ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS
SBORNÍK MENDELOVY ZEMĚDĚLSKÉ A LESNICKÉ UNIVERZITY V BRNĚ

Ročník LIV 14 Číslo 1, 2006

INFLUENCE OF POTASSIUM ON GROWTH, CONTENT OF MINERAL NUTRIENTS AND YIELD FORMATION OF THE SPRING BARLEY (*HORDEUM VULGARE* L.)

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Received: September 18, 2005

Abstract

ZEHNÁLEK, J., ADAM, V., KIZEK, R.: *Influence of potassium on growth, content of mineral nutrients and yield formation of the spring barley (Hordeum vulgare L.)*. Acta univ. agric. et silvic. Mendel. Brun., 2006, LIV, No. 1, pp. 145–154

In model experiment, an influence of increasing KCl doses on spring barley growth, accumulation of main mineral nutrients (N, P, K, Ca, Mg and Na) in main stalks, offshoots and roots and on yield formation and its structure was observed. Increase of weight of above-ground parts of plants was inhibited only at the beginning of experiment by increasing KCl doses, particularly, significantly lower growth of offshoots, but on the other hand production of dry weight of roots was negatively influenced during whole cultivation. Accumulation of main mineral nutrients in the plants was mostly influenced at potassium. Uptake of potassium by plant increased up to 37%. Yield of kernels was higher at variants with application of KCl but the correlation between higher K doses and the yield increase has not been statistically proved. Increase in the yield was reached by higher number of offshoots, higher number of kernels and higher weight of kernels in comparison with control. Content of main mineral nutrients in kernel was not influenced by application of KCl, but potassium content in straw was significantly increased.

Barley (*Hordeum vulgare* L.), plant nutrition, potassium, transport, yield formation, growth, mineral nutrients

Plants can uptake nutrients from the soil solution. Different mechanisms participate in the input of the nutrients to root hairs: in the case of potassium, the diffusion (78%) and the mass flux (20%) dominate ACHE et al. (2001); BERGMANN and NEUDERT (1976). The active (pumps, carriers) and passive (diffusion, mass flux) mechanisms contribute to the uptake of constituent nutrients PRZULJ and MOMCILOVIC (2003); ZEHNÁLEK and PROCHÁZKA (1986). Potassium plays a key role in the stomatal movement and it impacts the water balance of plants HUGOUVIEUX et al. (2002). Plants take potassium in an active and a passive way, as seen in cation K^+, depending on its concentration in the nutritive medium AMTMANN et al. (1999); KARLEY et al. (2000); MAATHUIS and SANDERS (1996); SANTA-MARÍA et al. (2000); SHABALA (2003). In low concentration, transport by carriers takes place. In high concentration, plasma membrane is more permeable and K^+ passive movement with transpiration flow prevails. The electrochemical gradient decreases on the inner part of the plasmatic membrane and because of this there is non-specific inhibition of the uptake of the other cations ENGELS and MARSCHNER (1993). Potassium availability in both agricultural and natural ecosystems frequently limits plant growth, development, and productivity. K^+ is most abundant cation in plant cells, and activates a wide range of biochemical reactions, including many that are central to primary metabolism and mRNA translation MAATHUIS and SANDERS (1996). Potassium also activates the osmotic potential in sieve tubes and thereby the speed of transport of assimilates source – sink DEEKEN et al. (2002).

The aim of this work was to investigate the influence of the uptake of potassium on growth content of main mineral nutrients (N, P, K, Ca, Mg and Na) at roots and shoots and yield formation at spring barley.

MATERIALS AND METHODS

Plant material: Spring barley (*Hordeum vulgare* L. convar. Zenit) was cultivated in Mitscherlich pots containing 6 kg soil with siliceous sand in ratio 1 : 1 (*m/m*). The soil (soil type: Cambisol, texture class: sand) used in the experiment was characterized ($mg.kg^{-1}$) according to Mehlich II MEHLICH (1978): P 37, K 103, Ca 2150, Mg 63 and pH/KCl 7.1. Fourteen days before sowing of barley the soil was fertilized by solutions of these mineral fertilizer: DAM – 390 (42.2% NH_4NO_3 and 32.7% urea); superphosphate – 8.3% phosphorus in the form of $Ca(H_2PO_4)_2$ and potassium salt – 49.8% potassium in the form of KCl. The scheme of the experiment and the doses of fertilizer per pots are given in Table I. Twenty-eight barley kernels were sown into the each Mitscherlich pot. After germination, 20 seedlings were left in each pot. The rest of them were removed. For each experimental variant (see Tab. I; K0, K1 and K2) 16 pots was used. The experiment was carried out in vegetational hall in 2004. A sufficient wetness of soil was kept by needful additions of demineralised water, which is measured in volume to each pot.

I: *Design of experiment*

Variant No.	Marking	Additional fertilization (g/pot)		
		N	P	K
1.	K0	0.40	0.35	0.00
2.	K1	0.40	0.35	2.00
3.	K2	0.40	0.35	4.00

Plant harvesting: A plant harvesting was done four times during growing season: I. harvesting at the beginning of shooting (28th days of cultivation) – GS 30 ZADOKS et al. (1974); II. harvesting after detection of last leave (43rd days of cultivation) – GS 37, III. harvesting after heading of the ear (54th days of cultivation) – GS 59 and harvesting after reaching the full maturity (96th days of cultivation) – GS 91. Plants were harvested from four pots of all variants at each harvesting time. Above-ground parts of harvested plants were divided on main stalks and offshoots. Roots of the plants were obtained from soil by water flooding.

Preparation of plant samples and its analysis: Fresh and dry weight determination and mineralization of plant material by solution containing H_2SO_4, H_2O_2 and selenium. Content of N, P, K, Ca, Mg and Na was determined in mineralised plant samples JONES et al. (1991). Content of N was determined by Kjeldahl method, P by spectrophotometry method, Ca and Mg by atomic absorption spectrometry method and K and Na by atomic emissive spectrometry.

Analysis of soil: Soil samples were taken from Mitscherlich pots due to determination of pH, concentration of KCl and content of available nutrients after plant harvest. Content of main mineral nutrients at the end of the experiment is shown in Tab. II.

II: *Content of mineral nutrients at the end of the experiment*

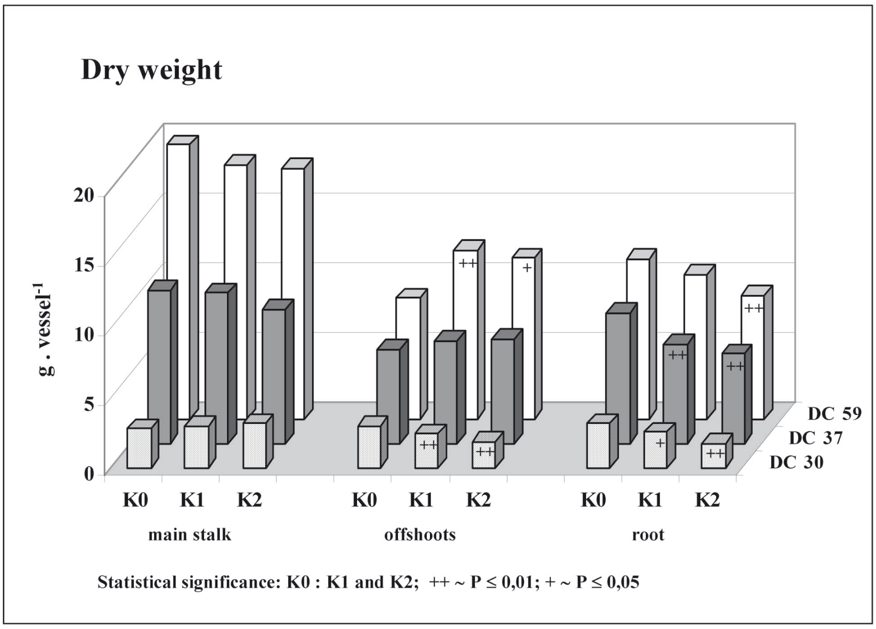
Marking	pH/KCl	Content of mineral nutrients (mg/kg)		
		P	K	Mg
K0	6.0	63	41	74
K1	6.4	76	145	78
K2	6.5	71	325	77

Statistical analysis and calculation: STATGRAPHICS® (Statistical Graphics Corp®, USA) was used for statistical analyses. The results were processed statistically and evaluated by the standard analysis of variance. Values of $p \leq 0.01$ and 0.05 were considered significant. R/S – weight ratio of above-ground and underground parts of plants.

RESULTS AND DISCUSSION

A vegetal production depends on uptake of mineral nutrients by plants ZEHNÁLEK et al. (2004). In our previous work, we studied the influence of potassium on spinach *Spinacia oleracea* L. MINÁŘ et al. (1989). In pot cultures with soil the effect was followed of fertilization with intensified doses of potassium in the form of KCl or K_2SO_4 at two levels of nitrogen nutrition. Additional fertilization with nitrogen and potassium resulted in an increased production of biomass. Only the highest dose of KCl had an inhibitory effect similarly to the lower doses. In the present study we decided to study influence of potassium on other plant species (spring barley).

Plant growth. Growth of spring barley (*Hordeum vulgare* L.) was evaluated by determination of dry and fresh weight during cultivation of main stalks, offshoots and roots (Fig. 1). Plant growth at GS 30 was inhibited by potassium doses (2 and 4 g per pot in the form of KCl) (see Fig. 1). We noticed dry weight decrease of above-ground parts (main stalks and offshoots) about 5.7 and 13.2% at K1 and K2, respectively, in comparison with K0 (control). Markedly slower growth of offshoots participated on decrease in dry weight of above-ground parts of plants. Dry weight of roots decreased about 20.3 and 46.2% at K1 and K2, respectively, in comparison with control.



1: *Dry weight of spring barley during cultivation at two different KCl doses. Other details in Material and Methods.*

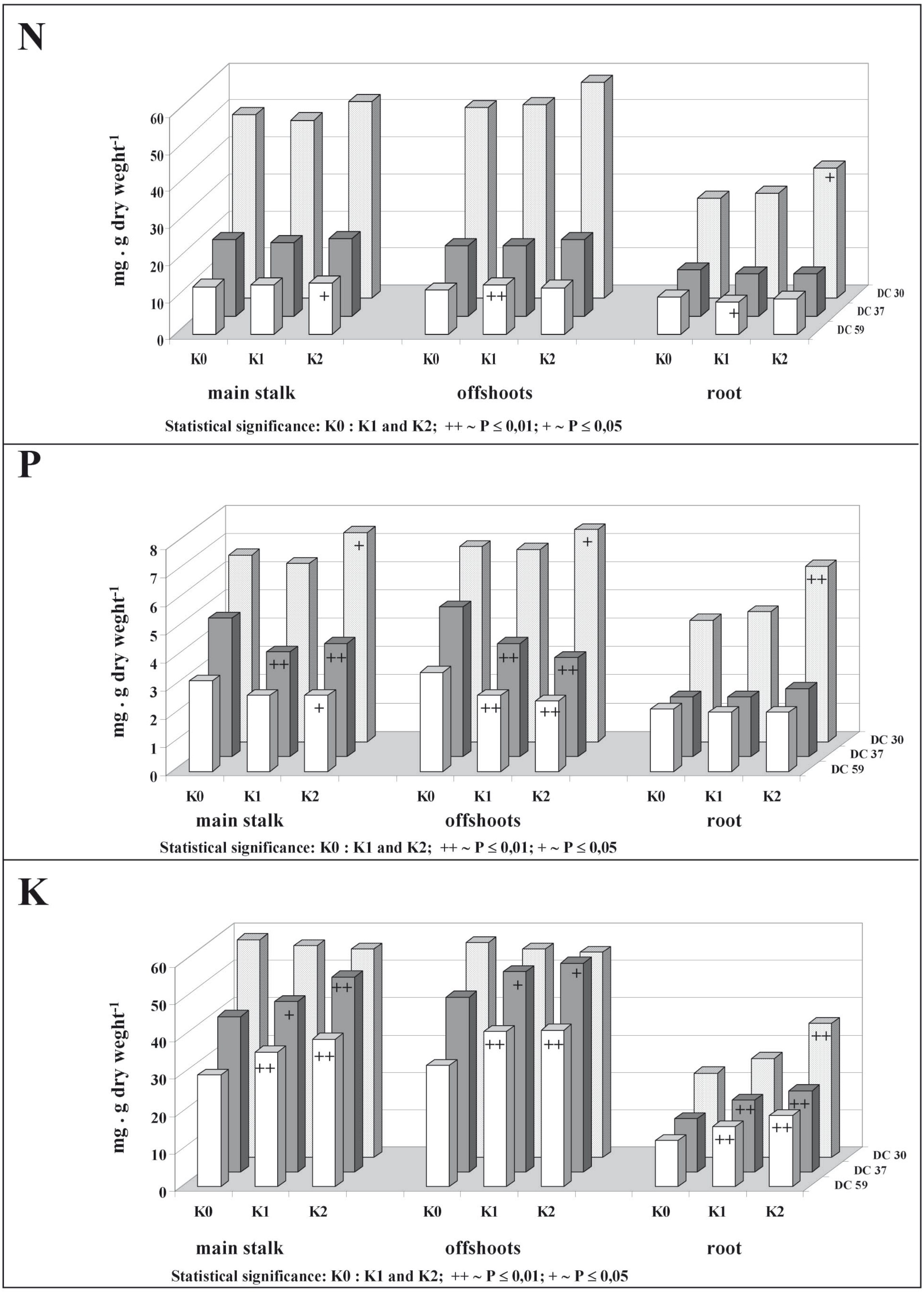
Presence of Cl^- in the soil also markedly influences plant growth and development. It is necessary to study the content and influence of this element BRITTO et al. (2004); CUIN et al. (2003); PEUKE and JESCHKE (1999). That is why the growth of spring barley was also influenced by increasing doses of Cl^-. The Cl^- anion does not form complexes readily, and shows little affinity (or specifity) in its adsorption to soil components. Thus, Cl^- movement within the soil is largely determined by water flows. Chloride is a useful element for higher plants, although it often accumulates in soil to levels much higher than required for optimal plant growth. It is present mainly as Cl^-. Chloride is a major osmotically active solute in the vacuole and is involved in both turgor- and osmoregulation. In the cytoplasm it may regulate the activities of key enzymes WHITE and BROADLEY (2001); XU et al. (2000). In general, there appears to be no consensus regarding either the regulation of Cl^- uptake XU et al. (2000), or the mechanisms of Cl^- toxicity. Recently the tolerance on Cl^- of different genotypes of barley was tested FLOWERS and HAJIBAGHERI (2001).

At second harvest time (GS 37), differences in dry and fresh weight of whole plant between K1, K2 and control (K0) did not observe (see Fig. 1). Fresh weight of main stalks decrease with increasing potassium doses. On the other hand, the decrease was compensated by increase in fresh and dry weight of offshoots. Furthermore, dry weight of roots decreased about 23.8 and 31.7% at K1 and K2, respectively, in comparison with control. We didn't notice differences in total dry weight of the above-ground parts of plants at GS 59. On the other hand we determined at plants K1 markedly increased weight of offshoots (about 40.1%) in comparison with control. Dry weight of roots was significantly lower only at K2 variant (about 23.1%). Ratio of weight of R/S (root/shoot) was decreasing with increasing KCl doses and with time of plant cultivation.

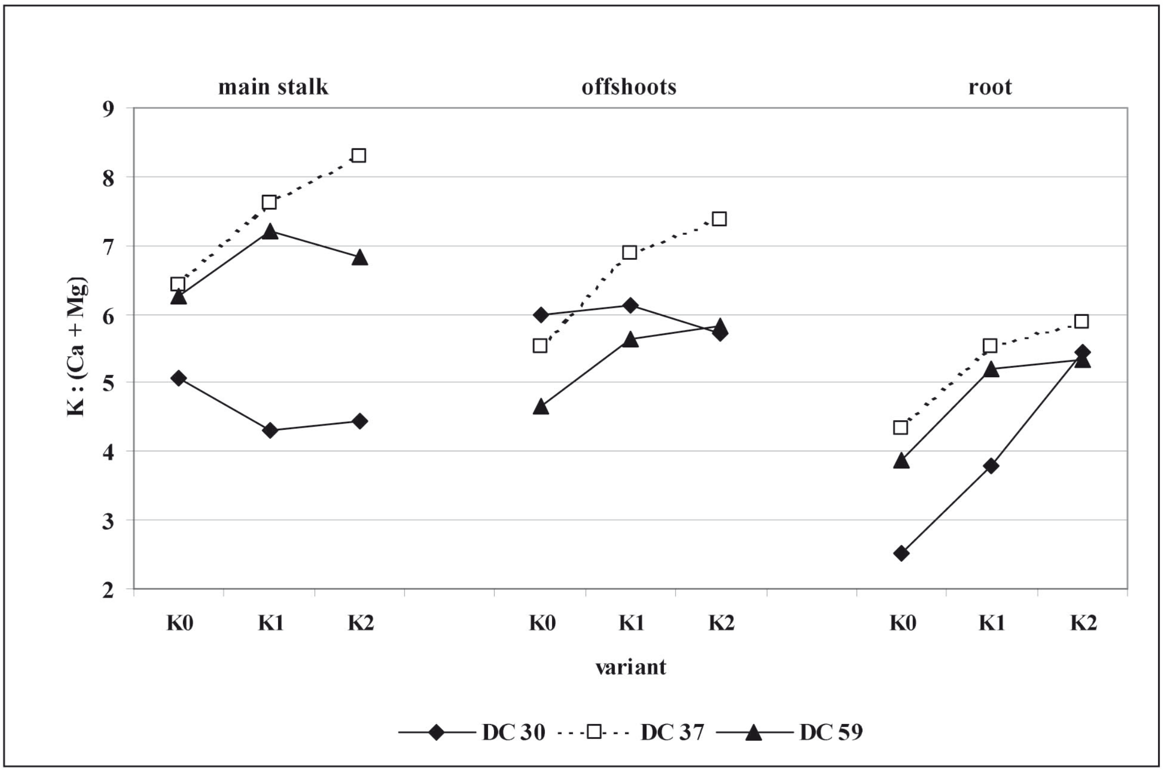
Accumulation of main mineral nutrients during cultivation. We determined the highest content of main nutrients (N, P, K, Ca, Mg and Na) in GS 30 samples whereas content of the elements in dry matter of above-ground parts was markedly higher then their content in dry matter of roots with the exception of magnesium and sodium. Content of main nutrients in plant dry matter markedly decreased in connection with time of cultivation (see Fig. 2). An accumulation of potassium was mostly influenced by applied KCl doses. We determined significantly increased content of potassium in dry matter of roots of K2 plants already at GS 30. Furthermore at GS 37 we detected significantly increased content of potassium in dry matter of roots and above-ground part of K1 and K2 plants. We observed the same result of potassium content at GS 59 in comparison with control plants.

Although content of potassium in dry weight decreased during cultivation, its uptake by plant was increasing. The uptake of potassium by above-ground parts in experimental variants K1 and K2 was higher about 33% and 37%, respectively, than in control plants. In spite of number of information about uptake, mobility and metabolic functions of main elements, it is less known about its interaction. Many important energetic bio-synthetic plant processes, which influence quantity and quality of produced biomass, depend on amounts and weight ratio of K : (Ca + Mg) MINÁŘ et al. (1989); MISRA and GEDAMU (1989); ZEHNÁLEK and MINÁŘ (1991). We calculated this ratio in our experiment (see Fig. 3). The ratio of K : (Ca + Mg) was increasing with increasing KCl doses.

The yield and its structure. Overall yield of kernels that is exposed by higher KCl doses (variants K1 and K2) was higher at K1 and K2 about 7 and 11% in comparison with control (K0) (Fig. 4). The increase in yield was reached by significantly higher yield of kernels from offshoots. Yield of kernel from offshoot at plants of K1 and K2 was higher about 25.4 and 59.4% in comparison with control. Rate of offshoots on overall yield of kernel was increased from 26.5% at control plants (K0) to 38% at exposed plants (K2). Increase in yield of kernels was obtained by increasing in number of kernels per plant (increase at K1 and K2 about 3.4 and 17%, respectively), by higher number of kernels in spikes of offshoots and by significantly higher weight of offshoot kernels from exposed plants (K1 and K2) in comparison with control. On the contrary, number of kernels in spikes of main stalks and its weight decreased at exposed plants in comparison with control (Table III).



2: *Accumulation of nitrogen, phosphorus and potassium in spring barley during cultivation. Other details in Fig. 2 and Material and Methods.*



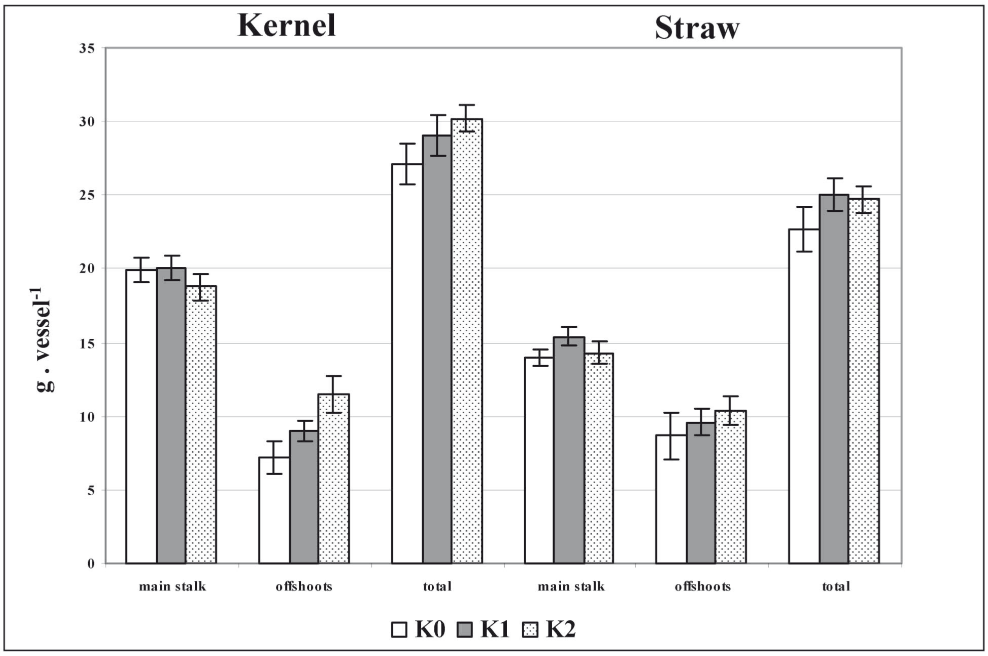
3: *The effect of increasing doses of potassium on the ratio of K : (Ca + Mg) in the dry mass of the plant parts of spring barley*

III: *The influences of two different KCl doses in plants of the spring barley grown in Mitscherlich pots on offshoot formation, number of kernels in the ear and weight of one thousand kernels*

Paramerter	Plant part	Variant K0	K1	K2
Number of the ear in one pot	main stalk	20.0	20.0	20.0
	offshoots	14.7	15.2	17.2
Number of kernels in one ear	main stalk	20.2	19.5^{+}	18.9^{++}
	offshoots	12.6	13.2	14.9
Weight of thousand kernels (g)	main stalk	48.1	47.2	45.6^{+}
	offshoots	38.4	42.4^{+}	41.5^{+}

K0 = 0 g K per pot, K1 = 2g K per pot, K2 = 4 g K per pot
Statistical significance: K0 : K1 and K2; ++ ~ P ≤ 0,01; + ~ P ≤ 0,05

Significantly differences in yield of straw between exposed plants and control plants were not observed (Fig. 4). Thus, the effect of K doses on increase in yield formation has not been proved. Kernel harvest index was: K0 = 54.5%, K1 = 53.7% and K2 = 55%. The influence of an interrupted K fertilisation on different K fractions of the soil, yield formation and K uptake by different crops was also investigated in a long-term field experiment on Luvisol derived from loess by SCHERER et al. (2003). Omitting K fertilisation decreased yields of sugar beet and potatoes while cereals were not affected, although K uptake of all crops reacted to the differentiated K supply to a different extent MENGEL and KIRKBY (1980).



4: *Yield of the spring barley cultivated in Mitscherlich pots at two different KCl doses*

Content of main mineral nutrients in full maturity of barley. Markedly differences in content of main mineral nutrients (N, P, Ca, Mg and Na) in kernels, main stalks and offshoots were not observed. In the contrary, content of potassium was higher in straw of offshoots (K1 and K2 about 27 and 48%) and main stalks (K1 and K2 about 50 and 71%) in comparison with control. Lower content of nitrogen was detected in straw of offshoots of exposed plants in comparison with control. Content of phosphorus was in straw of offshoots K1 plants higher in comparison with control but content of phosphorus in straw of offshoots K2 plants was lower in comparison with control. Content of magnesium in straw of offshoots K2 plants was significantly lower in comparison with control (Table IV).

IV: *Contents of elements (mg/g of dry weight) in grains and straw of the spring barley grown in Mitscherlich pots at two different KCl doses*

Element	Plant Part		Variant K0	K1	K2
N	kernel	main stalk	12.80	12.70	12.90
		offshoots	12.90	12.70	12.50
	straw	main stalk	4.88	4.63	4.98
		offshoots	6.45	5.60++	5.40++
P	kernel	main stalk	3.90	3.70	3.60
		offshoots	4.20	3.80	3.88
	straw	main stalk	0.58	0.70	0.70
		offshoots	0.80	0.85++	0.75++
K	kernel	main stalk	7.10	7.10	7.40
		offshoots	7.50	7.10	7.50
	straw	main stalk	26.95	34.25++	40.00++
		offshoots	20.80	31.25++	35.55++
Ca	kernel	main stalk	0.50	0.50	0.50
		offshoots	0.50	0.50	0.50
	straw	main stalk	6.60	8.15+	6.95
		offshoots	8.15	9.55	9.90
Mg	kernel	main stalk	1.60	1.40	1.50
		offshoots	1.60	1.50	1.50
	straw	main stalk	1.95	1.75	1.85
		offshoots	2.20	2.05	1.73++
Na	kernel	main stalk	0.10	0.10	0.10
		offshoots	0.10	0.10	0.10
	straw	main stalk	0.83	1.08	1.10
		offshoots	1.05	1.43	1.48

K0 = 0 g K per pot, K1 = 2g K per pot, K2 = 4 g K per pot
Statistical significance: K0 : K1 and K2; ++ ~ P ≤ 0,01; + ~ P ≤ 0,05

Content of mineral nutrients after plant harvesting in soil. We found out by analysis of soil after harvesting of barley that content of available potassium was changing at the individual variants. Content of potassium decreased in soil containing K0 plants (without potassium fertilization) from middle to small (was uptaken away by plants). On the contrary K content was increasing in soil containing K1 and K2 plants (with potassium fertilization) to middle at K1 and to higher at K2 variants.

SOUHRN

Vliv draslíku na růst, obsah minerálních látek a tvorbu výnosu ječmene jarního (*Hordeum Vulgare* L.)

V modelovém experimentu byl studován vliv zvýšených dávek KCl na růst, akumulaci hlavních minerálních látek (N, P, K, Ca, Mg a Na) ve stonku, v odnožích a kořenech a na tvorbu a strukturu výnosu u ječmene jarního. Zvýšení hmotnosti nadzemních částí rostlin byl inhibován zvýšenými dávkami KCl pouze na začátku experimentu, konkrétně jsme pozorovali mnohem pomalejší růst odnoží. Na druhou stranu, tvorba sušiny u kořenů byla negativně ovlivněna po celou dobu experimentu. Nejvíce byla draslíkem ovlivněna akumulace hlavních minerálních prvků v celé rostlině. Příjem draslíku rostlinou se zvýšil o 37 %. Výnos zrn byl vyšší u variant se zvýšenou dávkou KCl, ale korelace mezi vyšší dávkou draslíku a zvýšeným výnosem nebyla statisticky průkazná. Samotný nárůst ve výnosu byl dosažen vyšším počtem odnoží, vyšší množstvím obilek a vyšší váhou stejného počtu obilek ve srovnání s kontrolou. Množství hlavních minerálních prvků v obilkách nebyl ovlivněn aplikací KCl, ale obsah draslíku v slámě byl signifikantně zvýšen.

ječmen (*Hordeum vulgare* L.), rostlinná výživa, draslík, transport, tvorba výnosu, růst, minerální látky

ACKNOWLEDGEMENTS

This work was supported by grants of the Grant Mendel University of Agriculture and Forestry (IGA MZLU 250061/2005) and GAČR No. 525/04/P132.

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