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EFFECT OF GROWTH REGULATORS APPLIED TOGETHER WITH DIFFERENT PHOSPHORUS FERTILIZATION LEVELS ON THE CONTENT AND ACCUMULATION OF POTASSIUM, MAGNESIUM AND CALCIUM IN SPRING WHEAT

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Abstract

The objective of this study has been to trace the effect of endogenous growth regulators and different phosphorus fertilization levels on the content and accumulation of potassium, magnesium and calcium in spring wheat. The research was based on the results of a pot experiment established on soil of grain size distribution of light loamy sand. The soil was slightly acidic and moderately abundant in available phosphorus, potassium and magnesium. Against the background of stable NKMg fertilization (1.5 g N, 1.5 g K and 0.25 g Mg), increasing phosphorus rates (0.0 to 1.02 g P per pot) were tested. In order to compare the effect produced by growth regulators, applied in conjunction with rising doses of phosphorus, the pots were divided into 4 groups according to the sprays: distilled water (control), kinetin, gibberellin and auxin.

Kinetin and auxin increased the content of potassium in wheat grain, whereas gibberellin stimulate the removal of this element. Increasing P rates depressed the concentration of potassium in wheat except the oldest leaves. The highest uptake of potassium was observed following an application of 0.68 g P per pot. Gibberellin increased the content of Mg in leaves, glumes, oldest leaves and grain, whereas kinetin and auxin resulted in lower Mg levels. The highest Mg uptake occurred after using 0.68 g P per pot. The plant hormones raised the content of ca in wheat grain. Gibberellin and auxin increased the uptake of calcium by P non-fertilized wheat. Phosphorus fertilization broadened slightly the Ca:P ratio in grain, glumes and stems. Kinetin and auxin narrowed the Ca:P ratio in leaves. Higher phosphoru rates, especially in vegetative organs, narrowed the Ca:P ratio. Gibberellin narrowed the K:(Mg+Ca) ratio in grain and vegetative organs, which in con-

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trast was broadened by kinetin. Auxin broadened these proportions in wheat grain and leaves, while narrowing them in glumes and stems. The lowest and the highest phosphorus rates narrowed the K:(Mg+Ca) ratios in grain and glumes.

Key words: potassium, calcium, magnesium, phosphorus fertilization, growth regulators.

WPŁYW REGULATORÓW WZROSTU STOSOWANYCH W WARUNKACH ZRÓŻNICOWANEGO NAWOŻENIA FOSFOREM NA ZAWARTOŚĆ I AKUMULACJĘ POTASU, MAGNEZU I WAPNIA W PSZENICY JAREJ

Abstrakt

Celem pracy było prześledzenie wpływu endogennych regulatorów wzrostu i zróżnicowanego nawożenia fosforem na zawartość i akumulację potasu, magnezu i wapnia w pszenicy jarej. Podstawą badań było doświadczenie wazonowe założone na glebie o składzie granulometrycznym piasku gliniastego lekkiego, na której uprawiano pszenicę jarą odmiany Jasna. Gleba charakteryzowała się lekko kwaśnym odczynem i średnią zasobnością w przyswajalny fosfor, potas i magnez. Na tle stałego nawożenia NKMg (1,5 g N, 1,5 g K i 0,25 g Mg) zastosowano wzrastające dawki fosforu (0,0-1,02 g P na wazon). W celu porównania działania regulatorów wzrostu, stosowanych w warunkach wzrastających dawek fosforu, wazony podzielono na 4 grupy, w zależności od stosowanych oprysków: woda destylowana (kontrola), kinetyna, giberelina i auksyna.

Kinetyna i auksyna zwiększyły zawartość potasu w ziarnie pszenicy, natomiast giberelina stymulowała wynos tego pierwiastka. Wzrastające dawki P powodowały zmniejszenie koncentracji potasu w pszenicy, z wyjątkiem najstarszych liści. Najwyższe pobranie potasu uzyskano po zastosowaniu 0,68 g P na wazon. Giberelina zwiększyła zawartość Mg źdźble, plewach i najstarszych liściach oraz ziarnie, a kinetyna i auksyna zmniejszały jego koncentrację. Regulatory wzrostu zwiększyły też pobranie magnezu przez pszenicę nienawożoną fosforem. Najwyższe pobranie Mg uzyskano po zastosowaniu 0,68 g P na wazon. Regulatory wzrostu zwiększyły zawartość Ca w ziarnie pszenicy. Giberelina i auksyna zwiększyły pobranie wapnia przez pszenicę nienawożoną P. Nawożenie fosforem tylko w niewielkim stopniu wpłynęło na akumulację Ca w roślinach. Regulatory wzrostu nieznacznie rozszerzyły proporcje molowe Ca:P w ziarnie, plewach i źdźble. Kinetyna i auksyna zacieśniły stosunek Ca:P w liściach. Wzrastające dawki fosforu, głównie w organach wegetatywnych, zawężały proporcje Ca:P. Giberelina zawęziła, a kinetyna rozszerzyła proporcje K:(Mg+Ca) w ziarnie i organach wegetatywnych. Auksyna rozszerzyła te proporcje w ziarnie i liściach, a jednocześnie zawęziła w plewach i źdźble. Najniższe i najwyższe dawki fosforu spowodowały zawężenie proporcji K:(Mg+Ca) w ziarnie i plewach.

Słowa kluczowe: potas, wapń, magnez, nawożenie fosforem, regulatory wzrostu.

INTRODUCTION

Suitable supply of all nutrients throughout the whole growing season is a necessary condition for producing high and good quality wheat grain yields. Not only nitrogen fertilization but also phosphorus, potassium or magnesium nutrition is important. Phosphorus has a stronger effect on the development of generative rather than vegetative parts, and with respect to cereal crops, it is an essential nutrient for a proper growth of the root system and good tillering (SANDER et al. 1991, VALIZADEH et al. 2002).

Potassium is one of the cations which are absorbed by plants in advance to their biomass growth. Among cereals, the most rapid uptake of potassium coincides with the shooting stage and continues until the heading stage. Accumulation of potassium in wheat goes on until the flowering stage, after which it fell by half compared to the maximum uptake (WIERZBOWSKA, NOWAK 2000, PREZZ DU BENNIE 1991, LÁSZTITY 1988 a,b). During the grain filling, only a small fraction of magnesium present in grain originates directly from soil. Some of magnesium found in vegetative organs, mainly in the flag leaf, undergoes remobilisation and is transferred to kernels. However, excessive depletion of magnesium in leaves depressed photosynthesis and leads to lower yields (GRIMME 1987). Good magnesium supply favours higher content of nitrogen and proteins. Being a co-factor of enzymes responsible for synthesis and transport of carbohydrates, magnesium contributes to a larger mass of kernels, which in turn means higher grain yield (CHWIL 2001, GRZEBISZ 1999).

For farming and economic results, biologically active substances which act as growth regulators have a positive influence on metabolic reactions in crop plants. However, their effect is not reproducible. They can regulate the uptake of nutrients by plants and their further transport; they can also affect the remobilisation of nutrients during the formation of grains. These effects are associated with a better, stronger growth of the root system, especially root hairs, and consequently a more intensive uptake of mineral components from soil and fertilizers. The response of plants to plant hormones is varied, depending on the age and physiological state of a plant, environmental conditions as well as synergic or antagonistic reactions between endogenous and exogenous phytohormones.

The aim of this research has been to trace the effect of endogenous growth regulators and different phosphorus fertilization rates on the content of accumulation of potassium, calcium and magnesium in spring wheat.

METHODS

A two-factorial experiment, with 4 replications, was set up in Mitscherlich pots filled with 6.5 kg of light loamy sand, slightly acidic (6.4 pH in 1 mol $KCl \cdot dm^{-3}$) and moderately abundant in phosphorus, potassium and magnesium. Using a stable NKMg fertilization regime: 1.5 g N [NH_4NO_3], 1.5 g K [KCl and K_2SO_4 at a 1 : 1 ratio], and], 0.25 g Mg [$MgSO_4 \cdot 7H_2O$] per pot, increasing rates of phosphorus (0.0, 0.17, 0.34, 0.51, 0.68, 0.95 and 1.02 g P per pot in the form of [$Ca(H_2PO_4O_2 \cdot H_2)$]),were tested. All of the P and Mg rates and half the doses of N and K were added to soil before sowing wheat. The remaining portions of the nitrogen and potassium fertilizers were applied in 2 equal doses – at the early inflorescence and the ear shooting

stages. Twenty cv. Jasna wheat plants were grown in each pot. In order to compare the results produced by growth regulators under the effect of increasing phosphorus fertilization rates, the pots were divided into 4 groups (Table 1). Each spraying treatment consisted of an application of 0.5 dm^3 of a liquid containing 50 $mg \cdot dm^{-3}$ of a growth regulator.

Table 1

Design of the application of the plant growth regulators

Experiment variant	Spraying time and plant growth applied	
	beginning of tillering	beginning of flowering
I – control (C)	aqua destillata	aqua destillata
II – kinetin (K)	BAP (benzylaminopurine)	FAP (phurphurilaminopurine)
III – gibberellin (G)	GA_3 (gibberellic acid)	GA_3 (gibberellic acid)
IV – auxine (A)	IAA (indole-3-acetic acid)	NAA (naphthaleneacetic acid)

Wheat was harvested at the full maturity stage. Following the biometrical measurements, wheat plants were dissected into organs: grains, glumes including rachises, stems, flag leaf, penultimate leaf and other leaves. The plant material was ground and digested with concentrated sulphuric acid supplemented with hydrogen dioxide as an oxidizer. Next, potassium an calcium were determined by the emission atomic spectrophotometry (ESA) and magnesium – by the absorption atomic spectrophotometry (ASA).

RESULTS

The content of mineral components in cereal grains varies depending on the climatic factors and plant cultivation conditions (Makarska, Michalik 2003). In the present study as well as in the previous reports by Wierzbowska (2006a, b) and Wierzbowska and Nowak (2000, 2002), growth regulators had a more evident influence on the content of potassium, calcium and magnesium in wheat vegetative parts and grains than mineral fertilization.

Kinetin increased by nearly 13.8% the content of potassium in wheat grain and all vegetative organs except the flag leaf (Table 2). Auxin caused a nearly 11% increase in the concentration of potassium in grain; it also raised its levels in the penultimate leaf and in the other leaves, depressing the content of potassium in glumes (by 6.9%) and stems. The slightest effect on the concentration of potassium in wheat, compared to the control plants, occurred in the treatments involving gibberellin. Higher doses of phosphorus, except for the oldest leaves, depressed the content of potassium, which was confirmed by relatively high correlation coefficients.

Table 2

Potassium content ($g \cdot kg^{-1}$ d.m.)

Specification	Part of wheat					
	grain	glume	stem	flag leaf	penultimate leaf	remaining leaves
Mean for growth regulators						
Control	8.31	28.59	43.86	31.93	33.20	43.39
Kinetin	9.46	30.27	45.73	31.26	33.70	45.17
Gibberellin	8.57	27.46	44.91	30.64	31.83	42.67
Auxine	9.21	26.61	42.81	31.79	34.64	44.53
Mean for dose P						
0.00	9.35	30.33	45.35	32.60	34.20	43.40
0.17	9.03	28.58	45.10	31.60	33.75	44.63
0.35	9.43	29.55	45.88	31.13	34.35	44.60
0.51	9.28	28.60	44.38	31.60	33.58	44.60
0.68	9.03	28.60	43.80	30.93	32.90	43.63
0.85	8.45	26.60	43.65	31.03	32.58	44.33
1.02	7.68	25.38	42.15	30.95	32.05	42.40
r	0.61	0.54	0.56	0.48	0.54	0.37

r - correlation coefficient

The growth regulators to some extent stimulated the uptake of potassium by wheat plants (Figure 1). The strongest effect was produced by gibberellin (on average 79.14 mg k per plant) by stimulating the development of vegetative mass, particularly stems (Wierzbowska, Sienkiewicz 2004). Phosphorus fertilization, and the rate of 0.68 g P per pot, improved the uptake of potassium by wheat.

Gibberellin sprays contributed to increased content of magnesium in wheat organs except the flag and penultimate leaves (Table 3). The highest increment of magnesium (by 36%) was observed in glumes, whereas the grains contained just 5.4% more magnesium than the control. The other plant hormones tended to depress the level of Mg in particular organs of wheat. Increasing doses of phosphorus decreased the content of magnesium in grain (r=0.37) and in the penultimate leaf (r=0.49). In the flag leaf this dependence followed a parabolic course – the content of magnesium continued to increase following the application of small P doses, but declined after the highest phosphorus rates were used (r=0.63). Phosphorus fertilization, in the whole range of the test doses, increased the content of Mg in the other leaves.

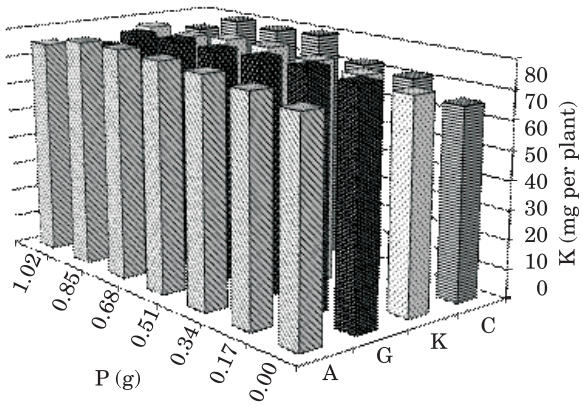

Fig. 1. Potassium uptake: C – control, K – kinetin, G – gibberellin, A – auxine

Table 3

Magnesium content ($g \cdot kg^{-1}$ d.m.)

Specification	Part of wheat					
	grain	glume	stem	flag leaf	penultimate leaf	remaining leaves
Mean for growth regulators						
Control	1.67	0.61	0.43	2.20	2.83	3.47
Kinetin	1.69	0.53	0.40	2.01	2.69	3.53
Gibberellin	1.76	0.83	0.47	1.96	2.81	3.79
Auxine	1.63	0.66	0.46	2.03	2.53	3.40
Mean for dose P						
0.00	1.75	0.65	0.48	2.03	2.95	3.43
0.17	1.68	0.68	0.40	2.13	2.83	3.43
0.35	1.75	0.63	0.45	2.18	2.68	3.58
0.51	1.68	0.60	0.40	2.15	2.70	3.73
0.68	1.65	0.60	0.45	2.15	2.73	3.53
0.85	1.68	0.55	0.45	1.95	2.68	3.60
1.02	1.63	0.90	0.45	1.78	2.45	3.55
r	0.37	0.33	0.00	0.63	0.49	0.32

r - correlation coefficient

The growth regulators sprayed over wheat plants grown without phosphorus fertilization improved the uptake of magnesium by 11% (kinetin) up to 23% (gibberellin) compared to the control plants (Figure 2). Phosphorus fertilization levelled the stimulating influence of the phytohormones on the

uptake of magnesium, although wheat sprayed with gibberellin absorbed over 5% more Mg than the control plants. On average, the highest magnesium uptake (79.66 mg Mg per plant) was obtained when 0.68 P per pot was applied.

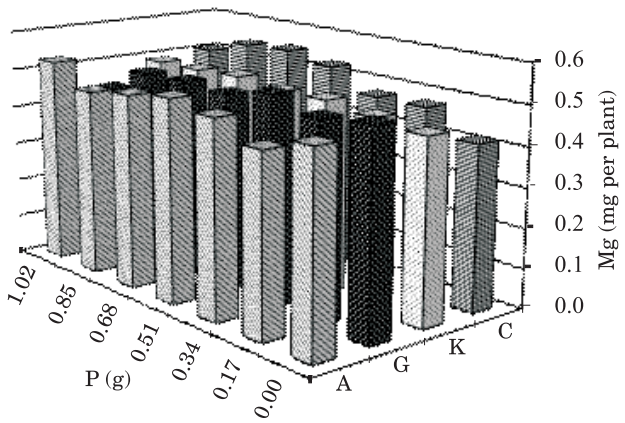

Fig. 2. Magnesium uptake (legends as Fig. 1)

Kinetin and gibberellin increased by over 20% the content of calcium in grain and glumes of wheat (Table 4). Under the influence of gibberellin the concentration of calcium also went up in the other vegetative organs, whereas kinetin depressed by 15% the content of Ca in the flag and penultimate leaves, decreasing it albeit less severely in the other leaves. In contrast, auxin had a very weak influence of the concentration of calcium in particular wheat organs. It was only when very low phosphorus rates had been applied that the content of calcium in grain, glumes and stems of wheat slightly increased (r=0.53). For al the range of the P rates tested, the concentration of calcium in the penultimate leaf increased (r=0.40), increasing in the other leaves (r-0.51).

Gibberellin and auxin sprayed over wheat grown without phosphorus nutrition increased by about 40% the uptake of calcium compared to the control plants. An analogous effect produced by kinetin reached only 20% (Figure 3). Likewise magnesium, phosphorus fertilization reduced the stimulating effect of the growth regulators on the uptake of calcium, but when analysing the means for each plant hormone it was discovered that the uptake of ca rose by a few per cent under the effect of gibberellin and auxin. Phosphorus fertilization only weakly improved the accumulation of calcium in wheat.

Our previous experiments showed that growth regulators modified the content of potassium, calcium and magnesium in wheat grain and vegetative parts to a higher degree than phosphorus fertilization (WIERZBOWSKA

Table 4

Calcium content ($g \cdot kg^{-1}$ d.m.)

Specification	Part of wheat					
	grain	glume	stem	flag leaf	penultimate leaf	remaining leaves
Mean for growth regulators						
Control	0.49	2.13	2.39	9.64	11.36	14.30
Kinetin	0.60	2.54	2.39	8.20	9.70	13.57
Gibberellin	0.61	2.61	2.56	9.63	13.00	15.84
Auxine	0.51	2.20	2.53	9.16	11.16	14.70
Mean for dose P						
0.00	0.58	2.50	2.53	8.85	12.85	14.10
0.17	0.65	2.55	2.55	8.63	11.68	14.38
0.35	0.58	2.43	2.65	10.08	10.70	14.55
0.51	0.55	2.23	2.40	8.93	10.78	14.53
0.68	0.50	2.40	2.55	10.13	10.83	14.63
0.85	0.48	2.20	2.30	8.58	11.28	15.80
1.02	0.55	2.30	2.28	8.93	11.03	14.25
r	0.32	0.35	0.53	0.28	0.40	0.21

r – correlation coefficient

2006a,b). According to NIEMYSKA and STARCK (1988), exogenous gibberellin can produce an effect of increased remobilization of K^+ ions from aging plant organs, which means that potassium ions are used more efficiently under nutrient deficiency conditions. The influence of exogenous plant hormones (IAA, GA_3) on the uptake and transport of ions can be diverse and depends on many factors including dates of application (CHOŁUJ 1988). Transport of ions can be regulated by IAA or ABA via their effect on the opening and closing of ionic channels in cellular membranes (BLATT 1993).

The growth regulators we tested slightly broadened the molar ratios of calcium to phosphorus in wheat grain, glumes and stems (Figure 4), mainly by increasing the amounts of calcium in plants. Kinetin and auxin narrowed the Ca:P ratio in leaves. Increasing rates of phosphorus, however, did not play any major role in shaping the Ca:P molar proportions in grain, although, due to decreasing calcium concentrations (glumes, the penultimate leaf) or increasing phosphorus content (the stem, flag leaf and other leaves), these two plant hormones narrowed the Ca:P ratio in the vegetative organs of wheat.

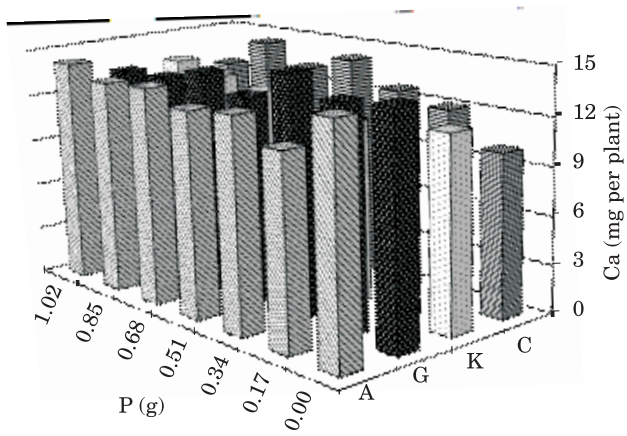

Fig. 3. Calcium uptake (legends as Fig. 1)

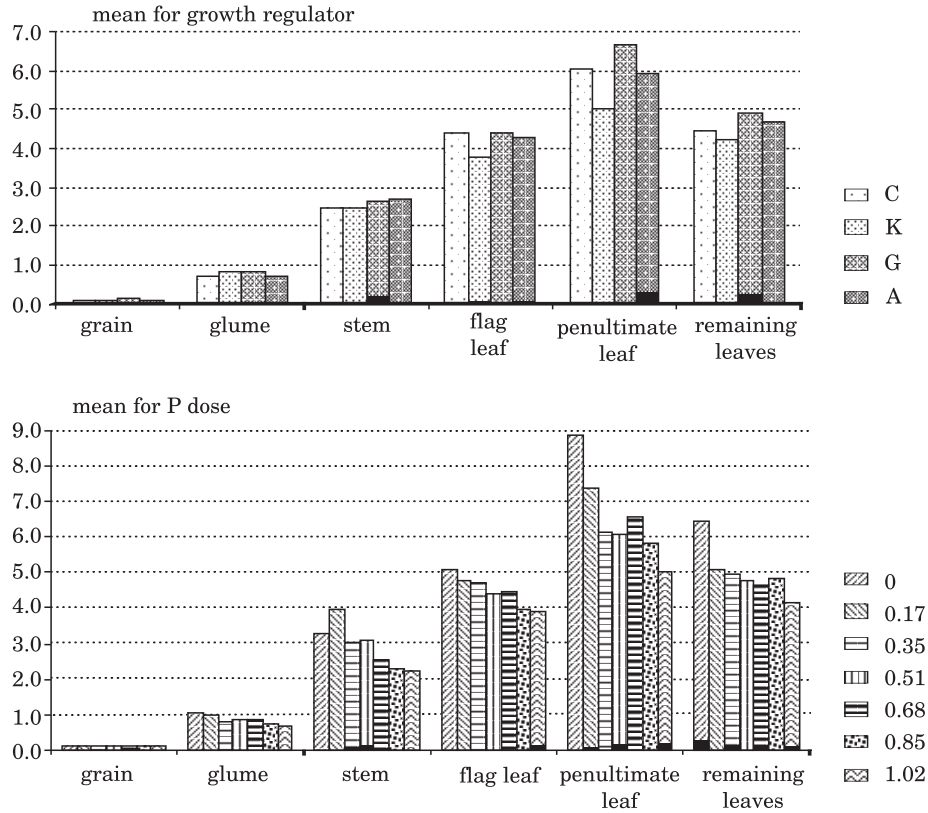

Fig. 4. Ca:P molar relations (legend as. Fig. 1)

Both mineral fertilization and growth regulators exert a more powerful effect on the modification of K:(Mg+Ca) ratios in vegetative organs than in grains of cereals (WIERZBOWSKA 2006b, MAKARSKA and MICHALIK 2003). In the present study, gibberellin, which depressed the content of potassium while rising that of calcium and magnesium in wheat, narrowed the K:(Mg+Ca) ionic ratio in wheat vegetative organs and grain (Figure 5). Wheat treated with kinetin responded differently, which meant that the proportions between the above ions were broader in grain and leaves but narrower in glumes and stems. The lowest and the highest doses of phosphorus resulted in the narrowing of the K:(Mg+Ca) ratio in grains and glumes. In the remaining parts of wheat plants, the phosphorus fertilization rates produced an ambiguous effect on the size of the K:(Mg+Ca) ratio.

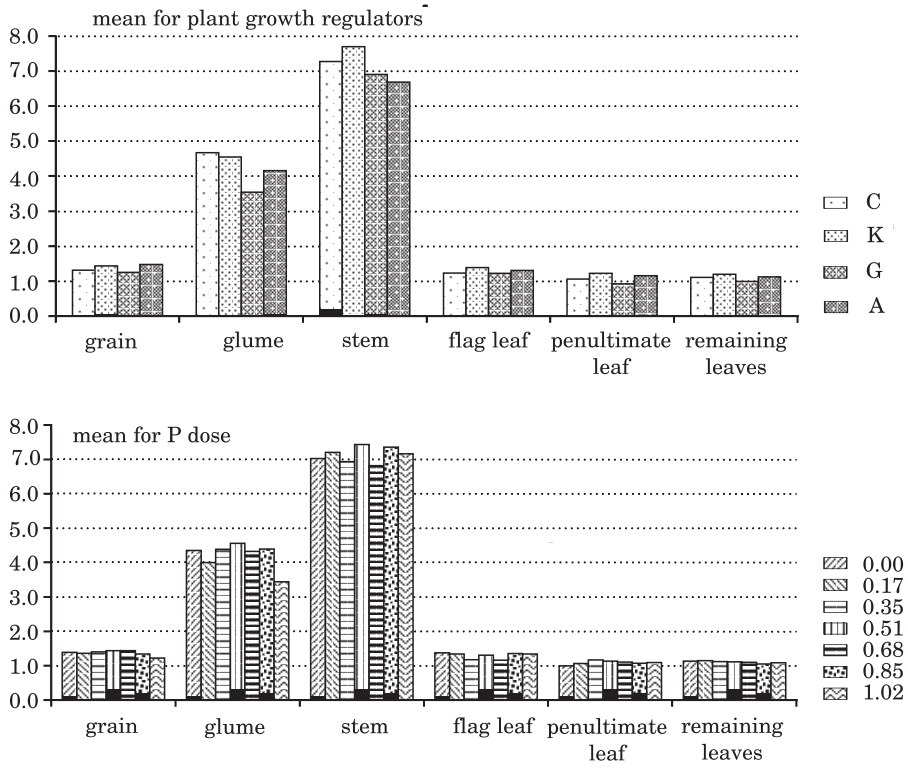

Fig. 5. K : (Ca+Mg) ionic relations (legends as. Fig. 1)

CONCLUSIONS

1. The growth regulators increased the content of potassium and calcium in wheat grain, with gibberellin raising also the concentration of magnesium in wheat grain. Increasing rates of phosphorus fertilization depressed the content of K, Mg and Ca in wheat grain and vegetative organs, except for the oldest leaves.

2. In general, the phyrohormones improved the uptake of potassium, calcium and magnesium by wheat. The highest uptake of potassium and magnesium occurred after the application of 0.68 g P per pot. Phosphorus fertilization had only a weak effect on improved Ca accumulation in wheat.

3. The growth regulators slightly broadened the Ca:P molar ratios in wheat grain, glumes and stems. Kinetin narrowed the Ca:P ratio in leaves. Increasing phosphorus rates did not produce any stronger effect on the Ca:P proportions in grains, but they narrowed the ratios between these two elements in wheat vegetative organs.

4. Gibberellin narrowed the K:(Mg+Ca) proportions in wheat grain and vegetative organs, in contrast to kinetin, which caused their narrowing. Auxin broadened these ratios in grain and leaves, while narrowing them in glumes and stems. The lowest and the highest phosphorus rates made the K:(Mg+Ca) ratios in grain and glumes narrower.

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