Potassium, magnesium and calcium content in individual parts of *Phaseolus vulgaris* L. plant as related to potassium and magnesium nutrition

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ABSTRACT

In a two-pot experiment of *Phaseolus vulgaris* L., the influence of K and Mg gradated doses upon K, Mg and Ca content in the pods, stem and leaves was studied. The content of cations changed significantly in individual parts of the plant. The highest content of potassium was found within the dry matter of the pods (it exceeded 4%) and stalk (3–4%). The highest content of calcium (3–4%) and magnesium (0.4–0.8%) was found within the dry matter of the leaves. The effects of K gradated doses were revealed significantly in its higher content increase mainly in the leaves (by as much as 83%) and the decrease of calcium content (31%) and magnesium content (37%) was observed in the leaves and less in the stalks. The effects of Mg gradated doses were revealed in the non-significant increase in its content in the leaves and stalks and the decrease of the potassium content in the leaves (by 19%) and in stalks (11%) and even in the decrease of the calcium content (52%) mainly in the pods.

Keywords: green bean (*Phaseolus vulgaris* L.); plant nutrition; potassium; magnesium; calcium; translocation

Minerals play a very important role in human nutrition. The disproportions in their intake can cause many serious illnesses. Vegetables are a significant source of minerals. Magnesium deficit is shown mainly in vegetables. Magnesium uptake and its utilization in plants depend on many factors (outer and inner). According to our earlier results, the problems of this cation could not be dealt with separately from other nutrients, especially cations (K^+, Ca^{2+}), from which arise the antagonistic relations in uptake. Dicotyledonous plants, among which a majority of vegetables belongs, have a different uptake and utilization of nutrients from monocotyledonous plants. The uptake, translocation and the utilization of main nutrients are not experimentally solved here. The aim of this work was to research the effect of the uptake of K, Mg, Ca and their translocation in the dependence on gradated K and Mg nutrition in the dicotyledonous plants (an experimental green bean plant) under given conditions.

The nutrient uptake is influenced by many factors – inner (genetic factors) as well as external (given conditions of the habitat – soil, climate). Plants take nutrients from the soil solution. According to Bergman and Neubert (1976), 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, on the other hand in the case of calcium and magnesium the mass flux (72 and 87%) and the root growth (28 and 13%) dominate. The active (pumps, carriers) and passive (diffusion, mass flux) mechanisms assert themselves in the uptake of constituent nutrients.

Plants take potassium in an active and a passive way, as seen in cation K^+, depending on its concentration in the nutritive medium. In low concentration, transport by carriers (active uptake) takes place. In high concentration, plasma membrane is more permeable and its passive movement with transpiration flow prevails (White 1993). The electrochemical gradient decreases on the inner part of the plasmatic membrane and because of this there is a non-specific inhibition of the uptake of the other cations (Engels and Marschner 1993). Potassium is easily mobile in a plant – through the xylem and phloem (up to 80% of all cations could be produced here). It could be redistributed from older leaves to younger tissues. Potassium occurs during the whole period of fulfilment of its physiological function in the form of cation K^+. It means that potassium

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is not built into organic matter (Marschner 1997, Nátr 2002). The significance of potassium in plants is multilateral and its physiological function has not been yet fully clarified. Potassium affects both phases of photosynthesis – in the thylakoid membranes it flows with cation Mg^{2+} in a different direction to H^+ flux and by this way it obtains electroneutrality. It influences the intensity of the CO_2 fixation in the Calvin cycle (Peoples and Koch 1979). Potassium impacts on the metabolism of sugars, their polymerization and on the synthesis of starch (Preusser et al. 1981). The potassium deficit results for example in thinner cell walls, in a decrease of mechanical plant resistance and in a lower production of reserve polysaccharides. It influences the tRNA bond to ribosome and the next steps of translation and subsequently the synthesis of proteins and their conformation (Wyn Jones et al. 1979). Potassium is a very important osmotic active matter. It activates the osmotic potential in sieve tubes and thereby the speed of transport of assimilates source – sink (Deeken et al. 2002). It activates the osmotic potential in cells of the stele of the root and the transport of matters through the xylem (root pressure – Hsiao and Läuchli 1986). Potassium plays a key role in the stomatal movement and it impacts the water balance of plants (Hugouvieux et al. 2002). It influences the growth and the elongation of cells as well as the nastic movements of plants. Potassium increases the hydration of protoplast, it positively affects the synthesis of vitamins and it is an activator of many more then 60 enzymes (e.g. glycolysis, citric acid cycle). The concentration of potassium in plants is relatively high (2–6%), for that reason the plants are notable for their higher demand for the potassium nutrition (Tůma 1992).

Calcium creates hardly soluble compounds with many organic substances, especially organic acids and phosphates. This process influences the uptake, transport and the redistribution of cation Ca^{2+}. Calcium is very partially mobile through the xylem and phloem. That is the reason why calcium does not have any possibility of reutilization. Plants demand its regular uptake for the whole growing season (Hocking 1980, Mohr and Schopfer 1995). In its case, an active uptake with the help of the high selective membrane transporters (Ca^{2+}-ATPase at the plasma membrane, $3H^+/Ca^{2+}$ antiporter at the tonoplast) was proved. The uptake could be also passive with the help of the Ca^{2+} channels inward rectifying at the plasma membrane and with the help of outward channels controlled by IP_3 at the tonoplast (Taiz and Zeiger 1998). The low cytosolic calcium concentrations are achieved by means of these membrane transporters. The vacuole, the endoplasmic reticulum and cell wall (mainly around the middle lamella) are the most important places for the storage of calcium (Evans et al. 1991). Calcium is a very important structural component; it is essential for the strengthening of the cell wall. The fundamental role of calcium is reflected in the cell division (it influences the structure of the mitotic spindle and middle lamella). It stabilizes the cell membranes (their permeability and e.g. function of the membranes of mitochondrion and chloroplasts where electrons are transported), it is already bound with some proteins and therefore it can change their form (influencing the activity of biocatalytic proteins). Calcium plays a key role as the second messenger in the signal transduction (hormones e.g. ABA, IAA, light, temperature, pathogenic infection and injury or mechanical stress – wounding) in plant cells (Roberts and Harmon 1992). Although indirectly, in its function as the second messenger, calcium also plays a key role in the cation-anion balance, in the osmoregulation of cells, in the osmoregulation of organelles (it neutralizes some organic acids) and in the coagulation of colloidal systems e.g. in the cytosol or it can have the detoxicating effect (Marschner 1997). The dependence between the season and Ca^{2+} concentration in the cytosol and in the nucleus (during the winter it is very low) was observed and the influence of calcium on dormancy was also proclaimed (Jian et al. 2003).

The functions of magnesium in plants were comprehensively reviewed by Tůma and Skalický (2001).

MATERIAL AND METHODS

The research was conducted in the form of two pot experiments. Green bean (*Phaseolus vulgaris* L. convar. *nanus*), Novores cultivars, was the experimental plant for both experiments. The experimental pots were polyethylene buckets with the perforated bottom placed into trays equipped with circular pads of plastic foam. Each experimental pot was filled with 10 kg of dry soil, including a dose of fertilizers. The agrochemical characteristics of

Table 1. The agrochemical characteristics of used soil

Soil type	Luvisols
pH/KCl	6.51
P (mg/kg)	116.7
K (mg/kg)	215
Mg (mg/kg)	150.2
Ca (mg/kg)	3 377
Rate Mg/K in sorption complex	2.27

Eluate by Mehlich 2 (Mehlich 1978)

Table 2. Scheme of experiments

Experiment	Variant No.	Marking	Chemicals (g/pot)		
			$Ca(H_2PO_4)_2$	KCl	$MgSO_4$
No. 1	1.	P	0.528	0	0
	2.	PK1	0.528	0.530	0
	3.	PK2	0.528	1.060	0
	4.	PK3	0.528	1.590	0
No. 2	1.	P	0.423	0	
	2.	PMg1	0.423	0	0.815
	3.	PMg2	0.423	0	1.630
	4.	PMg3	0.423	0	2.445

the used soil are presented in Table 1. The soil used in the experiment was characterized by the optimum value of pH, high phosphorus reserve and the adequate reserve of available potassium and magnesium (Neuberg et al. 1990). Similarly, the rate of equivalents Mg/K in the soil corresponded with the optimum data in accordance with Matula (1984). The input data indicate that there was not any dominant representation of potassium in the used soil and the soil corresponded to the criteria for harmonic nutrition by constituent cations.

In each experiment, four variants of fertilization in triple repetitions were used. The scheme of the experiments and the doses of fertilizer per pot are given in Table 2. In the experiment No. 1, the influence of gradated doses of K on the contents of cations K, Ca and Mg in dry matter of the above ground biomass were researched. The main aim of the experiment No. 2 was to study the influence of the gradated Mg nutrition. Five green bean seeds were sown into each experimental pot to the depth of 40 mm. The experiment was performed under the standard light conditions with an optimal water regimen.

For both experiments, the harvest passed through into the phase of green ripeness. The stalks, leaves and pods were separated during the harvest. These pieces were analyzed separately. The mineralization of dry matter was processed by the reference procedures (Ministry of Agriculture 1986). The content of cations, i.e. K^+, Ca^{2+} and Mg^+ in the solution after digestion was determined by means of atomic absorption. The results were processed statistically and evaluated by the standard analysis of variance. The statistical analyses were performed using the Statgraphics software.

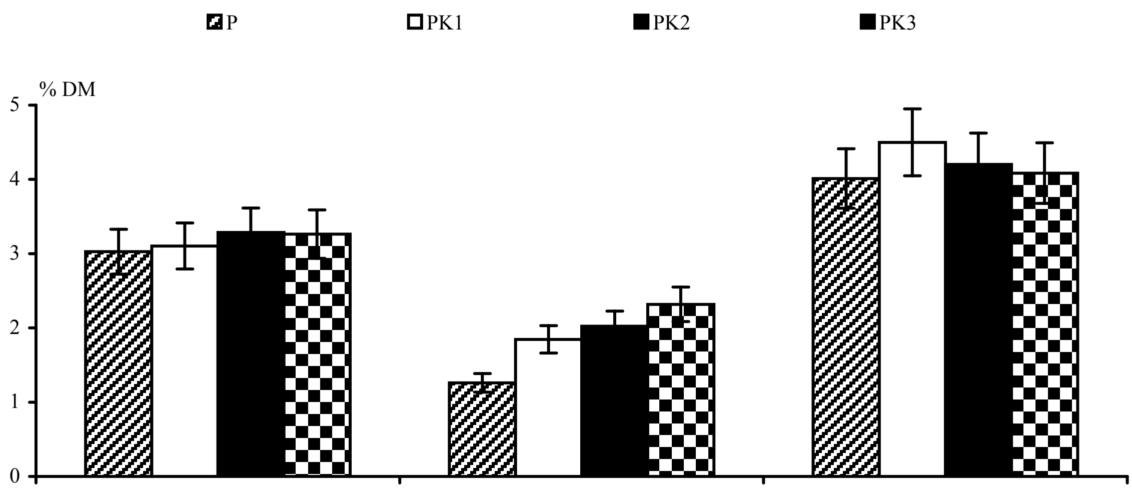

Figure 1. Content of K in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 1)

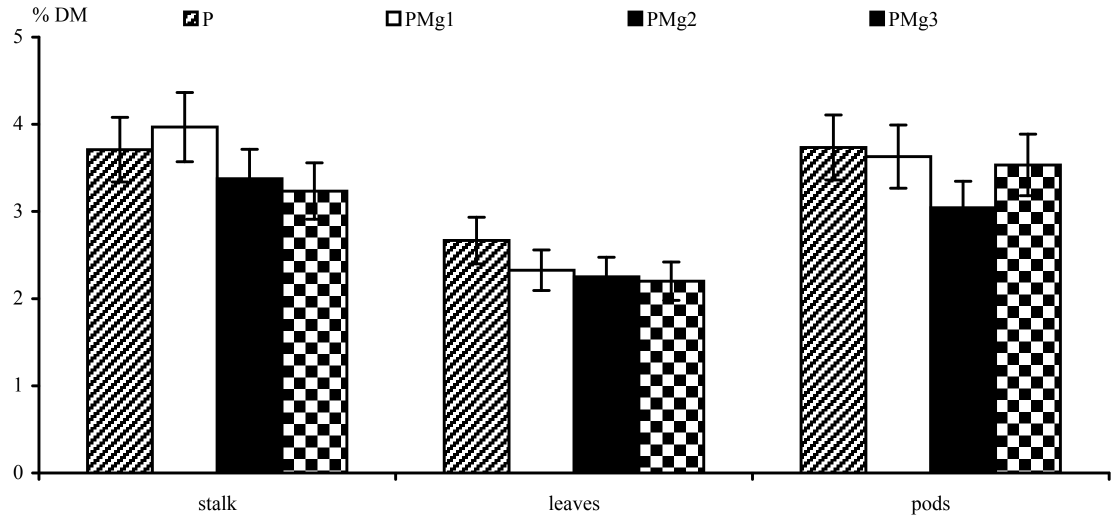

Figure 2. Content of K in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 2)

RESULTS

It should be clear from Figures 1 and 2 that the individual parts of the green bean plant differed significantly in the concentration of potassium within the dry matter. The highest content of K was found in the dry matter of green pods (it even exceeded 4% of dry matter). The second highest content of K was found in the stalk (it oscillated between 3.0 and 4.0% of dry matter). The lowest content was observed in the leaves (mostly under 2.5% of dry matter) but the influence of the gradated doses of potassium was the most significant here (Figure 1). Between the non-fertilized variant (P) and the fertilized variants (PK1–3) was observed a significant increase of content of potassium (by as much as 83%). There was not found any important increase of the content of K in the stalk while in the pods the K nutrition did not prove itself in the higher content of this element. The gradated doses of magnesium appeared as slight a decrease in the content of potassium in the leaves (by 19%) and the stalks (by 11%). Figures 3 and 4 demonstrate that in contrast to potassium there was the significantly highest content of calcium in the leaves (3.0–4.0% of dry matter). This is twice as much Ca in the leaves as in the stalk and there is more than three times as much Ca in the leaves compared with the pods. The gradate K nutrient (Figure 3) proved itself in significant decrease of the Ca content mainly in the leaves (by 31%) and a bit less in the stalk (by the highest dose of K significantly, too) and moderately stimulatory in the pods. The magnesium nutrition within experi-

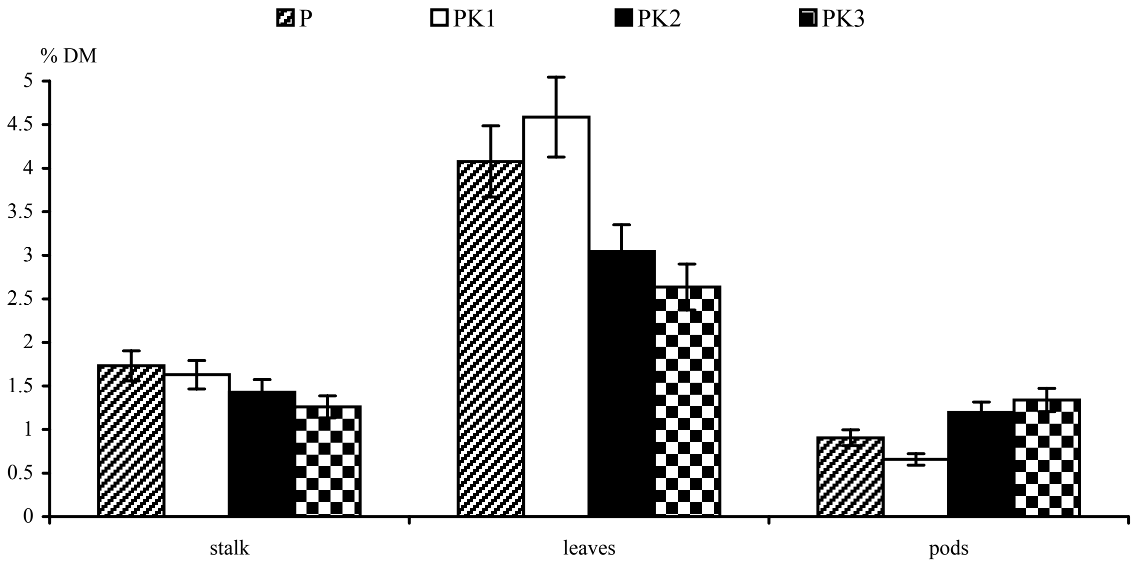

Figure 3. Content of Ca in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 1)

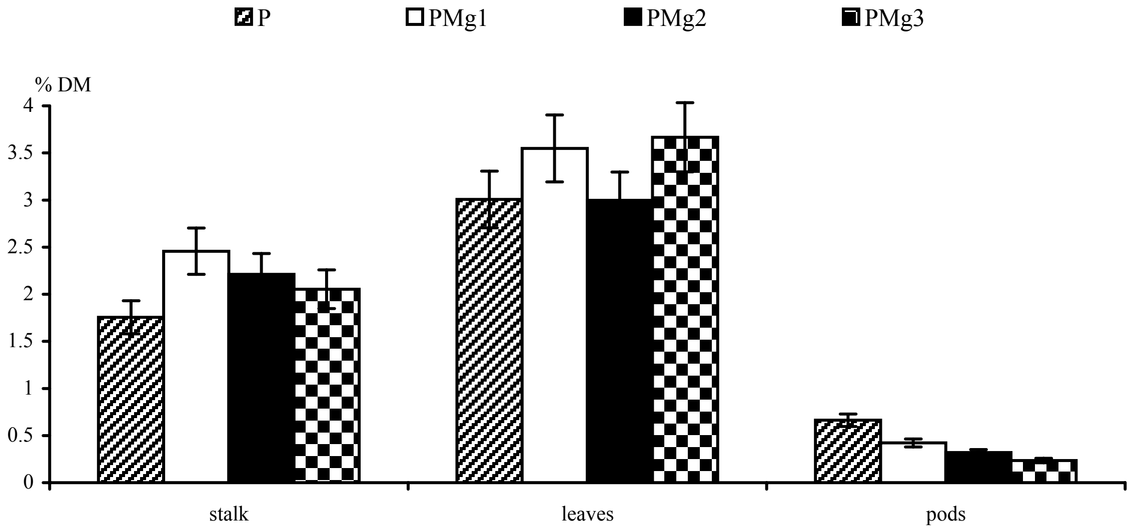

Figure 4. Content of Ca in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 2)

ment No. 2 (Figure 4) displayed imperceptibly in the decreased content of calcium in the pods (by as much as 52%) and in the stalk.

The total content of magnesium within the dry matter of the aboveground biomass was markedly lower as compared with K and Ca (Figures 5 and 6). The differences in its content among individual parts of the plant were less significant, too. Insignificantly higher content of Mg was found in the leaves where it ranged from 0.4 to 0.65% of dry matter. The gradated doses of K (Figure 5) displayed as the decreased content of Mg in all parts of the plant significantly (the most in leaves by 37%), though according to the lower values the higher dispersion was recorded here. The gradated doses of Mg did not change significantly the Mg content in aboveground biomass (Figure 6).

Figures 7 and 8 demonstrate the relative representation of K, Ca and Mg in the dry matter of individual parts of the green bean plant. It is interesting that the gradated K nutrition evidenced itself as an increased share of K in the stalk and in the leaves but the total sum of cations (K^+, Ca^+ and Mg^+) decreased.

DISCUSSION

The distribution of potassium in the green bean plant was similar to that of oat (Tůma and Skalický 2001), where the highest content of potassium was also recorded in the stalk, approximately one half in the leaves and even lower in the panicle. It should be clear that the high occurrence of potassium in

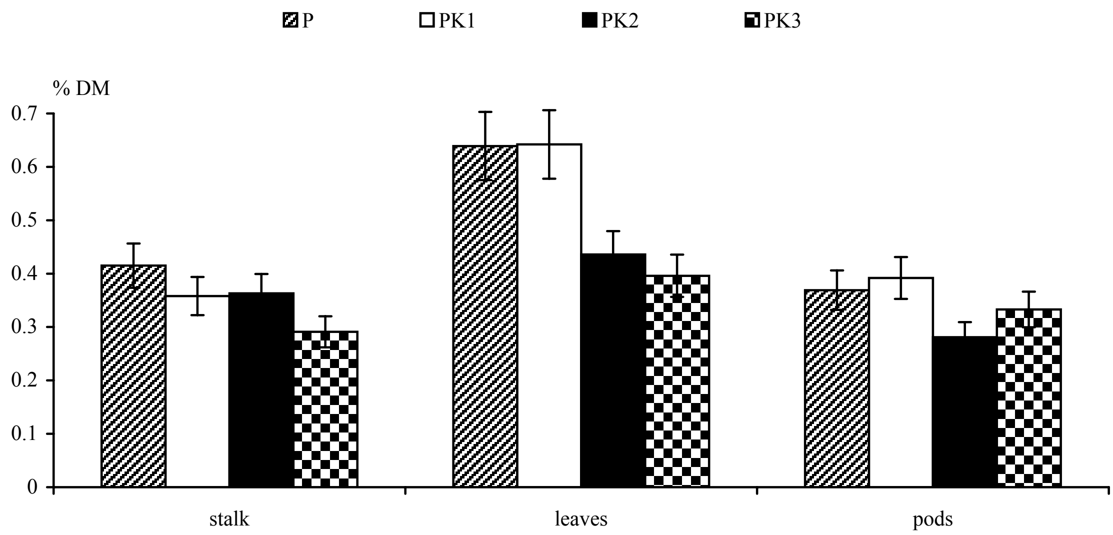

Figure 5. Content of Mg in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 1)

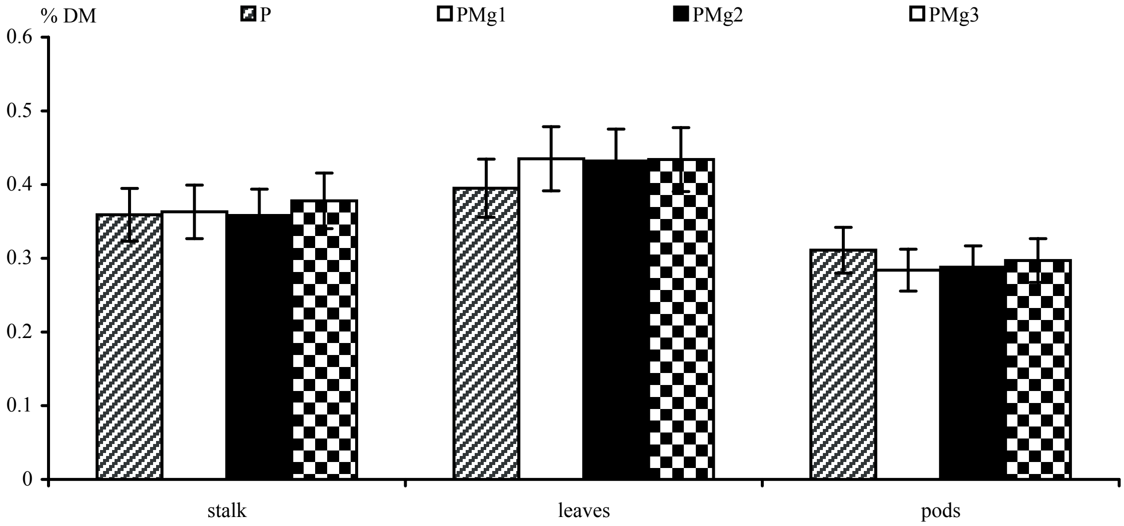

Figure 6. Content of Mg in dry matter of individual parts of *Phaseolus vulgaris* L. (experiment No. 2)

the stalk is probably related to the physiological function of potassium in the transport process in plants – primarily, it is the strongly osmotic active matter participation in the induction of root pressure and the transport of assimilates in phloem (Taiz and Zeiger 1998). Potassium circulates incessantly in the conducting tissue (Kirkby and Knight 1977). The author claims that there is a many times higher content of potassium in phloem than in xylem. On the other hand, the low K content in generative organs is genetically fixed. It was more than four times higher in the pod of green bean than in the panicle of oat. The content of potassium in photosynthetically active leaves was similar for both plants. It is again connected with the physiological function of potassium especially in the regulation of stomatal movement and metabolic activities, where it works as an activator of many enzymes. Potassium can be deposited here temporarily in a vacuole and successively drain for metabolic demand. Because of this fact the potassium nutrition evidently evidenced itself the most significantly just in green leaves. A slight decrease of the K content in the photosynthetically active leaves owing to the Mg nutrition was observed in oat (Tůma and Skalický 2001) and in orchard grass (Tůma 1992), too.

The calcium concentration is usually significantly lower in monocotyledonous plants compared to dicotyledonous plants. In our experiments, for example, it is three times lower in the leaves. The highest Ca content in the photosynthetically active leaves probably bears upon its physiological function in the plant. In leaves, calcium flows very

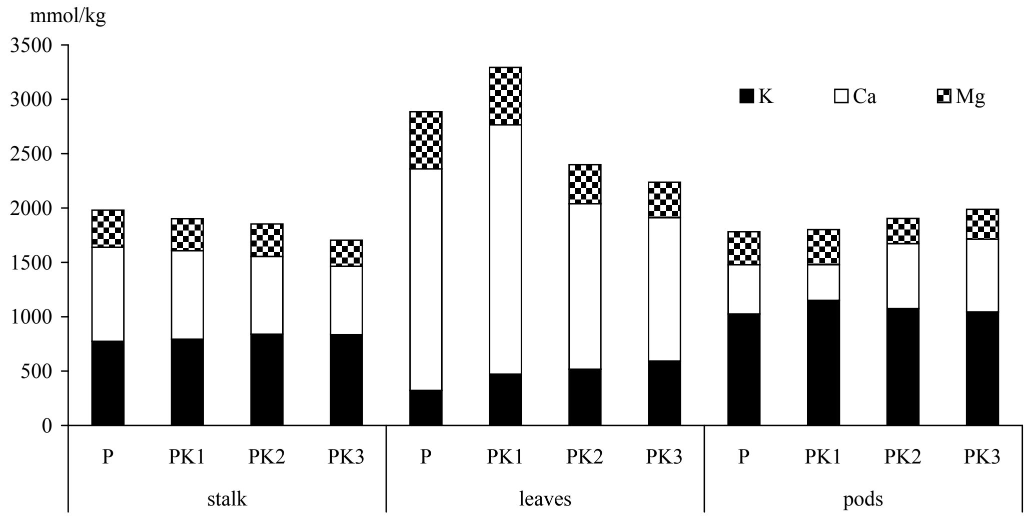

Figure 7. Rate of representation K, Ca and Mg in dry matter of individual parts of *Phaseolus vulgaris* L.; experiment No. 1 (gradated doses of K)

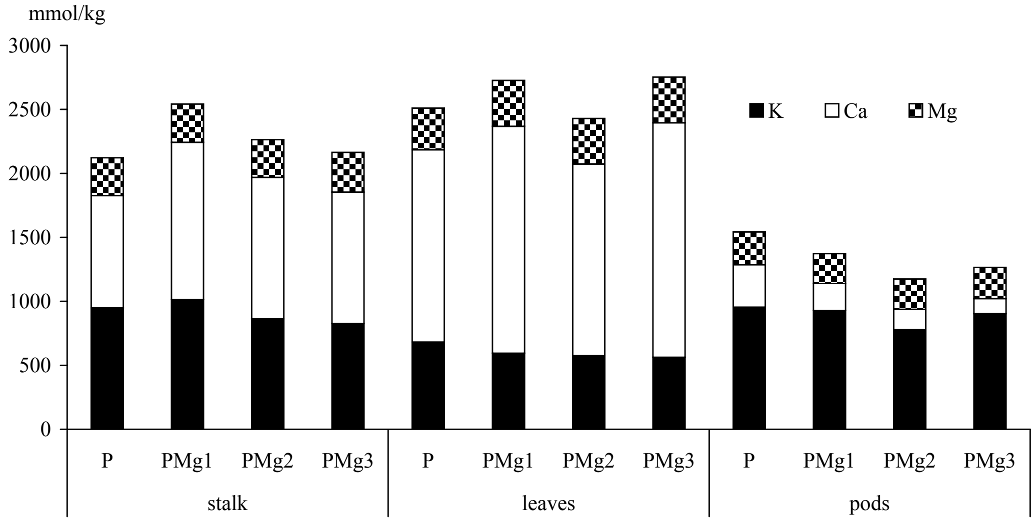

Figure 8. Rate of representation K, Ca and Mg in the dry matter of individual parts of *Phaseolus vulgaris* L.; experiment No. 2 (gradated doses of Mg)

slowly through the xylem. It accumulates at the deposits places here (vacuole, endoplasmic reticulum), it is released little by little and discharges its physiological function. The restricted redistribution impedes its next transport through the phloem (Zhong et al. 1998). It inserts in older cells and tissues where it accumulates in the vacuole in the form of oxalate or other hardly soluble salts. Therefore a much lower content of calcium was evidently found in the stalk as well as in the generative organs. The antagonistic effect of K on the Ca content exerted itself the most expressively in leaves. Antagonism between Ca and K is quoted in the literature but mostly in connection with unilateral higher doses of liming (Vaněk et al. 1995).

According to our experiment with oat, no more considerable differences within Mg content were observed in the individual organs of the plant. The highest content of Mg was in the leaves. It is logical, because of the fact that the leaves are the main location of photosynthesis, chlorophyll is usually in the highest concentration here, and magnesium is its building stone. And further, it is an activator of many enzymes in chloroplasts (Kruger et al. 1999). Magnesium, similarly to calcium, is accumulated in the leaves especially in the vacuole and progressively supplied into metabolic reactions. According to the latest knowledge, its reutilization and distribution through the phloem is relatively good. Therefore the differences between the content of magnesium in the leaves and in the stalk (possibly in the pods) are not so noticeable compared with calcium.

The significant decrease of the Mg content mainly in the leaves connected to the graded K nutrition is evidently related to the mechanisms of the uptake of these nutrients. The more facilitate uptake of the passive character is in the situation of higher concentration of potassium in the soil solution (for example produced by higher doses of K-fertilizer). Inside the membranes, plant cells have several types of K^+ channels that easily transport potassium ion into inner environment. Thereafter this ion balances the negative charges, caused by the active work of the proton pump, on the inner part of membrane and in this way begins the non-specific inhibition of the uptake of the other cations, especially magnesium, which is taken through the passive way only (Marschner 1997). We acquired some similar results in our earlier experiments (e.g. Tůma and Matula 1994). The process really depends on the actual soil condition of the biotope (how the soil is able to fix potassium supplied by fertilizers and thereby put potassium temporarily out of the cycle and, on the other hand, how it is able to intensively release potassium into the soil solution). When the concentration of potassium in the soil solution does not markedly decrease (e.g. crops sampling for a few years), the Mg fertilization through the soil often was less effective. In our case, its concentration in the soil solution could be, in the case of a good reserve of K in the soil, high and the Mg fertilization should not markedly display in its higher content in plants.

The decrease of the total sum of the equivalent of cations in the dry matter of plants after K fertilization was mainly related to the decrease of the rate of calcium in leaves, which is the dominant element here. This trend was found neither in the stalk, nor in the pods, where potassium is the dominant element. Similarly, it was not found in the case of monocotyledonous plants (orchard grass in our experiment), where the rate of calcium is lower (Tůma and Matula 1994).

REFERENCES

Bergmann W., Neubert P. (1976): Pflanzendiagnose und Pflanzen-Analysen. Gustav Fischer Verlag, Jena.

Deeken R. et al. (2002): Loss of the ATK2/3 potassium channel affects sugar loading into the phloem of Arabidopsis. Planta, *216*: 334–344.

Engels C., Marschner H. (1993): Influence of the form of nitrogen supply on root uptake and translocation of cations in the xylem exudate of maize (*Zea mays* L.). J. Exp. Bot., *44*: 1695–1701.

Evans D.E., Briars S.A., Williams L.E. (1991): Active calcium transport by plant cell membranes. J. Exp. Bot., *42*: 285–305.

Hocking P.J. (1980): The composition of phloem exudate and xylem sap from tree tobacco (*Nicotiana glauca* Groh). Ann. Bot., *45*: 633–643.

Hsiao T.C., Läuchli A. (1986): Role of potassium in plant-water relations. In: Tinker B., Läuchli A.: Advances in plant nutrition. Praeger Scientific, New York.

Hugouvieux V. et al. (2002): Localization, ion channel regulation, and genetic interactions during abscisic acid signalling of the nuclear mRNA cap-binding protein, ABH1. Plant Physiol. *130*: 1276–1287.

Jian L.C., Deng J.M., Li J.H. et al (2003): Seasonal alteration of the cytosolic and nuclear Ca^{2+} concentrations in over wintering woody and herbaceous perennials in relation to the development of dormancy and cold hardiness. J. Am. Soc. Hort. Sci., *128*: 29–35.

Kirkby E.A., Knight A.H. (1977): Influence of the level of nitrate nutrition on ion uptake and assimilation, organic acid accumulation, and cation-anion balance in whole tomato plants. Plant Physiol., *60*: 349–353.

Kruger N.J., Hill S.A., Ratcliffe R.G. (1999): Regulation of primary metabolic pathways in plants. Kluwer Acad. Publ., Dordrecht, Boston, London.

Marschner H. (1997): Mineral nutrition of higher plants. 2nd ed. Acad. Press Inc., London.

Matula J. (1984): Kationtová výměnná kapacita půdy a její využití ke hnojení. Agrochémia, *24*: 333–337.

Mehlich A. (1978): New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc. Commun. Soil. Sci. Pl. Anal., *9*: 477–492.

Ministry of Agriculture (1986): Fisheries and Food: the analysis of agricultural materials. A manual of the analytical methods used by the agricultural development and advisory service. 3rd ed. London.

Mohr H., Schopfer P. (1995): Plant physiology. Springer-Verlag, Berlin.

Nátr L. (2002): Fotosyntetická produkce a výživa lidstva. ISV, Praha.

Neuberg J. et al. (1990): Komplexní metodika výživy rostlin. ÚVTIZ, Praha.

Peoples T.R., Koch D.W. (1979): Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. Plant Physiol., *63*: 878–881.

Preusser E., Khalil F.A., Göring H. (1981): Regulation of activity of the granule-bond starch synthetase by monovalent cations. Biochem. Physiol. Pfl., *176*: 744–752.

Roberts D.M., Harmon A.C. (1992): Calcium-modulated proteins: targets of intracellular calcium signals in higher plants. Ann. Rev. Plant Physiol. Plant Mol. Biol., *43*: 375–414.

Taiz L., Zeiger E. (1998): Plant physiology. 2nd ed. Sinauer Assoc. Inc. Publ., Sunderland, Massachusetts.

Tůma J. (1992): The effect of the fertilizing system based on the principle of cation exchangeable capacity on the content of mineral substances in orchard grass. Rostl. Výr., *38*: 503–510.

Tůma J., Matula J. (1994): The effect of gradated nitrogen application rates on the yield, nutritive value, and mineral composition of orchard-grass herbage. Rostl. Výr., *40*: 241–252.

Tůma J., Skalický M. (2001): Magnesium content in individual parts of *Avena sativa* L. plant as related to magnesium nutrition. Rostl. Výr., *47*: 440–443.

Vaněk V. et al. (1995): Hořčík a jeho význam v zemědělství. AF ČZU, Praha.

White P.J. (1993): Characterization of high-conductance, voltage-dependent cation channel from the plasma membrane of rye roots in planar lipid bilayers. Planta, *191*: 541–551.

Wyn Jones R.G., Brady C.J., Speirs J. (1979): Ionic and osmotic relations in plant cells. In: Laidman D.L., Wyn Jones R.G.: Percent advances in the biochemistry of cereals. Acad. Press, London.

Zhong W.J. et al. (1998): Phloem loading of inorganic cations and anions by the seedling of *Ricinus communis* L. J. Plant Physiol., *152*: 328–335.

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ABSTRAKT

Obsah draslíku, hořčíku a vápníku v jednotlivých částech rostliny *Phaseolus vulgaris* L. v závislosti na výživě draslíkem a hořčíkem

Ve dvou nádobových pokusech s *Phaseolus vulgaris* L. byl sledován vliv stupňovaných dávek K a Mg na obsah K, Mg a Ca v luscích, stonku a listech. Obsah kationtů se významně měnil v jednotlivých částech rostliny. Draslík byl nejvíce zastoupen v luscích (převyšoval i 4 % sušiny) a ve stonku (3–4 % sušiny), vápník (3–4 % sušiny) a hořčík (0,4–0,8 % sušiny) v listech. Stupňovaná dávka draslíku se promítla v signifikantním nárůstu obsahu tohoto prvku hlavně v listech (až o 83 %) a ve snížení obsahu vápníku (o 31 %) a hořčíku (o 37 %) v listech a méně pak i ve stoncích. Stupňovaná dávka hořčíku se projevila v nevýznamném nárůstu jeho obsahu v listech a stoncích a ve snížení obsahu draslíku v listech (o 19 %), ve stoncích (o 11 %) i v poklesu obsahu vápníku hlavně v luscích (o 52 %).

Klíčová slova: fazol obecný (*Phaseolus vulgaris* L.); výživa rostlin; draslík; hořčík; vápník; translokace

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