999	
	A	B	A	B	A	B
1 10-29	0	0	0	0	0	0
2 30-49	0	0	0	0	0	0
3 51-59	0	0	0.085	0.071	0	0
4 61-69	0.025	0.022	0	0	0	0
5 71-90	0.034	0.031	0.046	0.045	0	0

The following idea will be taken into account concerning a future work: the crop models can estimate the optimal split of the available total nitrogen during the real growing season. The sensitivity analysis will be used as a tool for optimization of the partitioning the nitrogen fertilization for basic (September), production (February-March), and regeneration (April) fertilization.

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ABSTRAKT

Stanovení dusíkového stresu u ozimé pšenice růstovým modelem CERES

Deterministický dynamický růstový model CERES-Wheat byl použit k popisu vazby mezi úrovní dusíkového stresu a výnosem ozimé pšenice (odrůda Samanta). Klimatická, pedologická, fyziologická a agrotechnologická databáze tříletého experimentu (1996–1999) Zemědělského výzkumného ústavu Kroměříž, s. r. o., byla podkladem pro kalibraci modelu. Evaluace byla založena na výnosu, době vegetace a množství celkového dusíku v rostlině. Pro obě varianty lišící se v předplodině (varianta A = jarní ječmen, varianta B = vojtěška) byl modelován dusíkový stres pro pět růstových fází. Jejich hodnoty byly vztaženy k hodnotě indexu produkčního (výnosového) potenciálu Z, který je definován jako poměr mezi potenciálním a stresovaným (vodou a živinami limitovaným) výnosem. Nejnižší číselná hodnota Z = 72,3 % byla dosažena v roce

1997/1998 (varianta A), nejvyšší hodnota indexu $Z = 93,4\%$ byla dosažena v roce 1998/1999 (varianta B). Jejich statistická závislost (koeficienty determinace $r^2 = 0,6007-0,9686$) popisuje vazby mezi velikostí dusíkového stresu a výnosem a současně umožňuje určit význam časového vymezení velikosti dusíkového stresu ve vztahu k výnosu.

Klíčová slova: ozimá pšenice; růstový model, dusíkový stres, produkční potenciál

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Comparative study of water balance on the experimental catchments Všeminka and Dřevnice

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ABSTRACT

The paper deals with the computation of water balance of the 1997 growing season (April–October) on two small Moravian catchments Všeminka and Dřevnice both with different forested catchment areas (Všeminka 48%, Dřevnice 81%). It provides results using the WBCM-5 model reconstruction in the major water balance components and it also provides information on water storages in both unsaturated and saturated zones and the interactions between them. It reliably tests the capability of the model to reconstruct rainfall-runoff regimes in the period examined. The results have shown that on the Dřevnice catchment although much more forested than Všeminka, the total runoff in July 1997 was 65% higher there when the rainfall was only 30% higher. This event focuses on assumptions that a rainfall depth and its intensity is of greater importance than land use in a flood consideration. Further, the paper provides results of water balance components after implementing the scenario, which simulates 50% deforestation of the catchments. Changes on total runoff, direct runoff, interception and subsurface water storage have been computed. Under 50% deforestation, the direct runoff is 22–35% higher, summary interception is 38% lower (on both catchments) and subsurface water storages have been not significantly lowered as the flood year of 1997 was rich in rainfall depth. A conclusion can be made that the WBCM-5 model is an adequate tool for catchment water balance simulation both in real and scenario situations.

Keywords: water balance model; scenario simulation; rainfall-runoff processes; interception; evapotranspiration; surface water recharge and storage; retention and accumulation of runoff

Water regimes of a catchment can be well quantified by the analysis of water balance components with particular reference to direct runoff and subsurface water recharge. Also a role of land use on water balance is a matter of high importance in water resources management and flood control.

A case study based on water balance computation has been carried out using data of two small forested catchments Všeminka and the upper part of the Dřevnice catchment (district Zlín) flowing together as the left-side tributary of the Morava river (Figure 1). Both catchments are of the fourth order and while the Dřevnice catchment is more than 80% forested the Všeminka catchment is a typical example of an agri-forest territory with a degree of for-

estation less than 50%. The aim of this study in a broader sense is the effect of land use including forest diversity and structure on water retention and accumulation capacities in a catchment. The WBCM-5 water balance model has been used as a tool for such an analysis which respects areal variability of its parameters and can be implemented using GIS facilities. Partial aims of this study were:

- assessment of physiographic and land use characteristics of the catchments and determination of the model parameters
- reconstruction of areal water balance situation in the characteristic 1997 model year
- simulation of scenario situations reflecting the change of land use
- comparison of water balance components of both experimental catchments in real and scenario situations

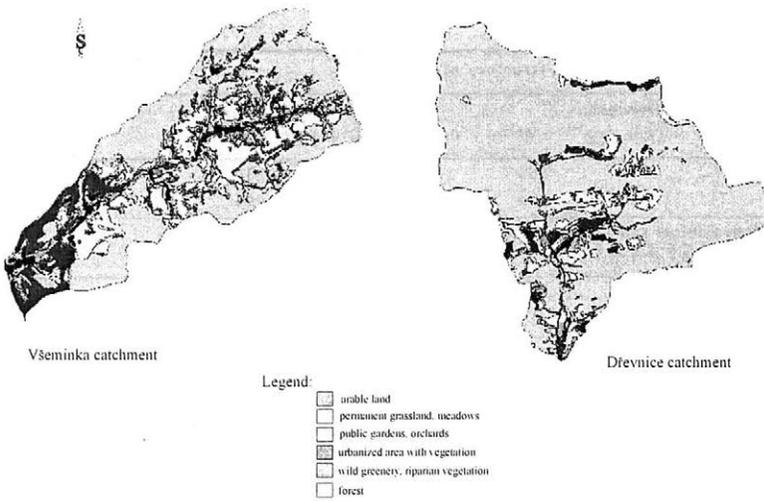
MATERIAL AND METHODS

Experimental catchments

Both experimental catchments cover almost the same area. The shape of the Všeminka catchment is longitudinal, the upper sides of the central valley are forested down from the water divide, land use on the other parts is diversified. The Dřevnice catchment is fan-shaped, highly forested and only its lower part has a more structured land



Figure 1. Situation of the experimental catchments



use which for both catchments is given in Figure 2. The physiographic characteristics of the catchments are given in Table 1 and the species and age structure of the forest, as well as the hydrological soil groups are presented in Table 2. These groups have been selected according to the methods widely used (U.S. SCS 1986).

Model

The WBCM model (version 5) that was implemented with the aim of quantifying the water balance on the Všeminka catchment is a lumped model with probability parameter distribution over the area. It is based on the integrated storage approach. Each storage element rep-

resents the natural storages of interception, soil surface, root (or active) zone, and the whole unsaturated zone and groundwater zone (if the latter is not very deep). The model with a daily step takes into consideration the storage of individual zones, and treats their daily values, including input and output rates, in line with physical regularities as reflected by the system of recurrent final difference and algebraic equations balancing the following processes (Kovář 1981, 1994, 1998):

- potential evapotranspiration, interception and through-fall
- surface runoff recharge
- active soil moisture zone dynamics
- soil moisture content and actual evapotranspiration
- ground water dynamics, base flow, total flow

Table 1. Basic physiographical characteristics of the catchments

Catchment characteristics		Všeminka	Dřevnice		
Catchment area	(km ²)	21.51	22.58		
Length of river	(km)	9.2	9.1		
Average river slope	(%)	3.6	3.5		
Average catchment slope	(%)	19.4	23		
Minimum catchment altitude	(m a.s.l.)	270	335		
Maximum catchment altitude	(m a.s.l.)	620	750		
Average catchment altitude	(m a.s.l.)	400	495		
Forestation	(%)	48.2	81		
Catchment perimeter	(km)	23.64	24.45		
Length of riparian vegetation	(km)	13.81	7.47		
Land use		Všeminka		Dřevnice	
	ha	%	ha	%	
1. Arable land	201	9.3	62	2.7	
2. Permanent grassland, meadows	521	24.2	203	9.0	
3. Public gardens, orchards	117	5.5	65	2.9	
4. Urbanized area with vegetation	91	4.3	18	0.8	
5. Wild greenery, riparian vegetation	182	8.5	82	3.6	
6. Forest	1036	48.2	1829	81.0	

Table 2. Species and age structure of forest; hydrological soil groups

Species and age structure of forest (ha)								
Age (years)	Všeminka			Dřevnice				
	0–10	10–40	> 40	0–10	10–40	> 40		
Coniferous forest	77	75	565	137	220	838		
Deciduous forest	7	27	295	52	107	496		
Class of slope	Hydrological soil groups (ha) and catchments slopes (%)							
	catchment slope		hydrological soil group					
			Všeminka					
	(%)	(°)	A	B	C	D		
I.	0–1	0–1	–	–	–	–		
II.	1–5	1–3	–	–	–	–		
III.	5–10	3–6	2	22	–	–		
IV.	10–20	6–11	1	127	50	–		
V.	> 20	> 11	–	884	5	–		
			Dřevnice					
	(%)	(°)	A	B	C	D		
I.	0–1	0–1	–	–	–	–		
II.	1–5	1–3	–	–	–	–		
III.	5–10	3–6	1	7	–	–		
IV.	10–20	6–11	3	363	–	–		
V.	> 20	> 11	60	1388	28	–		
Hydrological soil groups and land use (ha)								
Land use	Všeminka				Dřevnice			
	A	B	C	D	A	B	C	D
I. Arable land	–	53	47	92	5	22	12	21
II. Permanent grassland	–	46	241	192	4	53	79	45
III. Parks, gardens	–	4	66	42	2	14	30	14
IV. Urbanised area	–	1	30	58	4	5	4	4
V. Wild greenery	–	5	81	50	4	20	21	11

The individual parameters of WBCM-5 have the following physical meanings (the optimised parameters are bold): *AREA* – catchment area (km²)

FC – parameter characterising the average value of the field capacity of the active zone (–)

POR – parameter characterising the average value of soil porosity of the active zone

DROT – depth of active zone (mm)

WIC – upper limit of interception capacity (mm)

SMAX – parameter representing maximum capacity of unsaturated zone (mm)

ALPHA – parameter expressing non-linear filling procedure of unsaturated zone (–)

CN – runoff curve number (–)

P1, *P2*, *P7* – parameters affecting unsaturated zone dynamics (filling and exhausting processes) (–)

GWM – parameter expressing capacity of the active part of the ground water zone (mm)

BK – linear transformation parameter of base flow process (days)

The modified Monteith-Penman method, as well as the Priestley-Taylor method, or alternatively the Hamon method were used for daily values of **potential evapo-**

transpiration computation. The selection of one of these methods depends on input data availability. The model unit that computes **actual interception** and **throughfall** is based on the simulation of irregular distribution of local interception capacities around their mean value, *WIC*. These capacities oscillate between zero (bare soil) and a multiple of *WIC*. To avoid an abrupt threshold concept, a linear distribution around the *WIC*-value was accepted.

For quantifying **direct runoff recharge**, the US Soil Conservation Service (SCS) method based on curve number (*CN*) assessment was used. The standard procedure for the initial *CN* value was accepted, and the daily storages of the active zone SS were computed by this procedure. The **recharge of active (root)** and thus of all **unsaturated zones** depends greatly on the previous soil moisture content, and is controlled by the *FC* parameter. The evaluation procedure is based on the assumption that the distribution of local *FC*-values around their average is non-linear (parameters *P1*, *P2*, *P7*, *ALPHA*). Only where *FC* has not yet been reached, the recharge can replenish these zones (one by one) up to the *FC*-limiting value. The one-dimensional Richards equation is used in the finite difference form.

Table 3. The WBCM-5 parameters

Parameter value		Všeminka	Dřevnice
Non-optimised	POR (-)	0.45–0.50	0.44–0.48
	FC (-)	0.40–0.42	0.40–0.43
	DROT (mm)	300.0	300.0
	CN (-)	<62, 92>	<68, 94>
	WIC (mm)	2.0	2.2
	ALPHA, P1, P2, P7 (-)	1.0, 0.1, 0.2, 0.7	1.0, 0.1, 0.2, 0.7
Optimised	SMAX (mm)	582.0	600.0
	GWM (mm)	1100.0	1000.0
	BK (day)	8.5	10.0

The BK parameter values well correspond with those derived through catchment depletion curves analysis

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K(\theta) \left(\frac{\partial H}{\partial z} - 1 \right) \right] \quad (1)$$

in finite difference form:

$$\theta_{i+1,n} = \theta_{i,n} + \frac{q_{i,n-1} - q_{i,n}}{\Delta z} - \frac{AE_{i,n}}{\Delta z} \quad (2)$$

$$q_{i+1,n} = K(\theta)_{i,n+1/2} \cdot \left(\frac{H_{i,n+1} - H_{i,n}}{\Delta z} + 1 \right) \quad (3)$$

where: θ – soil moisture content (-)

H – pressure head (m)

t – time (s)

z – depth of saturation (m)

$K(\theta)$ – unsaturated hydraulic conductivity (m.s^{-1})

q – inflow to soil layer (m.s^{-1})

AE – actual evapotranspiration (m.s^{-1})

Simultaneously, exhaustion from this zone by evapotranspiration was computed. In order to simulate this procedure, an approach was applied which takes into account the proportion between actual and potential evapotranspiration according to the soil moisture content and according to the particular physical properties of the soil.

The saturated zone is filled with **groundwater recharge** and depleted through **base flow**. This is simulated only within the framework of short-term groundwater participation in the water balance. The Williams and La Seur

(1976) method was applied here. In cases where possible control of model efficiency can be achieved either through runoff or through groundwater table fluctuations, automatic optimisation is applied. The *SMAX*, *GWM* and *BK* parameters were optimised by minimising the sum of least squared differences between the computed and observed 10-day runoff depths on the experimental gauged catchments.

Thus, the water balance equation controls the volumes of the main components of the water balance:

$$SRAIN = AE + STF + (\Delta WP + \Delta WZ) = AE + STF + \Delta W \quad (4)$$

where: *SRAIN* – rainfall depth (mm)

STF – total runoff depth (mm)

AE – actual evapotranspiration (mm)

ΔWP – change in soil moisture content (mm)

ΔWZ – change in ground water storage (mm)

ΔW – change in subsurface storage (mm)

RESULTS AND DISCUSSION

For the Všeminka and Dřevnice catchments, the following data were used:

- daily rainfall data from the Slušovice, Vizovice (Všeminka) and Veliková (Dřevnice) stations
- daily data on free water evaporation from the Vizovice station

Table 4. Monthly water balance components in 1997 (in mm)

Month J	Rainfall <i>RAIN</i> (mm)		Actual evapotranspiration <i>AE</i> (mm)		Total runoff <i>STF</i> (mm)		Changes in sub-surface storage ΔW (mm)	
	Dřevnice	Všeminka	Dřevnice	Všeminka	Dřevnice	Všeminka	Dřevnice	Všeminka
	4.	48.9	44.1	39.3	39.2	26.3	16.8	-13.5
5.	118.4	144.3	91.5	91.5	37.4	54.9	-1.3	-2.1
6.	97.5	106.5	85.1	87.4	37.2	36.6	-32.0	-17.5
7.	384.7	296.1	68.3	68.7	226.3	136.9	81.3	90.5
8.	102.9	51.1	85.7	84.2	49.5	13.7	-50.5	-46.8
9.	44.0	37.4	38.6	36.5	15.8	6.8	9.2	-5.9
10.	37.5	33.5	15.5	15.2	9.8	7.1	16.7	11.2

Table 5. Seasonal water balance components in 1997

Date (1/4–31/10/1997; mm)		Dřevnice	Všeminka
Rainfall depth	<i>RAIN</i>	833.9	713.0
Total runoff depth	<i>STF</i>	402.3	272.8
Direct runoff (incl. <i>STF</i>)	<i>SOF</i>	227.5	79.3
Potential evapotranspiration	<i>PE</i>	449.4	449.4
Actual evapotranspiration	<i>AE</i>	424.1	422.9
Summary interception	<i>AIR</i>	183.0	171.4
Change in soil moisture content	ΔW_P	-91.7	-101.5
Change in groundwater storage	ΔW_Z	100.3	119.8
Change in subsurface storage	ΔW	8.6	18.3
Water balance difference	<i>DIF</i>	-1.20	-1.0
Efficiency coefficient	<i>RE</i>	0.96 (-)	0.96 (-)
Variation coefficient	<i>PE</i>	0.05 (-)	0.04 (-)

- daily runoff data from the Slušovice (Všeminka) and Kašava stations
- land use data, topographical and physiographical characteristics of the catchments
- hydrological and soil parameters from maps and soil analysis: as to be seen in Table 3
- initial soil moisture contents at the beginning of growing season (April 1) were assessed according to 30 days antecedent precipitation (in March)

Reconstruction, parameter calibration

The model was implemented with data to simulate the growing season from April 1 to October 31, 1997 in both experimental catchments. The *S_{MAX}*, *G_{WM}* and *B_K* parameters were optimised on this data. Tables 4 and 5 show the main water balance components in their monthly and seasonal values, respectively. Incoming and outgoing balance components should be equal on both sides sat-

isfying eq. 4. Goodness of fit of measured and computed decades (10 days), monthly and seasonal runoff values according to two criteria, i.e. efficiency coefficient (*RE*) and variation coefficient (*PE*) is very good. The values *RE* = 1.00, *PE* = 0.00 hold for the best goodness of fit. Also the balance errors not exceeding 1.2 mm (Dřevnice) and 1.0 mm (Všeminka) can be neglected. All significant water balance components have been plotted on the subtracting graph (Figure 3) where the lines were constructed as follows: $RAIN - AE - STF \pm \Delta W$. Formation and propagation of direct runoff and, on the other hand, appropriation of subsurface recharge are mostly influenced by the following factors:

- intensity and duration of rainfall
- physiographic catchment characteristics
- land use and watershed management

As the first two factors cannot be changed, however, changes in land use and watershed management have been implemented in the form of hypothetical scenarios simulating changes in land use.

Scenario simulation

From a possible spectrum of various scenarios, a simple scenario A simulating both experimental catchments after 50% deforestation when the forest older than 40 years was cut mainly on slopes steeper than 20%, has been chosen. This significant change in land use reflects changes in model parameters, in particular in *DROT* (depth of active zone), *CN* (curve number), *WIC* (limiting value of interception) and *B_K* (parameter of depletion curve). Other parameters (including two optimised parameters *S_{MAX}* and *G_{WM}*) remained unchanged. The existing (real) state was represented by scenario 0. Table 6 gives the parameter values in both scenarios implemented.

Altered parameter values in scenario A can be explained as follows:

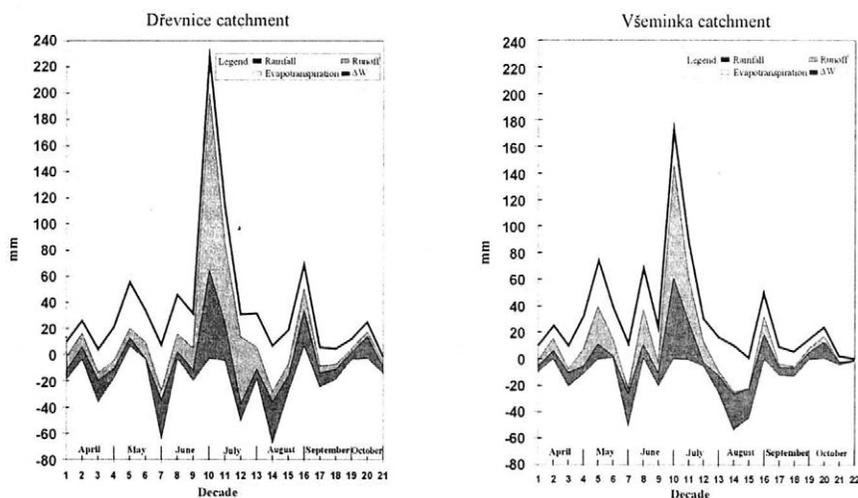


Figure 3. Water balance – catchments of Všeminka and Dřevnice 1997 (subtracted graphs)

Table 6. Changes of the parameter values of the WBCM-5 model

Value of model parameters	Všeminka		Dřevnice	
	0	A	0	A
<i>SMAX</i>	582 mm	582 mm	600 mm	600 mm
<i>GWM</i>	1100 mm	1100 mm	1000 mm	1000 mm
<i>BK</i>	8.5 days	7.0 days	10.0 days	8.0 days
<i>DROT</i>	600 mm	500 mm	600 mm	500 mm
<i>CN</i> (average)	72 (-)	76 (-)	70 (-)	75 (-)
<i>WIC</i>	2.0 mm	1.2 mm	2.2 mm	1.4 mm

Table 7. Scenario simulation of hydrological balance on the catchments Všeminka and Dřevnice in the growing period 1997 (1. 4.–31. 10.)

Water balance component (mm)		Všeminka		Dřevnice	
		0 (existing)	A (50% deforestation)	0 (existing)	A (50% deforestation)
Rainfall depth	<i>RAIN</i>	713.0	713.0	833.9	833.9
Total runoff depth	<i>STF</i>	272.8	284.0	402.3	421.3
Direct runoff (including STF)	<i>SOF</i>	79.3	96.6	227.5	307.5
Actual evapotranspiration	<i>AE</i>	422.9	417.3	424.1	410.3
Summary interception	<i>AIR</i>	171.4	105.6	183.0	112.2
Change in soil moisture content	ΔWP	-101.5	-109.0	-91.7	-97.3
Change in groundwater storage	ΔWZ	119.8	120.7	100.3	100.8
Change in subsurface storage	ΔW	18.3	11.7	8.6	3.5
Water balance difference	<i>DIF</i>	-1.0	-1.0	-1.2	-1.2

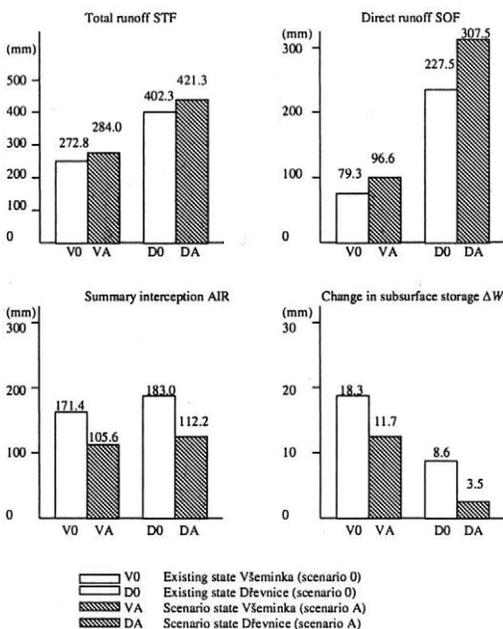


Figure 4. Comparison of the existing and scenario water balance on the catchments of Všeminka and Dřevnice in the growing season 1997

- Change of the *DROT* value corresponds with 50% deforestation when active zone becomes more shallow (root zone decreasing) temporarily by about 15–20%.
- Similarly, the limiting value of maximum daily interception capacity expressed in *WIC* is decreasing to 1.2 mm or 1.4 mm (Chow et al. 1988).
- *CN* and *BK* changes reflect land use changes according to scenario A (U.S. SCS 1986; Chow et al. 1988).

Comparison of the scenario values of the most important water balance components on both experimental catchments is given in Table 7. Graphs in Figure 4 provide the illustration of scenarios 0 and A.

CONCLUSIONS

The data on hydrometeorological observations, soil, land use and watershed management data have been recognised reliable enough and then spatially processed by ARC/INFO on the catchments of Všeminka and Dřevnice. Then, after the WBCM-5 model implementation on that data, the scenario outputs (0 and A) were analysed. Without overestimating the achieved results, the following conclusions can be made:

Total runoff and, in particular, **direct runoff** are very high on both catchments because of the significant rainfalls in July 1997 (Všeminka *STF* = 272.8 mm, *SOF* = 79.3 mm; Dřevnice *STF* = 402.3 mm, *SOF* = 227.5 mm).

Rainfalls on Dřevnice were even 90 mm (about 30%) higher than those on Všeminka. This 30% higher rainfall caused the direct runoff 2.8 times higher than on Všeminka. Therefore, in spite of the relatively greater percentage of forestation on Dřevnice (81.0% against 48.2% on Všeminka) a conclusion can be made that a depth of rainfall and its intensity are more important factors than land use in a flood consideration.

Scenario simulations of a land use considering rainfall-runoff processes when 50% of a former adult forest had been cut, well reflect this situation. The summary interception depth was 38% lower (on both catchments). Direct runoff under such deforestation was 22–35% higher, however, when active zones were fairly saturated, actual evapotranspiration did not change substantially much and similarly subsurface water storages were not significantly lowered. Obviously the latter two processes were deeply influenced by surplus of rainfall water which occurred in that flood year.

Changes in subsurface water storages due to deforestation, as described above, were not significant and they remained positive (+ sign) even during the growing season when they usually reach negative values that time. The water-abundant year of 1997 was the reason again.

In general, the WBCM-5 model is an adequate tool for such a simulation in both real (O) and scenario (A) situations. Some model parameters (namely the optimised *SMAX*, *GWM* and *BK*) will be further related to corre-

sponding physiographical/geomorphological parameters of the experimental catchments to achieve trends and correspondence, which are supposed to be extrapolated and utilised on ungauged catchments in the future.

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ABSTRAKT

Srovnávací studie hydrologické bilance experimentálních povodí Všeminky a Dřevnice

Příspěvek poskytuje řešení hydrologické bilance vegetačního období (duben–říjen) povodňového roku 1997 na dvou malých moravských povodích Všeminky a Dřevnice, s různou plochou zalesnění (Všeminka 48 %, Dřevnice 81 %). Uvádí výsledky rekonstrukce tohoto období modelem WBCM-5, pokud jde o hlavní složky hydrologické bilance, a přináší informace o objemech vody v nenasycené a nasycené zóně povodí a o interakcích mezi těmito zónami. Dokazuje schopnost modelu poměrně spolehlivě rekonstruovat srážko-odtokové režimy. Dosažené výsledky ukázaly, že na povodí Dřevnice, ačkoliv daleko více zalesněném než povodí Všeminky, dosáhl celkový odtok v červenci 1997 o 65 % vyšší hodnoty, i když byla výška červencových srážek pouze o 30 % větší. Tento jev potvrzuje známý předpoklad, že výška deště a jeho intenzita je pro vznik povodňových situací důležitější než změny využívání půdy a hospodaření na povodí. Dále pak příspěvek poskytuje výsledky simulace změn těchto hydrologických režimů způsobených změnami po 50% odlesnění povodí. Tento zásah byl simulován scénářem, reflektujícím změny parametrů modelu a přinášejícím zajímavé výsledky v odchylkách celkových i přímých odtoků, intercepce a dotaci podpovrchových vodních zásob obou experimentálních povodí. Scénářová podmínka 50% odlesnění poskytuje výsledky simulace přímého odtoku o 22 až 35 % vyššího, součtové hodnoty intercepce o 28 % nižší (na obou povodích) a dotace podpovrchových vod snížené jen nevýznamně, protože testovaný povodňový rok 1997 byl srážkově bohatý. Celkově se zdá, že model WBCM-5 je vhodným nástrojem pro simulaci hydrologické bilance reálných i scénářových situací.

Klíčová slova: model hydrologické bilance; scénářové simulace; srážko-odtokový proces; intercepce; evapotranspirace; vytváření povrchového odtoku; retence a akumulace odtoku

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Bypassing ratio and its measurement in macropore soils

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ABSTRACT

Bypassing ratio is defined as a ratio of the rate of macropore flow to the application rate which must be higher than the infiltration rate into the soil matrix. Four methods were used to measure the bypassing ratio in four soils in the Danubian Lowland: clay soil in Jurová, loamy soil in Macov and Most near Bratislava, and loamy-sand soil in Kalinkovo. It was found out that the bypassing ratio is high both at the soil surface and below the root zone during the whole vegetation season. Taking into account the extensive measurements made by Šútor (1986), the mean infiltration rate into the soil matrix was set to be 2 mm.hr⁻¹ for this region. As it was calculated by Faško (Lichner et al. 1999) from 10-year-lasting observations, the rain with intensity higher than 2 mm.hr⁻¹ and duration more than 1 hr can appear 24-times in the average in the south-western Slovakia during vegetation season. That rain in the combination with a high value of bypassing ratio can be the cause of a drop of fertilization efficiency, as well as the shallow groundwater pollution in the Danubian Lowland.

Keywords: macropore flow; bypassing ratio; Danubian Lowland

Water applied to the soil surface at rates higher than the infiltration rate into the soil matrix could pass rapidly down the surface-vented macropores and disappear to the subsoil without bringing a benefit to roots of plants, and without wetting and leaching the soil between macropores. The above-mentioned rapid macropore flow is the cause of a drop of irrigation and fertilization efficiency, as well as an increase of the shallow groundwater vulnerability to agrochemicals. At the same time, the matrix flow of water occurs in the soil at the rates up to four orders of magnitude slower than the macropore flow (Beven and Germann 1982). A dichotomy of the real soil is a basis of two-domain models of water flow and solute transport (Jarvis 1994). Neglecting the effects of macropore flow can be the cause of underestimation of the position of infiltration and redistribution front with the models based on the Richards' equation for a homogeneous soil (Štekauerová et al. 1999).

The bypassing ratio *BR* is defined as a ratio of the rate at which water bypasses the soil matrix (i.e. the rate of macropore flow) to the application rate (rain or irrigation intensity) (Kneale and White 1984). It is a useful characteristic of the rapid vertical movement of water and solutes along macropores through an unsaturated soil matrix. As it is a relative value, it can be used for a comparison of the effects of macropore flow in various soils, depths, etc., and therefore, as an indicator of a drop of irrigation and fertilization efficiency, as well as the shallow groundwater pollution (Lichner et al. 1999).

In this paper, four methods were used to measure the bypassing ratio and its variation in various soils under various crops during vegetation season. Combination of those results with the probability of heavy rain (with the intensity higher than the mean infiltration rate into the soil matrix and duration more than 1 hr) was used to make conclusions about the shallow groundwater vulnerability from agrochemicals in the Danubian Lowland.

MATERIAL AND METHODS

The Danubian Lowland is a large (1260 km²) agriculturally utilized area, with shallow (0.5–3 m) underlying aquifer containing about 10 km³ of freshwater. In this region, the bypassing ratio and its temporal variations were assessed on light, medium heavy, and heavy soil in the course of vegetation season. The light soil occurs in Kalinkovo [loamy-sand soil, Eutric Fluvisol (FAO 1994)]. The medium heavy soil occurs in Macov and Most near Bratislava [loamy soil, Calcari-mollic Fluvisol (FAO 1994)]. The heavy soil occurs in Jurová [clay soil, Calcari-mollic Fluvisol (FAO 1994)]. Basic characteristics of the soils under study were estimated by Fulajtár et al. (1998).

Four methods were used to measure the bypassing ratio and its variation in various soils under various crops during vegetation season. As the first method, the laboratory method for bypassing ratio measurement designed by Kneale and White (1984) was used. In this method, presumption of no outflow from the soil matrix serves to make the rate of outflow equal to the rate of macropore flow.

As the second method, the way similar to that designed by Watson and Luxmoore (1986) was used. The hydraulic conductivity of the soil matrix $K(-3\text{ cm})$ at the tension $h = -3\text{ cm}$ was measured with the tension infiltrometer, the saturated hydraulic conductivity of the soil K_s was measured with the double-ring infiltrometer (inner ring of 30-cm diameter and buffer ring of 55-cm diameter), and the bypassing ratio was calculated by:

$$BR = [K_s - K(-3\text{ cm})]/K_s \quad (1)$$

As the third method, the way similar to that designed by Wopereis et al. (1994) was used. In their design, shallow surface tillage (0–50 mm) was used to reduce the

macropore flow in a cracked clay soil. In our design, the double-ring infiltrometer (inner ring of 30-cm diameter and buffer ring of 55-cm diameter) was used to measure both the steady flow through an undisturbed soil surface [equal to the saturated hydraulic conductivity K_s (Šútor 1986)], and, after manual destroying the structural pores near the soil surface in the inner ring, the steady flow through the textural pores only (equal to the hydraulic conductivity K_{sd}). Bypassing ratio BR_d was calculated by:

$$BR_d = (K_s - K_{sd})/K_s \quad (2)$$

The relative error δ_{BR} of the BR_d measurement was calculated by:

$$\delta_{BR} = (BR_d - BR)/BR \quad (3)$$

where the value BR was deemed to be the true value.

In the fourth method, the leading edge of radioactive tracer $^{131}\text{I}^-$ was formed below the area of maximum plant uptake, and its displacement h was measured with the

Geiger-Müller detector. The bypassing ratio was calculated by:

$$BR = 1 - hn_{ef}/I \quad (4)$$

where: I is the cumulative infiltration of water resulting in the displacement h of the radioactive tracer leading edge formed in the soil matrix, $n_{ef} = \Theta_s - \Theta_r$ is the effective porosity of the soil under study, Θ_s is the saturated water content, and Θ_r is the residual water content of the soil matrix (Lichner 1997, 1998).

RESULTS AND DISCUSSION

The bypassing ratio measurement with the first method was undertaken in the undisturbed loamy soil column (20-cm diameter and approximately 35 cm long) sampled in the untilled field covered with grass in Most near Bratislava in September 2000. Water was applied at the soil surface with the rain simulator composed of the water applicator with 66 needles and a peristaltic pump. Outflow from the column began 33 minutes after starting the irrigation (with an intensity of 2.8 cm.hr⁻¹), but it did not reach a steady rate as it was observed in case of clay soil columns (Kneale and White 1984; Van Stiphout et al. 1987; Wopereis et al. 1994). As a result, the bypassing ratio increased from 4–90% in the course of 2-hr lasting measurement. It was concluded that the laboratory method for bypassing ratio measurement designed by Kneale and White (1984) fails in the case of medium heavy and light soils where the presumption of no outflow from the soil matrix cannot be fulfilled.

In the vegetation season 2000, the bypassing ratio measurements were undertaken in the soils under winter wheat with the second and third measuring method. From the results taken with the second method it was found out that the bypassing ratio BR varied in the topsoil between 89.2–99.8% in Jurová, 53.6–98.2% in Macov, and 76.8–98.2% in Kalinkovo (Tables 1–3 and Figure 1). The highest variations of BR were in the loamy soil in Macov. The values of BR were very high in the clay soil in Jurová during the whole vegetation season due to enormously high temperatures and low precipitation resulting in the formation of desiccation cracks. The values $K(-3\text{ cm}) > K_s$, as measured in Kalinkovo on May 18 and September 20, 2000, cannot be explained by the authors. An impact of the harvest (decrease of the BR -values in all the three soils) and shallow ploughing (increase of the BR -values in all the three soils) were in contrary to our anticipation.

As it can be seen in Tables 1–3, relative error δ_{BR} of the BR_d measurements was high in loamy and loamy-sand soil. It should be noted that closing the ports of surface-vented macropores was most effective in the soil with a high clay content (almost 60% of particles $\leq 0.01\text{ mm}$ was found in the surface layer of the soil in Jurová, Table 4).

In 1993–1996 the bypassing ratio was measured in the loamy soil in Most near Bratislava with the radioactive tracer technique [together with the TDR-measurements

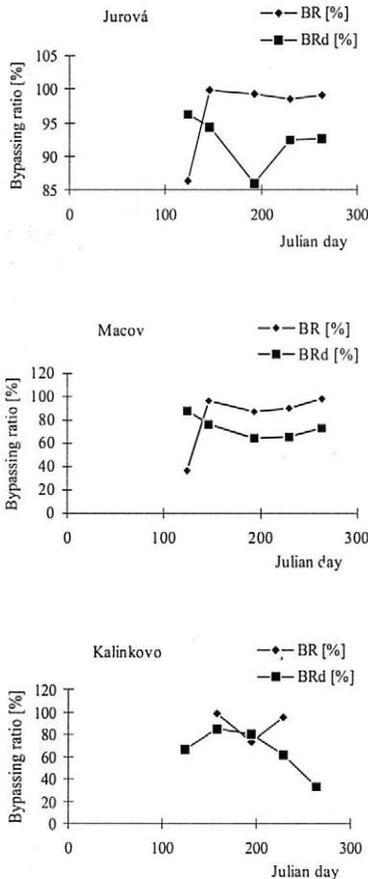


Figure 1. Variations of the bypassing ratio as measured in three soils in the vegetation season 2000; the values of BR and BR_d were calculated using eqs. (1) and (2), respectively

Table 1. Hydraulic conductivity, bypassing ratio and relative error δ_{BR} as measured in the clay soil in Jurová

Date	3. 5. 2000	25. 5. 2000	11. 7. 2000	16. 8. 2000	19. 9. 2000
$K(-3 \text{ cm}) \text{ (m.s}^{-1}\text{)}$	$9.03 \cdot 10^{-6}$	$1.47 \cdot 10^{-6}$	$1.83 \cdot 10^{-6}$	$3.17 \cdot 10^{-6}$	$1.42 \cdot 10^{-6}$
$K_s \text{ (m.s}^{-1}\text{)}$	$8.33 \cdot 10^{-5}$	$6.67 \cdot 10^{-4}$	$1.67 \cdot 10^{-4}$	$2.22 \cdot 10^{-4}$	$1.67 \cdot 10^{-4}$
$K_{sd} \text{ (m.s}^{-1}\text{)}$	$3.13 \cdot 10^{-6}$	$3.71 \cdot 10^{-5}$	$2.32 \cdot 10^{-5}$	$1.67 \cdot 10^{-5}$	$1.23 \cdot 10^{-5}$
$BR \text{ (\%)}$	89.2	99.8	98.9	98.6	99.1
$BR_d \text{ (\%)}$	96.2	94.4	86	92.5	92.6
$\delta_{BR} \text{ (\%)}$	7.8	-5.4	-9.1	-6.2	-6.6

Table 2. Hydraulic conductivity, bypassing ratio and relative error δ_{BR} as measured in the loamy soil in Macov

Date	3. 5. 2000	25. 5. 2000	11. 7. 2000	16. 8. 2000	19. 9. 2000
$K(-3 \text{ cm}) \text{ (m.s}^{-1}\text{)}$	$1.08 \cdot 10^{-5}$	$5.83 \cdot 10^{-7}$	$1.19 \cdot 10^{-6}$	$3.22 \cdot 10^{-6}$	$1.50 \cdot 10^{-6}$
$K_s \text{ (m.s}^{-1}\text{)}$	$2.33 \cdot 10^{-5}$	$1.67 \cdot 10^{-5}$	$7.83 \cdot 10^{-6}$	$3.33 \cdot 10^{-5}$	$8.33 \cdot 10^{-5}$
$K_{sd} \text{ (m.s}^{-1}\text{)}$	$2.78 \cdot 10^{-6}$	$3.92 \cdot 10^{-6}$	$2.78 \cdot 10^{-6}$	$1.15 \cdot 10^{-5}$	$2.22 \cdot 10^{-5}$
$BR \text{ (\%)}$	53.6	96.5	84.8	90.3	98.2
$BR_d \text{ (\%)}$	88.1	76.5	64.5	65.5	73.3
$\delta_{BR} \text{ (\%)}$	39.2	-20.7	-23.9	-27.5	-25.4

Table 3. Hydraulic conductivity, bypassing ratio and relative error δ_{BR} as measured in the loamy-sand soil in Kalinkovo

Date	18. 5. 2000	6. 6. 2000	13. 7. 2000	15. 8. 2000	20. 9. 2000
$K(-3 \text{ cm}) \text{ (m.s}^{-1}\text{)}$	$8.92 \cdot 10^{-6}$	$5.83 \cdot 10^{-7}$	$1.16 \cdot 10^{-5}$	$1.14 \cdot 10^{-6}$	$1.94 \cdot 10^{-5}$
$K_s \text{ (m.s}^{-1}\text{)}$	$8.33 \cdot 10^{-6}$	$3.33 \cdot 10^{-5}$	$5.00 \cdot 10^{-5}$	$2.33 \cdot 10^{-5}$	$4.17 \cdot 10^{-6}$
$K_{sd} \text{ (m.s}^{-1}\text{)}$	$2.78 \cdot 10^{-6}$	$5.13 \cdot 10^{-6}$	$1.01 \cdot 10^{-5}$	$9.01 \cdot 10^{-6}$	$2.78 \cdot 10^{-6}$
$BR \text{ (\%)}$	–	98.2	76.8	95.1	–
$BR_d \text{ (\%)}$	66.6	84.6	79.8	61.4	33.3
$\delta_{BR} \text{ (\%)}$	–	-13.8	3.9	-35.4	–

of macropore flow in 1995 (Alaoui et al. 1997)]. It was found out that the macropore flow was about 49% of the total flow ($BR = 0.49$) as measured in the depth of $z = 48 \text{ cm}$ in a spring barley field in April–May 1993, $BR = 0.15$ in the depth of $z = 56 \text{ cm}$ in a maize field in July 1995, $BR = 0.55$ in the depth of $z = 78 \text{ cm}$ in the grassland soil in August 1996. It can be seen that the warm and rainless second half of April 1993 (similar situation repeated in April 2000) resulted in the crack formation and as high macropore flow in the barley field as in the untilled soil with well-developed macropore systems.

The bypassing ratio measurement was repeated in the same untilled field covered with grass in September 2000 using the third method. From the measurements of the steady flow through an undisturbed soil surface and the steady flow through the textural pores only in the depth

of $z = 40 \text{ cm}$ with the double-ring infiltrometer techniques, $BR_d = 0.31$ was estimated.

The surface-vented macropores can lead water and solutes rapidly to the subsoil if the rain or irrigation intensity is higher than the infiltration rate into the soil matrix. Taking into account the extensive measurements made by Šútor (1986) in the Danubian Lowland, the mean infiltration rate into the soil matrix was set to be 2 mm.hr^{-1} for this region. As it was calculated by Faško (Lichner et al. 1999) from 10-year-lasting observations, the rain with intensity higher than 2 mm.hr^{-1} and duration more than 1 hr can appear 24-times in the average in the south-western Slovakia during vegetation season (April–October). That rain can be the cause of rapid transport of surface-applied agrochemicals down the macropores and shallow groundwater pollution in the Danubian Lowland, and

Table 4. Textural composition of the surface layer (0.1–0.2 m) of soils in Jurová, Macov, and Kalinkovo (Fulajtár et al. 1998)

Site	Sand (%)		Silt (%)		Clay (%)	
	$\geq 0.25 \text{ mm}$	0.25–0.05 mm	0.05–0.01 mm	0.01–0.001 mm	$\leq 0.001 \text{ mm}$	$\leq 0.01 \text{ mm}$
Jurová	1.54	11.35	27.84	37.32	21.92	59.27
Macov	0.86	36.14	28.84	19.94	14.22	34.16
Kalinkovo	6.04	55.77	22.48	10.22	5.49	15.71

therefore, the subsurface fertilizer banding [e.g. with the fertilizer applicator designed by Ressler et al. (1997)] should be used in this region.

CONCLUSIONS

Bypassing ratio yields an information about the part of rain or irrigation water which could pass rapidly down the surface-vented macropores and disappear to the subsoil without being of benefit to roots of plants, and without wetting and leaching the soil between macropores. It can serve as an indicator of a drop of irrigation and fertilization efficiency, as well as the shallow groundwater pollution.

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ABSTRAKT

Měření obtokového podílu v půdě

Obtokový podíl je definovaný jako podíl rychlosti proudění v makropórech a rychlosti infiltrace vody do půdy. Použili jsme čtyři metody měření obtokového podílu ve čtyřech půdách v Podunajské nížině: v jílovité půdě v Jurové, v hlinité půdě v Macově a v Mostu u Bratislavy a v hlinitopísčité půdě v Kalinkově. Zjistili jsme, že obtokový podíl byl vysoký jak na povrchu půdy, tak i v podkořenové oblasti během celé vegetační sezony. Z rozsáhlých měření, která prováděl Šútor (1986), jsme stanovili střední hodnotu infiltrační rychlosti do půdní matrice pro tuto oblast, která je $2 \text{ mm}\cdot\text{h}^{-1}$. Faško (Lichner et al. 1999) z desetiletých pozorování srážek zjistil, že déšť s intenzitou vyšší než $2 \text{ mm}\cdot\text{h}^{-1}$ a trváním delším než 1 h se v oblasti jihozápadního Slovenska vyskytne během vegetační sezony průměrně 24krát. Tento déšť ve spojení s vysokou hodnotou obtokového podílu může způsobit pokles účinnosti hnojení a kontaminaci mělkých podzemních vod agrochemikáliemi.

Klíčová slova: proudění v makropórech; obtokový podíl; Podunajská nížina

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Influence of the seed-tuber size on yield and yield parameters in potatoes

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ABSTRACT

In a potato-growing area above 400 m sea-level on a plot with the soil of brown type (loamy-sand soil) the impact of tuber size (25–30, 30–55, 55–75, 75–85 mm) on yields and yield elements was studied in the years 1996–1998. The varieties Krasa (very early table potato) and Svatava (semi-early table potato) were chosen for these experiments. A high impact of the particular year on the yield and yield elements was recorded in the described experiments. The differing results can be attributed to the high rainfall in May. In comparison with the other years, the growth in rainfall amounted to more than 300%. The tuber yield responded positively to the growing tuber size. The highest yields in both mentioned varieties were achieved in the variant with the largest seed tubers. The increasing seed-tuber size resulted in the growing percentage of emerged plants. Larger tubers were accompanied by the growth of the number of stems per plant. In both varieties, a growing number of stems per plant as the result of the growing seed tuber size was recorded. The growing size of tubers resulting in the decrease of average weight per tuber can be considered a trend. The recorded differences are statistically not significant. The differences recorded in other studied features were statistically significant. The results show that the growing size of seed tubers results in an increased yield security. Larger than standard seed tubers result in the increased weight and costs for the necessary seed tubers. To respond to the tuber size of acknowledged seed-tubers by double sorting. In larger seed tubers a larger seeding distance between tubers should be preferred and the number of individuals per hectare within the recommended density for the given utility class should be reduced.

Keywords: potatoes; seed-tuber size; yield; yield elements

In order to use the yield potential of potato varieties, it is necessary to apply healthy and size-selected seed-tubers (Rybáček 1988). In the sixties Votoupal (1964) studied size-selection and recommended to apply seed-tubers ranging between 40 and 60 mm. These seed-tubers resulted in higher yields. Wiersema (1989) compared small seed-tuber sizes with standard seed-tubers (40–60 g) and found that standard seed-tubers gave a higher total yield and yield rate of tubers exceeding 40 mm. Futkaradce (1998) also states increased yield and yield rate values of table tubers with a higher weight of seed-tubers. Čepl and Vokál (1996) achieved a yield higher by almost 6 t.ha⁻¹ with seed-tubers between 40 and 50 mm as compared with seed-tubers of 30 to 40 mm.

Kumar et al. (1991) state a significant increase in the weight of leaves, stems and leaf area index with larger seed-tubers as compared with the values achieved with seed-tubers of 25 g and 50 g. On the other hand, the authors recorded a higher tuber yield in seed-tubers of 25 g in another experiment.

Yields were always greater from the mixed populations of different seed sizes planted alternately than from the means of uniform populations (Hide et al. 1997).

Zarzynska (1993), Kulík and Kosík (1993) found that the growing seed-tuber size resulted in an increased number of stems, tuber numbers and their weight per plant.

Larger seed-tubers are accompanied with a weight increase of the required seed-tubers. Minx and Diviš (1994) considered the consumption of 3 t.ha⁻¹ economically efficient.

MATERIAL AND METHODS

The experiment was carried out in the potato-growing production region on 400 m above the sea-level. The soil of the plot was cambisol with loamy-sand character. The rainfall and temperature conditions and soil qualities are stated in Tables 1 and 2.

In the experiment the acknowledged varieties Krasa (very early table potato; grade of propagation C2) and Svatava (medium early table potato; grade of propagation C2) with the following sizes were tested:

- variant A = 25–30 mm
- variant B = 30–55 mm
- variant C = 55–75 mm
- variant D = 75–85 mm

Each of the variants was repeated four times. The fertilization scheme was the same for all variants: 120 kg N.ha⁻¹ (ammonium sulphate), 35 kg P.ha⁻¹ (superphosphate), 60 kg K.ha⁻¹ (potash salt). The crop density amounted to 45 thousand plants per ha (30 × 75 cm). The tuber planting by hand was followed by full mechanical cultivation.

Late blight of potato treatment (five times), Colorado beetle (one treatment). The calculation of yield per ha was based on the harvest area of 9 m². The number of emerged plants and the number of stems per plant were counted in 30 plants. The tuber count per plant and the mean weight per tuber were determined after harvest and repetitions.

The programme STATISTICA 6.0, dispersion variance analysis and Tukey HSD test were applied for the purposes of statistical evaluation.

Table 1. Rainfall and temperature conditions

Year/Growing season			
Average 1901-1950	1996	1997	1998
Rainfall (mm)			
620/427	712.8/489.3	706.3/482.3	579.5/341.0
Average temperature (°C)			
7.8/13.8	7.1/13.8	8.3/14.3	9.3/16.3

Table 2. Pedomorphological conditions (Mehlich II)

Year	pH/KCl	P	K	Mg	C _{ox}
1996	5.8	88.0	160.0	105.0	1.05
1997	6.3	78.0	142.5	64.5	1.32
1998	6.2	81.0	170.0	94.0	1.07

RESULTS AND DISCUSSION

A high impact of the particular year on the yield and yield elements was recorded in the described experiments. The differing results can be attributed to the high rainfall in May. In comparison with the other years, the growth in rainfall amounted to more than 300%.

The dispersion variance analysis of the recorded values showed the impact of seed-tuber size on yield elements and tuber yields, with the exception of mean tuber weight (Table 8). The growing size of seed-tubers in both varieties resulted in increased tuber yields (Table 3).

A more significant yield growth was recorded in the medium early variety Svatava. The highest tuber yields in both varieties were detected in the D variant, with seed-tuber sizes exceeding 75 mm – Svatava 31.82 t.ha⁻¹, Krasa 28.39 t.ha⁻¹. The achieved tuber yield results correspond with the data stated by Futkaradce (1988), Wiersema (1989), Čepl and Vokál (1996) as well as with the fact that the mentioned authors also recorded higher yields in larger seed-tubers. The differences among the individual tuber size variants were statistically significant. Only the differences of the variants C and D were statistically insignificant.

The number of emerged plants of both studied varieties responded to seed-tuber sizes. The plant counts showed negligible reduction – maximal reduction was in variant A. When comparing the variant B (tuber size 30–55 mm = 100%) with other variants, a decrease by 2.9% was recorded in Krasa and by 1.1% in Svatava. In variants C and D a higher number of emerged plants with a maximum increase was found in Svatava 2.3%. Although the differences are very small, the differences (Tables 7 and 9) between variant B and the other variants were statistically significant, the significance level amounting to 99%. The difference between variants C and D was statistically insignificant. A statistical impact of year and variety on the counts of emerged plants (Table 8) could not be proved.

Krasa variety showed a higher number of stems. In both varieties small differences were recorded between the variants A and B and the variants C and D (Table 4). Solely the differences of variants C and D as compared with variants A and B (Table 9) were of statistical significance. Larger tubers resulted in an increase of stem counts per plant. Similar results were stated by Kulík and Kosík (1993) and Zarzyńska (1993).

Table 3. Tuber yield (t.ha⁻¹)

Variety	Krasa					Svatava				
	1996	1997	1998	average 1996-1998	%	1996	1997	1998	average 1996-1998	%
A (< 30)	6.96	21.70	28.85	19.17	73.1	6.67	23.00	28.20	19.29	79.0
B (30-55)	11.48	29.89	37.28	26.22	100.0	13.59	26.26	33.43	24.43	100.0
C (55-75)	12.30	31.67	40.20	28.06	107.0	17.56	30.66	37.75	28.66	117.3
D (> 75)	15.11	32.04	38.03	28.39	108.3	22.59	33.78	39.08	31.82	130.2

Table 4. Number of emerged plants (per 30 seed-tubers)

Variety	Krasa					Svatava				
	1996	1997	1998	average 1996-1998	%	1996	1997	1998	average 1996-1998	%
A (< 30)	28.00	28.75	28.25	28.33	97.1	28.50	28.75	28.50	28.58	98.8
B (30-55)	28.75	29.25	29.50	29.17	100.0	28.25	29.00	29.50	28.92	100.0
C (55-75)	29.25	29.25	29.50	29.33	100.5	29.75	29.25	29.25	29.42	101.7
D (> 75)	29.75	29.75	30.00	29.83	102.3	29.00	29.00	29.75	29.25	101.1

Table 5. Number of stems per plant

Variety	Krasa					Svatava				
	1996	1997	1998	average 1996–1998	%	1996	1997	1998	average 1996–1998	%
A (< 30)	6.75	2.50	5.50	4.92	100.0	7.00	2.25	4.75	4.67	116.8
B (30–55)	4.00	5.00	5.75	4.92	100.0	3.75	3.25	5.00	4.00	100.0
C (55–75)	5.00	7.00	6.75	6.25	127.0	4.50	5.00	5.75	5.08	127.0
D (> 75)	5.75	7.50	6.75	6.67	135.6	5.75	6.00	5.75	5.83	145.8

Table 6. Average weight per 1 tuber (g)

Variety	Krasa					Svatava				
	1996	1997	1998	average 1996–1998	%	1996	1997	1998	average 1996–1998	%
A (< 30)	51.5	98.4	92.7	80.9	96.1	40.2	87.8	92.9	73.6	100.5
B (30–55)	54.5	99.0	99.2	84.2	100.0	46.8	80.3	92.6	73.2	100.0
C (55–75)	57.6	87.5	92.6	79.2	94.1	49.1	67.6	85.8	67.5	92.2
D (> 75)	61.9	93.1	91.7	82.2	97.6	50.1	70.5	87.3	69.3	94.7

Svatava variety showed a higher tuber number per plant in comparison with Krasa variety. This corresponds with the characteristics of the said varieties and their vegetation lengths. In both varieties a growth of tuber numbers per plant as a result of increasing tuber sizes was recorded. D variant in Krasa variety represented the only exception here, a decrease of tuber number per plant in comparison with C variant was detected. This yield element showed the most relevant differences among

variants, highest values were recorded in Svatava. The variety with a longer vegetation period (Svatava) responded to the growing seed-tuber size by a higher number of tubers per plant as compared with the variety with a shorter vegetation period (Krasa). The maximum growth of tuber number per plant between A variant and D variant in Svatava amounted to 5.58 pieces and in Krasa to 2.41 pieces (Table 6). Kulík and Kosík (1993) and Zárzyská (1993) stated similar results.

Table 7. Number of tubers per plant

Variety	Krasa					Svatava				
	1996	1997	1998	average 1996–1998	%	1996	1997	1998	average 1996–1998	%
A (< 30)	3.00	5.00	5.25	4.42	71.6	4.00	6.25	6.25	5.50	73.3
B (30–55)	4.75	7.00	6.75	6.17	100.0	7.00	7.50	8.00	7.50	100.0
C (55–75)	5.00	8.50	8.75	7.42	120.3	8.00	10.50	11.00	9.83	131.1
D (> 75)	5.50	7.75	7.25	6.83	110.7	10.75	11.25	11.25	11.08	147.7

Table 8. Analysis of variance

Factor (interaction)	df per plant	tuber yield	F-ratio			Number of emerged plants (per 30 seed-tubers)
			number of tubers per plant	tuber weight	number of stems	
1	2	4093.77**	43.41**	15102.41**	7.03**	1.14
2	1	8.30	123.76**	2755.26**	14.26**	0.38
3	3	547.55**	81.59**	126.33	15.40**	5.49**
1 × 2	2	58.16**	2.39	370.94**	3.51*	0.09
1 × 3	6	6.98	2.20	254.63**	15.67**	0.75
2 × 3	3	27.81	12.45**	36.94	0.90	0.82
1 × 2 × 3	6	8.46	0.45	23.53	0.32	0.20

1 = year, 2 = variety, 3 = seed-tuber size; * $p = 0.05$, ** $p = 0.01$

Table 9. Tukey HSD test

Variant	A	B	C	D
Tuber yield				
A		**	**	**
B	**		*	**
C	**	*		NS
D	**	**	NS	
Number of tubers per plant				
A		**	**	**
B	**		**	**
C	**	**		NS
D	**	**	NS	
Tuber weight				
A		NS	NS	NS
B	NS		NS	NS
C	NS	NS		NS
D	NS	NS	NS	
Number of stems per plant				
A		NS	**	**
B	NS		**	**
C	**	**		NS
D	**	**	NS	
Number of emerged plants				
A		NS	*	**
B	NS		NS	NS
C	*	NS		NS
D	**	NS	NS	

* *p*-level 0.05, ** *p*-level 0.01, NS – no significant differences

As opposed to the findings of Zarzyńska (1993), the seed-tuber size did not respond relevantly by the changing weight of a single tuber. The recorded differences were negligible and statistically insignificant (Table 9). Svatava showed a lower weight per tuber as compared with Krasa, which can be assigned to the higher tuber count per plant. In the very early variety Krasa the weight increase per tuber amounts up to 12.9 g in D variant as compared with the medium early variety Svatava (Table 5).

In both varieties differing in the vegetation period length, the growing tuber size resulted in an increased number of stems and tubers per plant. The increased

number of tubers per plant was accompanied by a decreased average weight per tuber.

Double sorting in an acknowledged seed potato variety makes it possible to respect the tuber size in the seeding process. In larger seed tubers a larger seeding distance between tubers should be preferred and the number of individuals per hectare within the recommended density for the given utility class should be reduced.

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ABSTRAKT

Vliv velikosti sadbových hlíz na výnos a výnosové prvky u brambor

V bramborářské zemědělské výrobní oblasti ve 400 m n. m. na pozemku s půdou typově hnědou (půdní druh hlinitopísčité) byl v letech 1996 až 1998 ověřován vliv velikosti sadby (25–30, 30–55, 55–75, 75–85 mm) na výnos a výnosové prvky. Byly vybrány odrůdy Krasa (konzumní, velmi raná) a Svatava (konzumní, poloraná). Byl zaznamenán vysoký ročníkový vliv na výnos a výnosové prvky, pouze ročník 1996 se odlišoval, což lze vysvětlit vysokými srážkami v květnu. Ve srovnání s ostatními roky byl dosažen více než 300% nárůst. Výnos hlíz byl pozitivně ovlivněn zvyšující se velikostí hlíz, nejvyššího výnosu u obou odrůd bylo dosaženo u varianty s největšími sadbovými hlízkami. S narůstající velikostí sadby se zvyšovalo procento vzešlých rostlin, větší hlízký přinesly nárůst počtu stonků na jednu rostlinu. U obou odrůd byl zjištěn

zvyšující se počet hlíz na jednu rostlinu s narůstající velikostí sadby. Velikost sadbových hlíz neovlivnila průměrnou hmotnost jedné hlízy. S narůstající velikostí hlíz dochází k poklesu průměrné hmotnosti jedné hlízy; vzniklé rozdíly byly statisticky neprůkazné. U ostatních sledovaných znaků byly vzniklé rozdíly statisticky průkazné. Z výsledků vyplývá, že s narůstající velikostí sadbových hlíz se zvyšuje výnosová jistota. Nadsadbové hlízy výrazně zvyšují náklady na potřebnou sadbu. Požadavek na velikost hlíz lze u uznané sadby splnit dvojitým tříděním: u větších sadbových hlíz volit při výsadbě větší vzdálenost a snížit počet jedinců na 1 ha v rámci doporučené hustoty pro jednotlivé užitkové směry.

Klíčová slova: brambory; velikost sadbových hlíz; výnos; výnosové prvky

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The influence of substitution of wheat flour by amaranth flour on fermentative gas production and quality of bread

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ABSTRACT

The importance of substitution of wheat flour by amaranth flour (10, 15 and 20% w/w) on fermentative gas (CO₂) production and on quality of bread (specific product volume and sensory quality) was determined. Substitution of 10% and 15% (w/w) wheat flour by amaranth flour has a positive effect on dough quality (increased binding of flour, better dough processing), the amount of produced CO₂ (increased), porosity of bread-inside (more regular with softer pores) and nutritive value of products increased as well. A considerable decreased content of gluten and a negative effect on dough quality (adhesiveness) and bread (very low specific volume, considerable amaranth flavour) for 20% (w/w) substitution of wheat flour by amaranth flour was determined.

Keywords: amaranth; substitution; flour; fermentative gas; bakery products

There is a very propagative trend of the rational nourishment these days and it is one of the reasons to mix in different cereal and pseudocereal flours to the classic wheat flour products. So amaranth flour increases the nutritive value of products because of the protein content in amaranth flour (14.5–17.8%), higher fibre value and moreover, because of the higher value of sulfuric amino acids (Sánchez-Marroquín et al. 1985; Brümmer and Morgenstern 1992; Chaturvedi et al. 1993; Magomedov 1998). The main reason for mixture of amaranth flour to the wheat flour products is nearly three-time higher content of an essential amino acid – lysine in amaranth flour than in wheat flours (Becker et al. 1981; Betschart et al. 1981; Dodok and Halášová 1997; Bejosano and Corke 1998).

Amaranth is an old cultivated crop and belongs to the oldest cereals cultivated by people as it has been proved by the excavations in South America, Nepal and India (Williams and Brenner 1995; Lehman 1996). This crop has been used only recently in Slovakia (research field of AF SPU Nitra or VÚRV Piešťany). Amaranth has a great potential to be a food and fodder plant because of its high rate growth characteristic for C4 photosynthesis type plants and because of ability to grow in the regions where temperate zone plants are not very successful.

By evaluation of the amaranth seed we can say that the seeds are very small (1 mm in diameter) with specific morphological structure (Betschart et al. 1981). Seeds comprise a single-layered coat with no apparent cellular structure, adjacent to the perisperm and two cell layers adjacent to the embryo (Williams and Brenner 1995).

Amaranth flour does not contain gluten (suitable for people with celiakie sprue disease), has spicy and slightly pungent flavour and beige colour (Jarošová 1995). The seed is utilized not only for production of bread and bakery products, but also for pancakes, gruels and granish, too.

MATERIAL AND METHODS

Bread wheat flour (BW), special wheat bakery flour (SWB) (Mlyn a pekáreň Jedľa, Bratislava, SK), amaranth grain – genotype K 343 from 1997 (AF SPU Nitra, SK). The whole-grain flour was obtained by grinding of the amaranth seeds in the laboratory mill (LMIM QC 109 Hungary). Raw materials used for bread dough preparation: bakery yeast (Fala, French), saccharose for food use, NaCl for food use, Diasta, margarine Palmarin (Palma Tumys, Bratislava, SK).

Methods according to standards for determination of flour properties were used: determination of flour moisture (STN 56 0512-7), determination of gluten and its quality (STN 56-0512).

Nitrogen was determined by the Kjeldahl micromethod (Davídek et al. 1981).

Dough preparation: 0.3 kg of flour, 1.7% NaCl, 1.5% saccharose, 1% margarine, 4% yeast, water (according to binding of flour). Wheat flour was substituted by amaranth flour for 10, 15 and 20% w/w. Farinograph was used for dough mixing with dough consistence of 600 BU (Brabender unit).

The measurement of an increase of CO₂ amount was run using Fermentometer SJA (Harberg system) and Fermentograph (Brabender).

Bakery experiment

Dough preparation for baking: kneaded dough was left to mature at 30°C for 45 min and again slightly kneaded and divided into six pieces, 0.07 kg each. These samples were shaped and left to ferment for a period determined by maturographical test. Then they were baked at 230°C in the laboratory oven warmed for 13–15 min.

Table 1. Average amounts of dry matter and gluten qualities in wheat and mixed flours

Sample	Dry matter (%)	Wet gluten (% in d.m.)	Dry gluten (% in d.m.)	Elasticity/Tensibility	Imbition (cm ³)
SWB	87.0	31.6	11.8	1/3	23.0-c
SWB + 10% subst.	87.4	28.0	10.1	1/3	24.5-c
SWB + 15% subst.	87.6	26.8	9.1	1/3	19.2-c
SWB + 20% subst.	87.8	25.1	8.9	1/2	15.0-c
BW	87.8	35.6	13.3	1/3	10.0-m
BW + 10% subst.	88.1	28.9	11.5	1/3	10.5-m
BW + 15% subst.	88.3	26.6	10.3	1/2	11.0-m
BW + 20% subst.	88.5	24.3	9.2	1/2	11.3-m
Amaranth	91.2	-	-	-	-

number of measurement $n = 2$, c = limpid solution, m = soft opaque solution

number of elasticity 1 = very elastic gluten, number of tensibility 2 = less tensible gluten, number of tensibility 3 = medium tensible gluten

RESULTS AND DISCUSSION

Standard flour analyses (moisture, wet gluten content and gluten properties) of special wheat bakery flour (SWB), bread wheat flour (BW) and mixed flour (wheat flour substituted by amaranth flour: 10, 15 and 20% w/w) were done. These results are shown in Table 1. Wet gluten content in mixed flour, especially in flour with the higher substitution (20%), decreased not only because of high substitution by amaranth flour (no gluten) but also of higher dough friability due to covering particles present in amaranth flour. And some gluten properties

(elasticity, tensibility and imbition) with increasing substitution by amaranth flour are deteriorated too.

Amount of total nitrogen in wheat and mixed flours and their products was determined by Kjeldahl method. Results are shown in Figure 1. From these results it is obvious that by increase of amaranth flour substitution nitrogen amount increases in mixed flours and in products as well. It is probably due to the fact that amaranth flour contains $2.66 \pm 0.02\%$ of total nitrogen, what is 16.63% protein ($N \times 6.25$), SWB only $2.12 \pm 0.04\%$ (12.08% protein, $N \times 5.7$) and BW $2.13 \pm 0.03\%$ (12.14% protein, $N \times 5.7$). These results are corresponding with

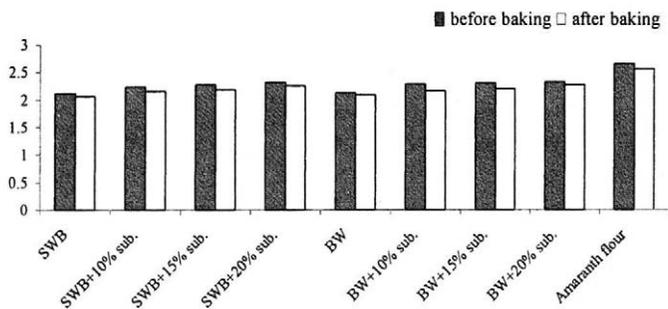


Figure 1. Comparison of total nitrogen content in bread before and after baking (% in d.m.)

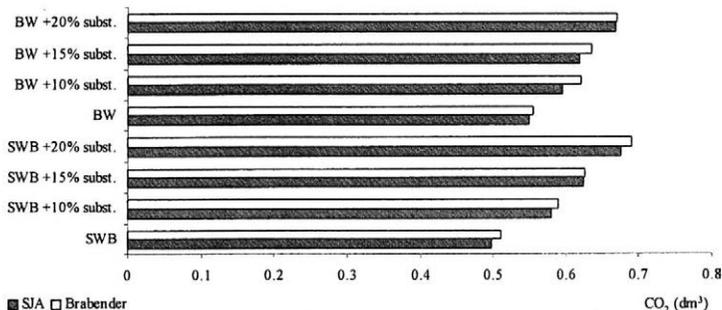


Figure 2. Determination of gas volume on both apparatuses

Table 2. Dough volume measured on SJA

	SWB	SWB + 10% subst.	SWB + 15% subst.	SWB + 20% subst.	BW	BW + 10% subst.	BW + 15% subst.	BW + 20% subst.
Dough volume (dm ³ after 2 h) × 10 ⁻³	495 ± 7.9	358 ± 4.03	346 ± 8.06	330 ± 9.64	309 ± 8.61	275 ± 9.67	262 ± 4.03	246 ± 6.56
S _r (%)	1.01	0.71	1.47	1.85	1.76	2.22	0.97	1.69

S_r – relative standard error, number of measurement *n* = 4

Table 3. Evaluation of bakery experiment

Sample	SWB	SWB + 10% subst.	SWB + 15% subst.	SWB + 20% subst.	BW	BW + 10% subst.	BW + 15% subst.	BW + 20% subst.
Binding of flour (%)	48.8	49.5	50.0	51.4	54.8	55.3	55.7	56.5
Specific volume (cm ³ /100 g bread)	250 ± 10	204 ± 12	199 ± 20	192 ± 21	178 ± 8	169 ± 13	165 ± 8	161 ± 7
S _r (%)	3.7	5.6	9.4	10.2	4.3	7.3	4.6	4.0

number of measurement for binding of flour *n* = 2, S_r – relative standard error for specific volume, number of measurement for specific volume *n* = 6

other authors' data (Betschart et al. 1981; Brümmer and Morgenstern 1992; Valle et al. 1993; Hózová et al. 1996), where the addition of amaranth flour into products from wheat and other cereal flours has increased their nutritive value.

The results of observation of the amaranth flour influence on development fermentative gas amount are shown in Figure 2. An increase of fermentative gas (CO₂) amount with increasing substitution by amaranth flour for both types of flour and both apparatus is seen. These results were verified by measurement on both apparatus (Fermentograph and Fermentometer). Higher percentage increase of developed CO₂ was detected at SWB than at BW. Based on our results supported by studies of Brümmer and Morgenstern (1992), Haber et al. (1994), Karpilenko et al. (1994), we concluded that addition of amaranth flour has a positive effect on fermentative processes in

dough. It may be caused by higher content of fermentable saccharides (glucose, fructose, maltose and saccharose) in the amaranth grain (Williams and Brenner 1995; Hózová et al. 1996; Haber et al. 1994). An effect of some enzymes, such as amylolytic enzymes, has not been proved yet.

Dough volume was measured on Fermentometer SJA. The measured data of dough volume are shown in Table 2. Dough volume of both flours (SWB, BW) with increasing substitution by amaranth flour decreases, what is probably due to the lower gluten content and its decreased ability to retain fermentative gas in dough. As the gluten content has decreased, sufficiently strong gluten net cannot be produced. For explanation of lower dough volume in more substituted flours (increased CO₂ production) can be considered a disruption of gluten net and so a leakage of gas.

Table 4. Sensory evaluation of breads

	Sample	SWB	SWB + 10% subst.	SWB + 15% subst.	SWB + 20% subst.	BW	BW + 10% subst.	BW + 15% subst.	BW + 20% subst.
Product form	camber	4	3	3	2	3	3	2	2
	regular	3	4	4	4	4	4	4	4
Crust	colour	4	4	3	3	4	3	3	3
	hardness	4	4	4	4	4	4	4	4
Crust/Inside	aroma	4	4	3	3	4	4	3	3
	flavour	4	4	3	2	4	4	3	2
Inside	elasticity	4	4	4	4	4	3	3	3
	porosity	3	4	4	3	3	4	3	3
	colour	4	4	3	3	4	4	3	3
	hardness	4	3	3	3	4	4	4	4
	adhesion	4	3	3	2	3	4	3	2
Points together		42	41	37	33	41	40	35	33

4 = excellent, 3 = very good, 2 = good, 1 = acceptable, 0 = unfit

At the end of the study a bakery experiment was made to give the most complex results of the amaranth flour effect on CO₂ trapping and final quality of bakery products. Results of this experiment are shown in Table 3. The specific volume values of breads have decreased with increasing substitution by amaranth flour (it corresponds with the results of dough volume in Table 2). It is probably caused by decreased gluten content and by its lower ability to retain gas and water steam. All baked products made from SWB had higher specific volume than all BW products, what is connected with the results of dough volume measured on SJA. The content of wet gluten at BW flour was high enough but its quality, especially number of imbibition, was significantly lower than for SWB flour. Binding of flour is very important for technological aspects (Table 3). With increasing substitution by amaranth flour binding of flour has increased, what is a very positive bakery aspect (more products) but with 20% substitution the dough has been more adhesive.

The sensory quality of products (Table 4, twelve quality values for each product) has slowly decreased with increasing substitution by amaranth flour. There was a change to worse quality of flavour (stronger amaranth flavour), colour of crust and inside (very deep) and camber (has lowered) and adhesiveness to palate (slightly increased) in the products with higher substitution (20%) by amaranth flour. Improved porosity of bread inside (more regular with softer pores) was determined for products of 10% and 15% (w/w) substitution of wheat flour by amaranth flour.

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ABSTRAKT

Vliv substituce pšeničné mouky amarantovou moukou na tvorbu kvasného plynu a jakost chleba

Byl sledován vliv náhrady části pšeničné mouky moukou amarantovou, v poměru 10, 15 a 20 %, především na produkci kvasného plynu (CO₂) a na kvalitu hotových výrobků – chlebů (specifický objem výrobků a senzorkou kvalitu). Z výsledků vyplývá, že 10% a 15% náhrada amarantovou moukou má pozitivní účinek na kvalitu těsta (zvyšila se vaznost mouky, zlepšila se zpracovatelnost těsta), množství vyprodukovaného CO₂ (zvýšení), pórovitost střídky chleba (pravidelnější a jemnější póry) a zvyšila se také nutriční hodnota produktů (obsah bílkovin). U 20% náhrady amarantovou moukou se výrazně snížil obsah lepku a tato hodnota substituce má negativní účinek i na kvalitu těsta (lepivé) a hotových výrobků (velmi malý specifický objem výrobků, výrazná chuť i vůně po amarantu).

Klíčová slova: amarant; substituce; mouka; kvasný plyn; chleba

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Simulated and observed sugar beet and spring wheat yields and yield variability in a long-term field experiment

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ABSTRACT

Potential and water-limited yields of sugar beet and spring wheat in the period 1964–1993 were simulated with the WOFOST 6.0 crop growth model. Three different available water contents in the upper 100 cm of the soil at emergence, 20, 15 and 10 cm (20 WAC, 15 WAC and 10 WAC, resp.) were simulated. Outputs of the model were compared with observed yields from a long-term field trial at Prague-Ruzyně, Czech Republic. The experiment was conducted in one field so each of the experimental crops was grown every other year. There were four fertilizer treatments, nil, organic, inorganic and a combination of the last two. Our study aimed to estimate the difference between simulated yields only limited by climatic factors and observed yields in the intensive two-crop rotation and to estimate yield variability. For the 15 years when beet was grown, the mean potential, water-limited (at 15 WAC) and actual yields (averaged over the four treatments) were 15.2, 12.3 and 10.9 t.ha⁻¹, resp. The equivalent figures for wheat were 8.3, 7.9 and 4.0 t.ha⁻¹. The inter-season variability of simulated water-limited beet yields reached 20–38% (the increase being due to decrease of WAC) and 22–34% in observed yields with higher values in nil treatment. The observed variability in wheat ranged from 16–21% in fertilized and nil treatments, while the variability of simulated yields ranged between 4–17%. The correlation between observed (fertilized treatments) and simulated water limited yields was better in sugar beet ($r = 0.60\text{--}0.75$) than in wheat ($r = 0.27\text{--}0.44$). There was no correlation between potential and observed yields in both crops. The analysis of residuals showed possible ways for improvement of simulation results.

Keywords: WOFOST model; potential yield; water-limited; variability; spring wheat; sugar beet

Crop models are used as a tool for answering questions in research, crop management and policy. Crop modelling has been used for estimating the extent of yield limitation by weather and non-weather related factors by comparing potential crop yields with the actual yield in a field (e.g. Aggarwal and Kalra 1994). The potential yields are calculated assuming an optimal supply of nutrients, pest-, disease- and weed free conditions, for either water-limited or non-limited conditions. Yield predictions and inter-annual yield variability reflecting fluctuations of weather conditions are of interest to government agencies, commodity firms and producers (Koning and Diepen 1992; Chipanshi et al. 1997; Supit 1997).

We used the WOFOST 6.0 crop simulation model (Hijmans et al. 1994; Supit et al. 1994) to quantify the yield gap between actual yields of sugar beet and spring wheat in a two-year crop rotation and simulated potential and water-limited yields. The inter-seasonal variability of observed and simulated yields was compared.

MATERIALS AND METHODS

Field experiment

A long-term field experiment was established in 1964 at the Research Institute of Crop Production in Prague-Ruzyně (50°05' N, 14°20' E) in Czech Republic to study

the long term changes of soil organic matter and total N (Klír 1995). A fixed two-year crop rotation of sugar beet – spring wheat was used from 1964 to 1993. The experiment was conducted in one field so each of the experimental crops was grown every other year. Wheat years were the odd ones (1967, 1969 ... 1993), sugar beet years were the even ones (1964, 1966 ... 1992). Throughout the experiment the same doses of inorganic and organic fertilizers were applied in four basic treatments: without fertilization (nil), only inorganic fertilizers (NPK), organic fertilization (FYM), and a combination of the previous treatments (NPK + FYM). The yields analysed here represent the average yields of subtreatments (different rates of phosphorus and potassium) of the four basic treatments. The actual observed yields were expressed as a dry matter (assuming that sugar beet has 23% dry matter, wheat grain 85%).

The soil is Orthic Luvisol, elevation 340 m a.s.l. The ground water level is about 20 m below the field surface, the upper 30 cm contains 27% clay, increasing to 40% in the 30–40 cm layer and to 49% in the 40–50 cm layer. The soil pH was about 6.5. Precipitation per year is 464 mm and temperature 8.0°C (long-term averages). Meteorological data from 1961–1993 are shown in Figure 1.

Cultivars of spring wheat in the experiment were: Zlatka (1967–1979), Mephisto (1981), Jara (1983), Sandra (1985–1993). Sugar beet: Dobrovická N (1964 and 1966), Dobrovická A (1968–1988), Semona (1990 and 1992).

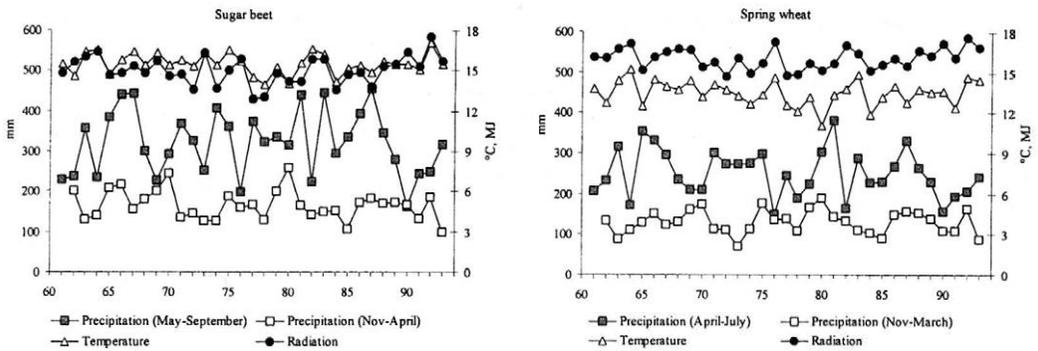


Figure 1. The average data on temperature, radiation and sum of precipitation for the growing period from May to September (sugar beet), from April to July (spring wheat) and inter-seasonal precipitation (November to March or April) in the years 1961–1993

Simulations

WOFOST 6.0, acronym for World Food Studies, is a generic crop growth model (Diepen et al. 1989; Hijmans et al. 1994; Supit et al. 1994). The suppliers of WOFOST 6.0 is Alterra in Wageningen, the Netherlands. WOFOST is a process-based model that simulates the potential and water-limited production of crops determined by crop species, soil type, hydrologic conditions and weather during the growing season. Potential yields indicate the production ceiling for farming non-limited by water, nutrients or other abiotic and biotic stresses. Crop growth and soil water balance are described with a time resolution of one day in the model.

We used sugar beet parameters supplied with WOFOST without changes. As the version of WOFOST model does not include a spring wheat crop data file, we constructed it by modifying winter wheat crop data input parameters with use of spring wheat parameters given in the literature (Laar et al. 1997 and others). The sums of effective temperatures were slightly modified according to experimental data of spring wheat grown in a nearby field trial in 1982–1985 (not shown). Time series of monthly mean values for minimum and maximum temperature, sunshine hours, wind speed and humidity, as well as daily precipitation data were available for the period 1961–1993 from the meteorological station three km from field site (Figure 1). We specified water available capacity (WAC = actual water content minus water content at wilting point) at emergence equal to 20, 15 and 10 cm water in 100 cm of soil profile (treatments 20 WAC, 15 WAC, and 10 WAC, resp.). In beet, water supply in spring estimated from inter-season precipitation (October–April) was used for the simulation as well. The amount of water supplied during the growth by precipitation was left unchanged, i.e. as observed.

We simulated potential and water-limited yields of spring wheat grain and sugar beet in the period 1964–1993. We performed simulations for both crops using the actual date of sowing. For sugar beet the final day of simu-

lation was determined as the day of beet harvest, while for spring wheat the final day was determined as the simulated date of maturity. From the national agriculture statistics (Švec 1998) a time series of average crop yields for wheat and sugar beet were abstracted for the experimental period. The linear trends of observed, simulated and national yields were calculated. Besides statistical national yields, detrended yields were recalculated assuming there was no increasing yield trend during the period, were used.

RESULTS

Sugar beet

Simulated and observed beet yields are shown in Table 1. The observed yields in nil and NPK + FYM treatments were on average of years 43 and 72% of potential simulated yields, resp., and 53 and 89% of water-limited (at 15 WAC) ones, resp. There were negative linear trends in the observed yields per year of 166 kg·ha⁻¹ and 83 kg·ha⁻¹ in nil and NPK + FYM treatments, resp. Average simulated potential beet yields were 15.2 t·ha⁻¹. The water limited simulated (15 WAC) yields were reduced to 81% of the potential ones. The variability (as coefficient of variability) of the observed yields (21.8–34.2%) was similar to the simulated water-limited ones, but twice of the potential non-limited yields (12.9%) (Table 1).

The positive correlation between observed yields and simulated water limited yields was in range of $r = 0.41$ – 0.59 and $r = 0.60$ – 0.75 in nil and fertilized treatments, resp. (Table 2, Figure 2). Potential yields were not correlated with the observed yields. The residuals after regression of the observed on simulated beet yields showed a positive relation to the sum of precipitation during May–September ($r = 0.66$) (Figure 3). Observed yields (fertilized treatments) were positively correlated with the sum of precipitation during May–September (Figure 4). When yields were simulated with water supply at emergence

Table 1. The summary of average simulated, observed and national sugar beet and spring wheat yields (t.ha⁻¹) and their variability (*CV* = coefficient of variation); nil, organic (FYM), inorganic (NPK) and combination of organic and inorganic fertilization treatments (NPK + FYM)

Period	Ruzyně 1964–1992				Potential	Water-limited		
	nil	FYM	NPK	NPK + FYM		20 WAC	15 WAC	10 WAC
	beet-observed				beet-simulated			
In beet years (1964, 1966, 1968 ... 1992) (<i>n</i> = 15)								
Average yield	6.6	9.3	9.4	10.9	15.2	13.3	12.3	10.4
<i>CV</i> (%)	34.2	24.5	27.6	21.8	12.9	19.6	26.5	37.6
National yields in beet years								
Average yield	8.0							
<i>CV</i> (%)	12.6							
	wheat-observed				wheat-simulated			
In wheat years (1967, 1969, 1971 ... 1993) (<i>n</i> = 14)								
Average yield	2.5	3.2	3.9	4.0	8.3	8.2	7.9	6.8
<i>CV</i> (%)	15.9	17.9	21.4	21.2	4.4	5.1	7.3	16.9
National yields in wheat years								
Average yield	3.0							
<i>CV</i> (%)	12.6							

estimated from the between-seasonal precipitation (October–April), the agreement between the observed and simulated yields slightly improved ($r = 0.80$) (Table 2).

Spring wheat

Wheat grain yields are shown in Table 1. There were negative linear trends of 6 kg.ha⁻¹ and a positive one of 31 kg.ha⁻¹ per year, resp., in observed nil and NPK + FYM treatment yields. Average simulated potential yields were 8.3 t.ha⁻¹. Water limited simulated yields at 20 WAC equalled the potential ones, and they were only by 0.4 t.ha⁻¹ lower

than the potential ones at 15 cm of initial water supply (15 WAC). The observed yields in NPK + FYM and nil treatments reached on average of years 51 and 32% of simulated yields (at 15 WAC), resp. (Table 1). The variability of observed yields (15.9–21.4%) was pronouncedly higher than the variability of simulated ones (4.4–7.3%), except for the 10 WAC treatment (16.9%) (Table 1).

The correlation between observed and simulated water limited yields in fertilized treatments ranged between $r = 0.27$ – 0.43 (Table 2). The exclusion of outlying years 1991 and 1993 from the correlation increased the agreement ($r = 0.62$). The residual from regression of the observed on simulated wheat yields (NPK + FYM treatment)

Table 2. The summary of correlation coefficients between observed, simulated and national yields (see legend to Table 1)

Sugar beet	Nil	NPK	FYM	NPK + FYM	CZ-beet (detrended)	CZ-beet (statistical)
Potential	0.16	-0.15	0.06	0.08	-0.01	0.01
20 WAC	0.59	0.67	0.67	0.72	0.61	0.49
15 WAC	0.53	0.70	0.67	0.75	0.58	0.51
10 WAC	0.41	0.64	0.60	0.71	0.49	0.47
Winter supply	0.51	0.72	0.67	0.80	0.64	0.60
CZ-beet (detrended)	0.47	0.63	0.52	0.61		
CZ-beet (statistical)	0.26	0.48	0.38	0.54		
Spring wheat	Nil	NPK	FYM	NPK + FYM	CZ-wheat (detrended)	CZ-wheat (statistical)
Potential, 20 WAC	-0.15	0.25	0.03	0.15	-0.13	0.35
15 WAC	-0.01	0.30	0.27	0.32	-0.17	0.22
10 WAC	0.21	0.34	0.40	0.43	-0.04	-0.06
CZ-wheat (detrended)	0.27	0.25	-0.08	0.34		
CZ-wheat (statistical)	0.02	0.56	0.36	0.47		

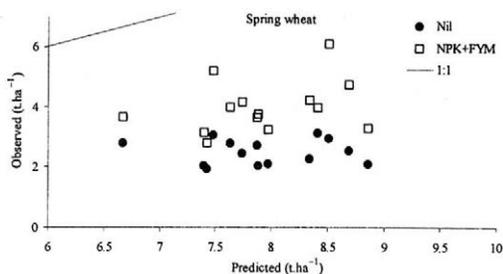
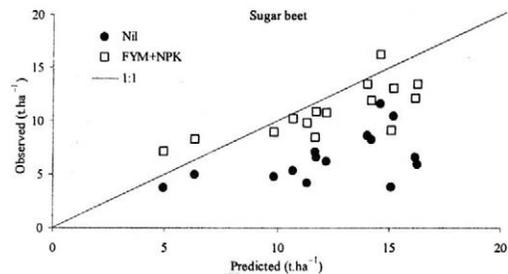


Figure 2. The relation between simulated water limited (at 15 WAC) and observed yields (in $t \cdot ha^{-1}$) of nil and combination of organic and inorganic fertilization (NPK + FYM) treatments in in Prague-Ruzyně (15 WAC = 15 cm of available soil moisture in 100 cm soil profile at emergence)

showed a positive relation to the average temperature during May and June ($r = 0.65$) (Figure 3). The observed yields were negatively correlated with the average temperature during April–July [$r = (-0.6) - (-0.73)$] and especially in April–May [$r = (-0.59) - (-0.82)$] (Figure 4).

Statistical yields of spring wheat and sugar beet in Czech Republic

Average national yields (in dry matter) of both sugar beet and spring wheat in the Czech Republic (Švec 1998)

were about 25% lower than the observed yields in NPK + FYM treatment (Figure 5). The calculated linear increase of beet yields during the period was $43 \text{ kg} \cdot ha^{-1}$ per year. However, it was less regular in beet ($r = 0.27$) than in wheat ($r = 0.89$). There was a positive relation between simulated water-limited and both statistical and observed yields. The calculated linear increasing trends of wheat during the period 1961–1993 were of 58 kg per year, almost the double the yield level at the beginning of the period. When wheat yields were corrected (detrended) for the linear trend, the variability was almost the same in both crops (14.3% and 14.8%).

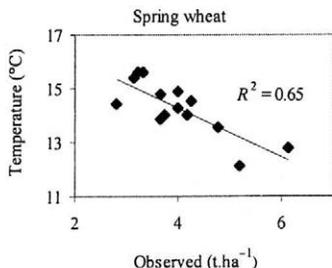
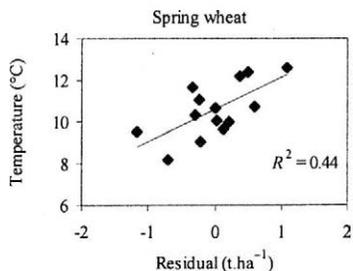
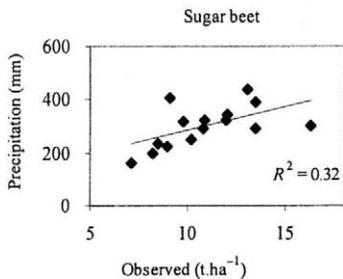
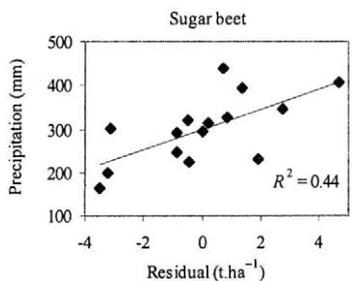


Figure 3. The relation between the residuals after linear regression of simulated (at 15 WAC) on observed yields (FYM + NPK) and average temperature (May–June) or sum of precipitation (May–September)

Figure 4. The relation between the observed yields and sum of precipitation (May–September) or average temperature (May–June)

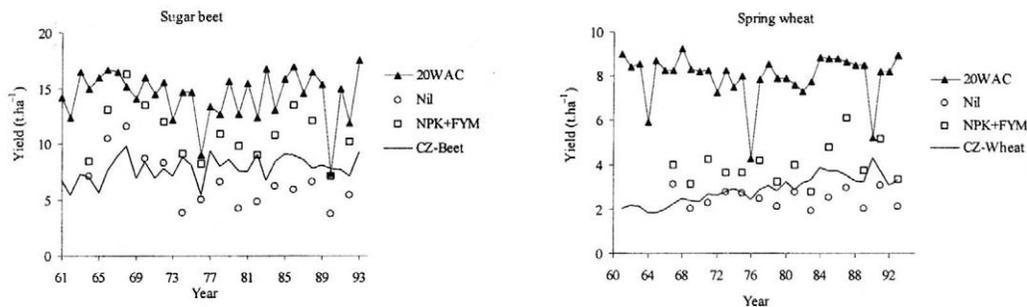


Figure 5. The comparison of statistical average yields of spring wheat and sugar beet ($\text{t}\cdot\text{ha}^{-1}$) in the Czech Republic (CZ), simulated (20 WAC) and observed yields in Prague-Ruzyně

DISCUSSION

We compared the observed yields in sugar beet and spring wheat from a long-term stationary field experiment in Prague-Ruzyně, Czech Republic, with the yields simulated by the WOFOST model.

The simulation of sugar beet yields corresponded better to observed field yields than that of spring wheat. A good agreement between simulated and observed yields in beet was supported (unlike wheat) by a positive relation between both observed and simulated yields and average statistical yields. Average simulated water-limited (15 WAC and 10 WAC) beet yields approached observed yields in fertilized treatments. In both crops potential and water-limited yields at 20 WAC overestimated observed yields. The high water supply 20 cm (20 WAC) represents field capacity of the rooted 100-cm depth of soil that can alleviate water shortage during dry periods.

The good relation of beet yield to the level of water supply or to water use (e.g. Groves and Bailey 1997) is well known. The total water consumption in spring cereals is lower than in beet (Roth et al. 1997); still, the effect of water-limiting conditions on simulated wheat yields in our simulation seems to be unrealistically weak. One of reasons may be that wheat crop is not able to utilise water supply in the whole 100-cm depth of rooted soil profile as assumed in the model. Jamieson and Ewert (1999) concluded in their analysis that root restriction (i.e. low density in deep soil layers) is often underestimated in wheat simulation models which results in overestimating of water uptake and soil water depletion under moderate to severe water limitation. According to our observations (Haberle, unpublished) the maximum rooting depth of spring wheat in a near field was between 80–120 cm in several years; water and mineral nitrogen was effectively utilized from 70–90 cm. On the opposite, sugar beet may be able to utilize deeper layers than spring wheat, so the increase of 100-cm rootable depth (as assumed in model) may slightly improve water-limited yields in beet.

High simulated wheat yields showed that climatic conditions, radiation and temperature were favourable for growth and high yields. However, the high yield poten-

tial was not realized in field due to some reasons. The gap is big, even when taking into consideration that plant parameters refer to modern intensive cultivars and the fact that wheat years, by chance, do not include the three most dry seasons in years 1964, 1976 and 1990. The average yields of both crops simulated in all years 1961–1993 were similar to the average yields in selected wheat or beet years (Haberle and Diepen 1999). Simulated wheat yield level is high but realistic considering today's top yields in Czech Republic. In favourable year 1990 the average yield of spring wheat in Czech Republic reached $5.1 \text{ t}\cdot\text{ha}^{-1}$. In our study the highest yields of both crops in fertilized treatments were about 25% higher than the republic averages that corresponds with common gap between farm and trial yield levels. It should be also mentioned that no forehead calibration of the model was done. The reliability of simulated wheat yields is supported by the similar level of spring barley yields simulated with the same input data in years 1965–1993 (not shown).

The negative relation between the residuals of regression of simulated on observed wheat yields and average temperature and the corresponding negative relation between average temperature and observed yields suggest that the agreement between predicted and observed yields could be improved by a modification of crop input physiological data in the model. A high radiation and temperature produce high potential yields. However, early sowing especially in years with a warm spring, is known to be decisive for high yields in spring wheat. A prolonged period of a relatively cold weather in spring supports tillering and formation of a greater number of grain in developing ear as opposite to a hot weather when development is too fast (Petr et al. 1988).

The results of comparisons of simulated and observed wheat yields in a long period accomplished by other authors vary from case to case. Moulin and Beckie (1993) used two simulation models to predict spring wheat grain yield for long term (1960–1989). Both models poorly predicted annual yields ($r^2 = 0.16$), but long-term mean yield was predicted better. Roloff et al. (1998a, b) found that simulation explained of 18 to 66% the variability observed in a spring wheat long-term experimental trial (1967–1993)

in ten different treatments. Touré et al. (1994) found great differences between five simulation models used for spring yield wheat in the period 1912–1992 ($R^2 > 0.25$) and according to Moulin and Beckie (1993), the models underestimated yields in high-yielding environments and overestimated those in low-yielding ones. Donatelli et al. (1997) concluded that CropSyst model was not able to predict durum wheat yield contrary to several other crops in the study. The authors remarked that rotation effects caused a large amount of variability. As for beet, for example according to Smit and Struik (1995) the mean explained variance from the analysis of six models used for beet yields from several fields, regions and years varied between 10–67%.

The reasons of the yield gap between the potential and realized yields are believed to be due to phytopathology problems. The recommended maximal concentration of beet is about 20% but no unusual phytopathology problems were observed in the experiment. Other factors which affect crop growth and yield along a long period include change of cultivars, farm machinery (sowing, soil tillage, harvest technology) and use of agrochemicals. Also changes of soil fertility in a long-term experiments (Klír 1995) may differentially affect the water relation or nitrogen dynamics in soil, especially in dry and wet years. Roloff et al. (1998a) found that water dynamics in a soil profile under spring wheat was properly simulated and it was probably not responsible for a poor agreement between the simulated and observed spring wheat yields in long-term trials (Roloff et al. 1998b). However, the authors found a low precision of nitrate-N prediction, especially in deeper layers (also Smit and Struik 1995). Further, year-to-year variation in root depth modifies the access of a crop to the nitrate leached to subsoil and water reserves (Haberle et al. 1999; Haberle and Svoboda 2000).

CONCLUSIONS

We found a good agreement between the simulated water-limited and observed yields in sugar beet and a weak relation in spring wheat in a long-term field experiment. The model also satisfactorily predicted year-to-year yield variability in beet. Regression analysis showed the possible way for improving the results of the simulation.

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ABSTRAKT

Simulované a pozorované výnosy a výnosová variabilita cukrové řepy a jarní pšenice ve víceletém polním pokusu

Pomocí růstového modelu WOFOST jsme simulovali potenciální a vodou limitované výnosy cukrové řepy a jarní pšenice v letech 1964 až 1993. Výstupy modelu byly porovnány s experimentálními výsledky z dlouhodobého polního pokusu v Praze-Ruzyni. Tento pokus probíhal na jednom pozemku, kde se střídaly cukrovka (celkem 15 ročníků) a pšenice (celkem 14 ročníků). Použili jsme výnosové údaje ze čtyř variant: bez hnojení, pouze organické nebo anorganické hnojení a kombinace dvou předchozích. Simulaci výnosů jsme provedli pro potenciální nelimitované podmínky a vodou limitované podmínky se třemi odlišnými scénáři zásoby dostupné vody na počátku vegetace ve vrstvě půdy 0 až 100 cm: 20, 15 a 10 cm vody (označeno 20 WAC, 15 WAC a 10 WAC). Byly použity denní údaje o srážkách a průměrné měsíční hodnoty teploty, radiace a vlhkosti vzduchu (obr. 1). Cílem práce bylo určit rozdíl mezi simulovanými a pozorovanými výnosy v intenzivním osevním postupu a rozdíl ve variabilitě výnosů. Průměrné potenciální, vodou limitované (při 15 WAC) a pozorované výnosy cukrovky (průměr variant hnojení) dosáhly v přepočtu na absolutní sušinu 15,2, 12,3 a 10,9 t.ha⁻¹. Odpovídající údaje pro pšenici byly 8,3, 7,9 a 4,0 t.ha⁻¹ (tab. 1). Nejvyšší výnosy poskytovala u obou plodin varianta s kombinací organického a minerálního hnojení. Meziroční variabilita simulovaných, vodou limitovaných výnosů cukrovky stoupala s klesající jarní zásobou vody v půdě (WAC) z 20 na 38 % (tab. 1). Meziroční variabilita výnosů cukrovky se pohybovala mezi 22 a 34 %; nejvyšší byla u nehnojené varianty. Variabilita simulovaných výnosů pšenice byla nízká (5 až 17 %) ve srovnání s variabilitou pozorovaných výnosů (16 až 21 %) (tab. 1). Korelace mezi pozorovanými a simulovanými výnosy byla lepší u cukrovky ($r = 0,60$ až $0,75$) než u pšenice ($r = 0,27$ až $0,44$) a u obou plodin byla těsnější u hnojených variant než u nehnojené kontroly (obr. 2, tab. 2). Potenciální vodou nelimitované výnosy neměly vztah k výnosům v polním pokusu. Výnosy pšenice byly v negativní korelaci s průměrnou teplotou v době vegetace, u cukrovky jsme zaznamenali dobrý vztah výnosů a úhrnu srážek (obr. 4). Současně jsme zjistili, že reziduál z regrese pozorovaných a simulovaných výnosů pšenice měl negativní vztah k průměrné teplotě v období duben až květen ($r = -0,66$) a u cukrovky jsme zjistili kladnou korelaci mezi reziduálem a soumou srážek ve vegetačním období ($r = 0,65$), což ukazuje na možnosti zlepšení výsledků modelováním (obr. 3).

Klíčová slova: model WOFOST; potenciální výnos; vodou limitovaný výnos; variabilita; jarní pšenice; cukrová řepa

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K životnímu jubileu prof. Ing. Jiřího Petra, DrSc., Dr. h. c.

Prof. Jiří Petr je uznávanou osobností mezi rostlináři a obilnáři u nás i v zahraničí. Narodil se 13. května 1931 v Hradci Králové v rodině sládků. Po absolvování reálného gymnázia vystudoval Vysokou školu zemědělskou v Praze, kde po ukončení studia v roce 1953 začal pracovat na katedře rostlinné výroby nejdříve jako vědecký aspirant a od roku 1956 jako odborný asistent. V roce 1966 se habilitoval na docenta v oboru speciální produkce rostlinná, v roce 1989 mu byl udělen titul doktora věd a posléze byl jmenován profesorem. Díky svým vědeckým, pedagogickým a organizačním schopnostem vykonával v letech 1990 až 1994 funkci rektora VŠZ. Pod jeho vedením škola významně rozšířila spolupráci s řadou univerzít a vědeckých institucí v Evropě i jinde ve světě.

Vědecká osobnost prof. Petra přerostla české poměry a stal se uznávanou evropskou vědeckou kapacitou. Za celoživotní vědeckou práci v oblasti obilnářství mu byl udělen v roce 1999 na švédské zemědělské univerzitě v Uppsale čestný doktorát agronomie.

Vědeckou dráhu zahájil prof. Petr v roce 1953 studiem biologie českých pšavíek. Ve své kandidátské práci se zabýval kombinací vlivu fotoperiody a jarovizace na generativní vývoj těchto forem pšenice. V 50. letech se zaměřil na otázky zimovzdornosti pšenice a postupně celou problematiku produkčních procesů u obilnin. Významným přínosem prof. Jiřího Petra je propojení růstové analýzy – tvorby biologického výnosu s tvorbou jednotlivých výnosových prvků tvořících strukturu hospodářského výnosu. Dynamické pojetí, které u nás zavedl, umožňuje kvantitativní hodnocení změn při tvorbě jednotlivých výnosových prvků v čase, určení kritických období pro tvorbu jednotlivých výnosových prvků a návrh regulačních opatření. Rostlinná produkce se stala pod jeho vedením tvůrčím procesem. Výsledky těchto výzkumů shrnul prof. Petr s kolektivem autorů v knize *Tvorba výnosů polních plodin*, která u nás vyšla v roce 1980 a následně byla přeložena do čtyř jazyků.

Rozpracováním teorie tvorby výnosu obilnin byl vypracován systém agrobiologické kontroly porostu, který významně přispěl k zavedení moderní agrotechniky a k ústupu od jejího tzv. receptářského pojetí. Aplikaci výsledků výzkumu do praxe napomohly publikace *Intenzivní obilnářství*, *Rukověť agronoma*, řada metodik pro praktické pěstování obilnin i desítky tzv. polních kázání, přednášek a odborných článků. Výsledky studia odrůdových zvláštností při tvorbě výnosu přispěly také k formování systému odrůdového zkušebnictví. Prof. Petr řadu let pracoval jako předseda státní odrůdové komise při MZe ČR a podílel se na zavedení tzv. odrůdové agrotechniky. Současně vystihl i význam variability ročníku v podmínkách klimatu střední Evropy. Teoretické podkla-

dy a výsledky řady pokusů shrnul se spoluautory v knize *Počasi a výnosy*. Tato vynikající publikace byla rovněž přeložena do několika jazyků. Její praktická aplikace vyústila do rozpracování ročníkových agrotechnik.

V následných letech se prof. Petr podílel na vytváření koncepce účelových pěstebních technologií podle zaměření produkce a užitkových směrů, nejdříve u sladovnického ječmene a potravinářské pšenice, později i pro škrobářenskou pšenici. Vedle těchto hlavních obilnin věnoval prof. Petr pozornost i dalším druhům, jako je žito, tritikale, proso, pohanka a laskavec, a v nemalé míře i luskovinám. Alternativní plodiny měly blízko i ke studiu problematiky alternativního a ekologického zemědělství, pro jehož propagaci vykonal prof. Petr v 90. letech mnoho záslužné práce. Stejně intenzivně se v posledních letech věnuje otázce kvality cereálií.

Rozsáhlé vědecké činnosti odpovídá i jeho bohatá publikační činnost, kterou představuje 75 původních vědeckých prací, 210 referátů na vědeckých konferencích, 260 odborných článků, 20 metodik pro zemědělskou praxi a 54 monografií určených pro studenty i odbornou veřejnost. Prof. Petr je řešitelem řady výzkumných projektů a grantů, v současné době předsedá komisi Grantové agentury ČR Rostlinná produkce, šlechtění a genetika rostlin, je předsedou redakční rady časopisu ČZU Scientia Agriculturae Bohemica a redakční rady časopisu Úroda. Byl členem různých vědeckých společností, komisí a vědeckých rad domácích i zahraničních institucí.

Rozsáhlé zkušenosti z vlastní výzkumné práce i aktuální poznatky, získané též díky širokým zahraničním kontaktům, předal prof. Petr stovkám posluchačů – studentům i odborníkům z praxe při přednáškách, cvičeních, seminářích apod. Jeho vystoupení jsou vždy vysoce odborně fundovaná, bohatá na praktické poznatky a ukazují směr vývoje do budoucnosti. Proto jsou jeho přednášky hojně navštěvovány a velmi ceněny. Vysoká invence se projevuje v době zadaných tématech diplomových a dizertačních prací, která jsou vždy aktuální, úzce spjatá s výzkumnými úkoly a napomáhají řešit problémy praxe či ověřit hypotézy základního výzkumu. Prof. Petr dokáže obdivuhodně přenášet své nadšení na své okolí, proto má vždy tolik zájemců o spolupráci. K vědecké práci vychoval jako své pokračovatele a následovníky více než 100 diplomantů a přes 20 doktorandů. Úspěchy si nenechává pro sebe, rád se podělí o zkušenosti a poznatky, které ochotně předává dál, a pomáhá rozvíjet vědecké i osobní kvality svých spolupracovníků. Je příkladem člověka, jenž zasvětil svůj život vědě a vzdělávání.

Doc. Ing. Jan Moudrý, CSc.

Doc. Ing. Jan Křen, CSc.

Doc. Ing. František Vrkoč, DrSc.

Pseudogetreidearten – Buchweizen, Reismelde und Amarant Pseudoobilniny – pohanka, merlík a laskavec

W. Aufhammer

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Jednou z cest restrukturalizace rostlinné výroby je zavádění alternativních plodin rozšiřujících diverzitu osevních postupů i spektrum rostlinných produktů pro spotřebitele. Kniha prof. Dr. W. Aufhammera je významným příspěvkem přibližujícím tři ve světě aktuální pseudoobilniny, z nichž pohanka je u nás tradiční, ale opomíjenou kulturní plodinou, zatímco merlík i laskavec byly dosud známy spíše jako plevelné rostliny. Autor čerpá z dlouholeté výzkumné práce svého kolektivu s těmito plodinami. Více než polovina údajů v knize jsou vlastní výsledky a navíc cituje 160 a odkazuje na dalších 78 odborníků, specialistů na dané plodiny.

Kniha je rozčleněna do tří základních částí, jak je zřejmé z názvu. V úvodu představuje autor vybrané pseudoobilní druhy a charakterizuje jejich společné vlastnosti a vzájemné odlišnosti. Rozsáhlá a zajímavá je kapitola o původu a historii pěstování pojednávaných rostlin, jejich šíření a hodnocení současného stavu vývoje ploch, výnosů a produkce v jednotlivých částech světa.

Uvedené pseudoobilniny náleží v botanickém systému k různým rodům, mají poměrně pestré druhové členění s řadou poddruhů, agroekotypů a forem s výraznými morfologickými, fyziologickými i užitkovými vlastnostmi. Významným příspěvkem knihy je začlenění přehledu důležitých institucí zabývajících se uvedenými plodinami. Autor uvádí seznamy genetických zdrojů v jednotlivých genových bankách i charakteristiky vybraných odrůd. Současně vytyčuje šlechtitelské cíle a agronomické i zpracovatelské požadavky, resp. doporučené parametry

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Standardně je členěna kapitola o pěstování vybraných plodin. Autor vychází převážně z řady pokusů prováděných na pokusných bázích univerzity ve Stuttgartu-Hohenheimu. Zvláštní pozornost je věnována problematice vzházejivosti a vyrovnanosti porostů, odolnosti proti stresovým faktorům, zvláště biotickým faktorům redukcujícím výnos a kvalitu a otázkám dozrávání porostů, sklizně a sklizňových ztrát. Významné jsou poznámky o dalším využití pohanky, laskavce a merlíku jako zelenin, píce, ale i okrasných rostlin a o jejich mimoprodukční funkci.

Od erudovaného vědce a pedagoga dostáváme do rukou hutnou, srozumitelnou, zajímavou a inspirující, tedy velmi kvalitní vědeckou publikaci. Specifikou knihy je i její styl. Autor neodděluje jednotlivé plodiny, ale ve všech kapitolách i dílčích hodnoceních je vždy porovnává a hodnotí společně. Na první pohled se zdá obtížnější se v knize orientovat, o to více však inspiruje k přemýšlení. Kniha je univerzálně použitelná pro praktiky, studenty vysokých škol i odborníky z výzkumu.

Doc. Ing. Jan Moudrý, CSc.

POKYNY PRO AUTORY

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Manuscript layout: paper of standard size (210 × 297 mm), double-spaced typescript. A PC diskette should be provided with separate text and graphic files. Tables, figures and photos should be enclosed separately. The text must contain references to all these appendices.

If any abbreviation is used in the paper, it is necessary to mention its full form for the first time it is used, abbreviations should not be used in the title or in the summary of the paper.

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Introduction has to present the main reasons why the study was conducted, and the circumstances of the studied problems should be described briefly.

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Only original **methods** should be described, in other cases cite the method used and any modifications. This section should also contain a description of experimental material.

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