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EFFECT OF MINERAL STRESS ON PRODUCTIVITY OF SELECTED GENOTYPES OF PEA (*Pisum sativum* L.) AND YELLOW LUPIN (*Lupinus luteus* L.)

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ABSTRACT

The pot experiment investigated an effect of varied phosphorus, potassium and magnesium fertilisation on the intensity of photosynthesis, transpiration, intercellular CO_2 concentration and stomatal conductance as well as some plant biometrics obtained from 'Jaspis', a traditional home cultivar pea, and from homozygotic isoline, 'RRRbRb', and yellow lupin; 'Teo', a traditional cultivar, and 'Markiz', a self-completing cultivar. A lowered phosphorus and potassium fertilisation decreased the intensity of photosynthesis in pea forms researched. The photosynthesis in the yellow lupin cultivars investigated was higher in the pod-filled stage than the intensity of the process in 3-7– true leaf phase. However the transpiration intensity was lower in the pod-filled stage. The research results showed that out of all the three applied macroelements only lowering of the magnesium dose decreased the weight of seed weight from plant both in the tested pea and in yellow lupin cultivars.

Key words: pea, yellow lupin, mineral stress, gas exchange indices, LI-COR 6400 (DMP AG SA LTD) mobile gas analyser

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INTRODUCTION

Plants are exposed to the factors which can result in stresses [10], disturbing their vital activities and varied deformations, which can also lead to death [11]. One of the stresses disturbing plant growth and development, resulting in lowered both yielding and yield quality is a shortage of minerals [18]. Minerals are included in many organic structures and co-enzymes, they can be activators of enzymatic reactions, as well as act as osmoregulators [14]. Both a shortage and surplus of any of the components results in a stress in plants and indirectly affects the phytophages and their parasites and predators [2]. Crops which develop when exposed to a shortage of macroelements (N, P, K and Ca) and microelements (Fe, B, Zn, Mn, Mo) generally decrease the number of diaspores which also have a lowered viability and vigour [7].

A nitrogen shortage inhibits the growth of plants and yellow-leaf disease [2]. Seeds collected from plants with its shortage lose their germination capacity rapidly. A shortage of phosphorus, on the other hand, decreases the total number of seeds per plant. Such seeds germinate slower, while the plants grown from them accumulate less dry matter or can show disease symptoms [6]. Besides a lack of phosphorus makes the uptake of other nutrients impossible, while the plants exposed to its shortage are frequently dwarf, dark green and their ripening is delayed [2,9]. They record inhibited metabolism of proteins and limited auxin synthesis. Phosphorus is also indispensable to an adequate photosynthesis [2]. An excessively low level of phosphorus in pea limits its growth as well as leads to a lower survival rate of nodule bacteria and limits nitrogen fixation [9].

Potassium regulates the synthesis of starch, protein and chlorophyll, affects the translocation of sugars, division of cells and plant growth. Plants accumulate high contents of soluble aminoacids and reducing sugars and little proteins [2]. When exposed to potassium deficit, the seeds obtained from plants germinate prematurely, while their germination capacity decreases rapidly. Potassium malnutrition deteriorates the use of carbohydrates in the pentose phosphate pathway and inhibits the synthesis of ribulose 5-phosphate and degradation of mitochondria [6]. Majsurian [12] in his research showed that fertilisation with phosphorus and potassium accelerates lupin emergence, shortens the vegetation period and increases the weight of 1000 seeds and seed yield. Potassium plays a crucial role in photosynthesis as well as enhances the nitrogen fixation [9].

Mineral shortages can disturb the stability of cytoplasma membranes, which is observed as a change in their selective permeability of ions and products of photosynthesis [18]. Ions of nitrogen, potassium, phosphorus and magnesium play a key role in photosynthesis, transport and distribution of assimilates [18]. A large part of organic nitrogen is located in chloroplasts. Membranes of tylacoids contain from 1/4 to 1/5 of the total nitrogen in leaf; its shortage results in changes in membranes and disturbs their functioning [13]. The level of one of the most important proteins, RuBisCO, decreases [18]. Inhibited synthesis of proteins and chlorophyll leads to the formation of chloroplasts with a low photosynthetic output. The nitrogen deficit also lowers the stomatal conductance, which inhibits the intensity of photosynthesis [21]. Insufficient amounts of potassium increase the stomatal resistance, which makes CO_2 diffusion through stomata limited. The K deficit inhibits protein synthesis, RuBP - carboxylase, in particular [18]. Additionally a potassium shortage decreases the activity of numerous enzymes, mainly those involved in sugar and starch metabolism [8]. Similarly P deficit deteriorates photosynthesis [4], increases starch accumulation, while insufficient amounts of inorganic P inhibits ATP biosynthesis [18].

Scientific hypothesis assumed that lowering a fertiliser dose from the optimal to ¼ will decrease the vital processes intensity in pea (‘Jaspis’ and ‘RRRbRb’) and yellow lupin cultivars (‘Teo’ and ‘Markiz’) and plant productivity. The present research aimed at defining the activity of photosynthesis, transpiration, inter-cellular CO_2 concentration, stomatal conductance and plant productivity of selected pea and lupin cultivars treated with lower doses of nutrients.

MATERIALS AND METHODS

The pot experiment was carried out in two series over 1999-2000 in the computer-controlled green house and studied a varied mineral fertilisation on traditional ‘Jaspis’ and homozygous ‘RRRbRb’ (obtained from the John Innes Institute, Norwich, England) pea cultivars and traditional ‘Teo’ and self-completing ‘Markiz’ yellow lupin cultivars. The plants were fertilised twice prior to sowing and at the stage of 3-4–true leaf with the optimal and decreasd-to-1/4 doses of P, K and Mg (Table 1). Additionally, plants were fertilised with basic microelements (Fe, Mn, Zn, Cu, B, Mo) (Table 2). Pea was sown into flowerpots while yellow lupin into pots. Chemical control and pesticides (Amistar 250 SC (twice) and Talstar 100 EC (four times) were applied.

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Table 1. Doses of macroelements

Macroelement	N	P	K	Mg
Dose, mg ·1 kg^{-1} of soil	2.7	1.7	5.0	1.8
Salt form	NH_4NO_3	$Ca(H_2PO_4)_2 \cdot H_2O$	KCl	$MgSO_4 \cdot 7H_2O$

Table 2. Doses of microelements

Microelement	Dose, mg ·1 kg^{-1} of soil	Form
Fe	0.590	$C_{10}H_{12}FeN_2NaO_8$
Mn	0.056	$MnCl_2 \cdot 4H_2O$
Zn	0.057	$ZnCl_2$
Cu	0.011	$CuCl_2 \cdot 2H_2O$
B	0.027	H_3BO_3
Mo	0.0054	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$

The investigation defined the intensity of photosynthesis and transpiration, intercellular CO_2 concentration, stomatal conductance with the LI-COR 6400 (DMP AG SA LTD) mobile gas analyser over varied plant development phases as well as essential plant biometrics.

RESULTS

The present results showed that lowering the fertilisation dose of P and K decreased the intensity of photosynthesis in the pea forms studied. Mg fertilisation at ¼ of the optimal dose also decreased its intensity in RRRbRb line, while 'Jaspis' recorded a slight increase (Fig. 1). In yellow lupin cultivars studied photosynthesis intensity at the filled-pod stage was higher than at 3-4–true leaf stage (Fig. 2). A varied mineral fertilisation did not affect this process considerably.

Fig. 1. Pea photosynthesis intensity in 3-7 -leaf phase under mineral stress

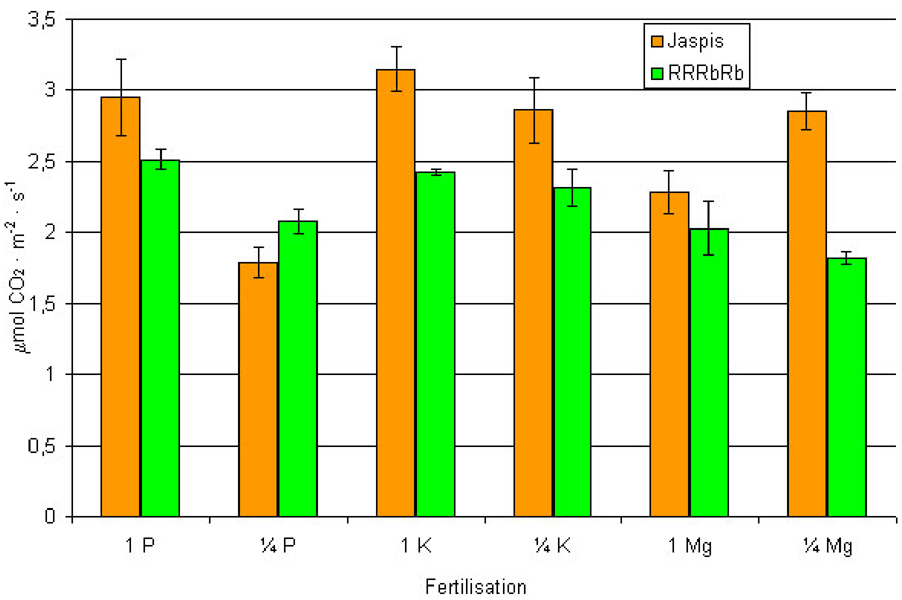

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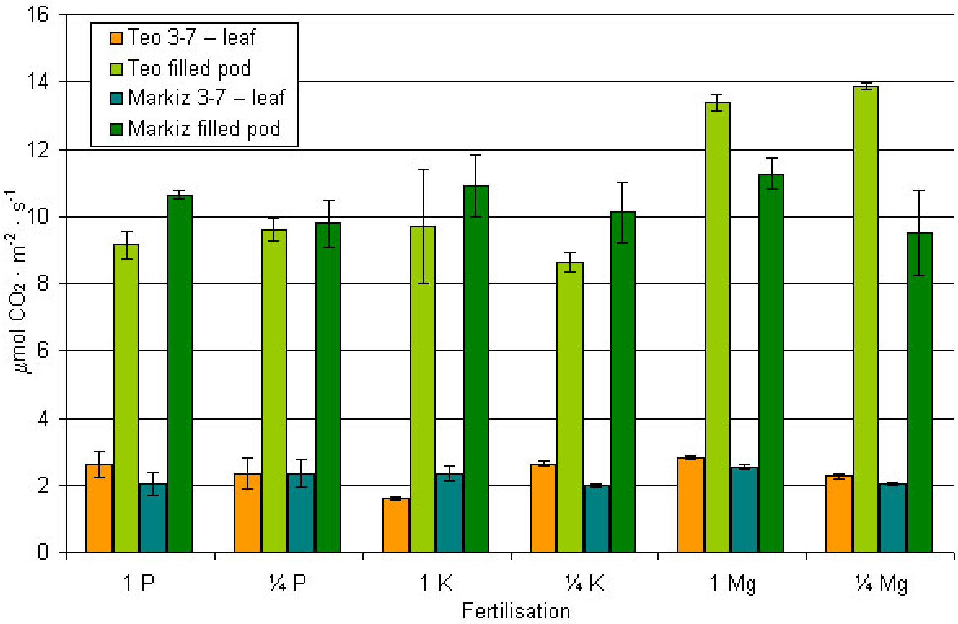
Fig. 2. Yellow lupin photosynthesis intensity in 3-7–leaf and filled pod phases under mineral stress



Mineral stress in 'Jaspis' enhanced transpiration, while in 'RRRbRb' line it remained unaffected (Fig. 3). A varied mineral fertilisation of yellow lupin did not affect transpiration (Fig. 4) whose intensity was lower at the filled-pod stage.

Fig. 3. Pea transpiration intensity in 3-7 - leaf phase under mineral stress

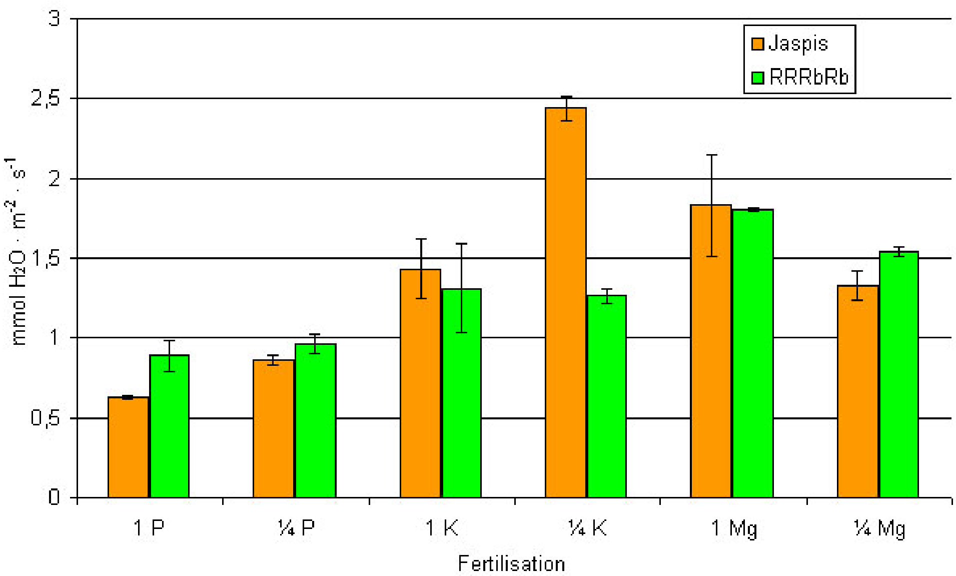


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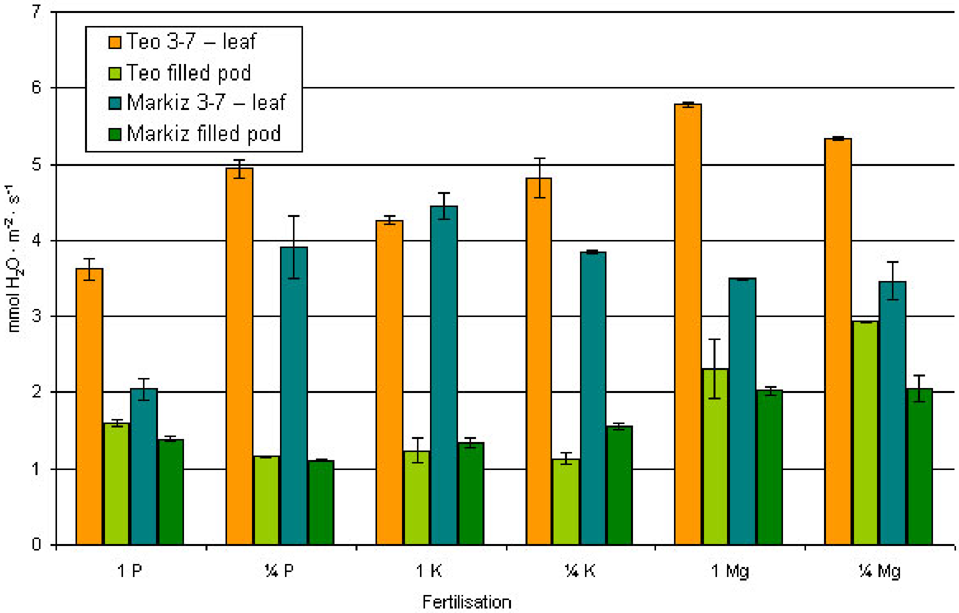
Fig. 4. Yellow lupin transpiration intensity in 3-7–leaf and filled pod phases under mineral stress



When exposed to a lower dose of P and K, 'Jaspis' recorded an increase in inter-cellular CO_2 concentration, and when exposed to ¼ dose of Mg – no significant differences were observed. 'RRRbRb' line grown under lowered P and Mg doses showed its decreasing trend, however a lower dose of K – resulted in slightly higher inter-cellular CO_2 concentration (Fig. 5). In the yellow lupin cultivars studied, a varied mineral fertilisation did not differentiate it significantly (Fig. 6).

Fig. 5. Intercellular CO_2 concentration in pea leaves in 3-7 - leaf phase under mineral stress

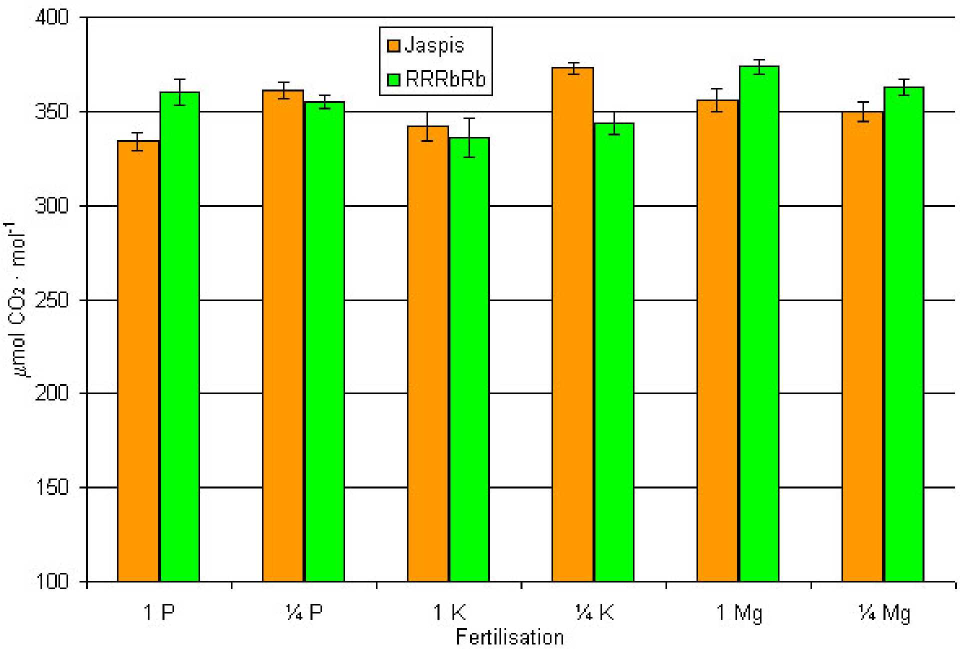


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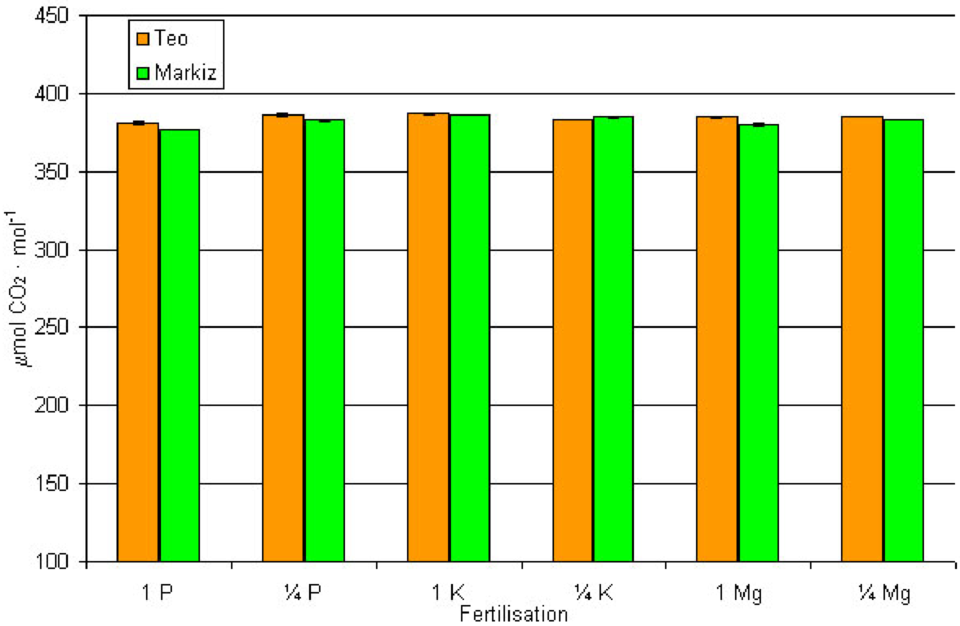
Fig. 6. Intercellular CO_2 concentration in yellow lupin leaves in 3-7 - leaf phase under mineral stress



Stomatal conductance in yellow lupin cultivars was much higher than in pea cultivars (Figs. 7 and 8); in filled-pod stage lupin, it was more than 90% lower than in 3-7-leaf stage lupin and rather unaffected by mineral fertilisation dose. A lower stomatal conductance in 'Jaspis' at the 3-7–leaf stage was observed under P shortage, while in 'RRRbRb' line – under K and Mg doses.

Fig. 7. Pea stomatal conductance in 3-7 - leaf phase under mineral stress

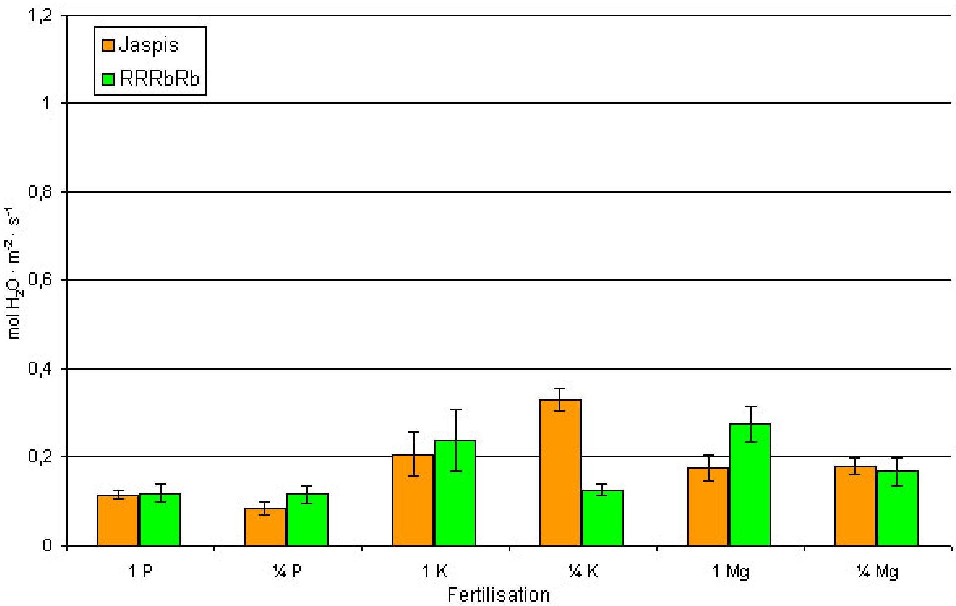


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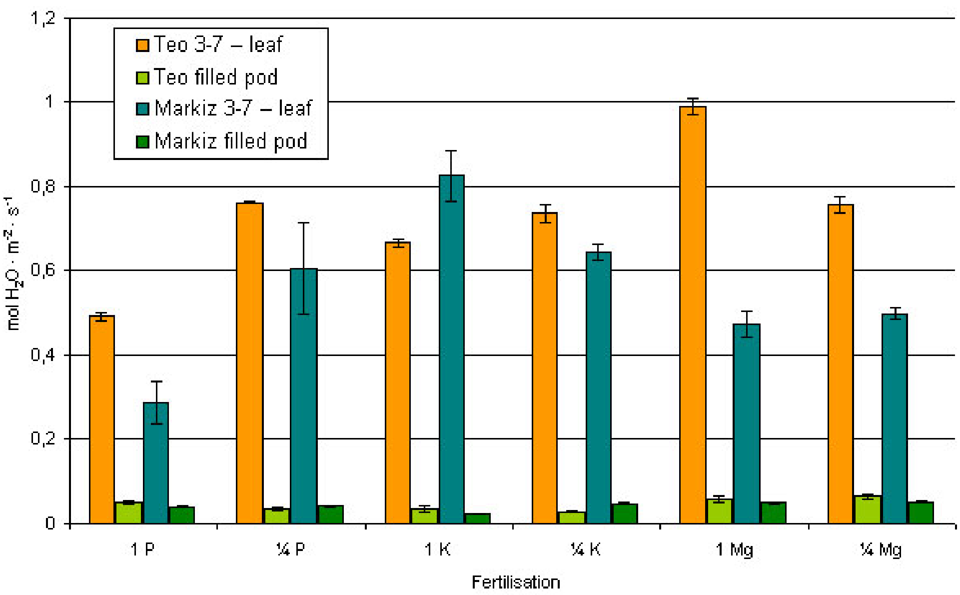
Fig. 8. Yellow lupin stomatal conductance in 3-7–leaf and filled pod phases under mineral stress



The present results show that a varied P, K and Mg fertilisation had a varied effect on some pea biometrics. Phosphorus and potassium, regardless of the dose applied, did not affect biometrics and seed yield per plant significantly. The two pea forms studied yielded similarly (Tables 3 and 4). A shortage of Mg increased the plant height and decreased the number of seeds per pod and the seed weight per plant (Table 5); the other biometrics did not differ significantly. 'Jaspis' plants showed a significantly shorter stem than 'RRRbRb' line plants, yet the former developed more pods per plant and fewer seeds per pod. The seed weight per plant and 1000 seed weight of both forms did not differ significantly.

Table 3. Some biometrics and seed weight per plant in pea cultivars studied exposed to varied phosphorus fertilisation doses

Cultivar/ isoline	P fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Jaspis RRRbRb	1P	31.1 A 30.5 A	29.9 A 29.5 A	1.3 A 1.1 A	1.9 A 2.5 A	278 A 255 A	0.78 A 0.72 A
Jaspis RRRbRb	¼ P	31.2 A 26.5 A	29.4 A 25.8 A	1.5 A 1.1 A	2.0 A 2.5 A	278 A 229 A	0.95 A 0.69 A
Mean for cultivars							
Jaspis RRRbRb		31.1 A 28.5 A	29.7 A 27.6 A	1.4 A 1.1 A	1.9 A 2.5 A	278 A 242 A	0.87 A 0.70 A
Mean for P fertilisation							
1P ¼ P		30.8 A 28.9 A	29.7 A 27.6 A	1.2 A 1.3 A	2.2 A 2.3 A	267 A 253 A	0.75 A 0.82 A

A - Homogenous groups according to the Fisher test

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Table 4. Some biometrics and seed weight per plant in pea cultivars studied exposed to varied potassium fertilisation doses

Cultivar/ isoline	K fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Jaspis RRRbRb	1K	26.2 A 28 .4 AB	27.8 A 27 .5 A	1.3 AB 1 .1 AB	2.2 A 2 .9 A	292 AB 247 A	0.81 A 0 .83 A
Jaspis RRRbRb	¼ K	30.6 B 27 .0 AB	28.2 A 25 .8 A	1.4 B 1 .1 A	2.9 A 2 .7 A	305 B 277 AB	1.02 A 0 .91 A
Mean for cultivars							
Jaspis RRRbRb		28.4 A 27 .7 A	26.5 A 26 .7 A	1.3 B 1 .1 A	2.5 A 2 .8 A	298 B 262 A	0.92 A 0 .87 A
Mean for K fertilisation							
1K ¼ K		27.3 A 28 .8 A	26.1 A 27 .0 A	1.2 A 1 .2 A	2.6 A 2 .8 A	269 A 291 A	0.82 A 0 .97 A

A, AB, B - Homogenous groups according to Fisher test

Table 5. Some biometrics and seed weight per plant in pea cultivars studied exposed to varied magnesium fertilisation doses

Cultivar/ Isoline	Mg fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Jaspis RRRbRb	1Mg	31.0 A 29.9 A	28.2 A 27.7 A	1.5 B 1.1 A	2.4 A 3.5 B	294 A 272 AB	1.08 B 1.04 B
Jaspis RRRbRb	¼ Mg	30.2 A 72.4 B	28.3 A 29.4 A	1.3 AB 1.0 A	1.9 A 2.6 A	289 AB 244 A	0.79 AB 0.62 A
Mean for cultivars							
Jaspis RRRbRb		30.6 A 51.2 B	28.3 A 28.5 A	1.4 B 1.1 A	2.1 A 3.0 B	291 A 258 A	0.93 A 0.83 A
Mean for Mg fertilisation							
1Mg ¼ Mg		30.5 A 51 .3 B	28.0 A 28.9 A	1.3 A 1.1 A	2.9 B 2.2 A	283 A 266 A	1.06 B 0.70 A

A, AB, B - Homogenous groups according to Fisher test

The results presented in Table 6 show that P shortage significantly decreased the yellow lupin number of seeds per pod only, while the other biometrics and seed weight per plant differed insignificantly. ‘Teo’ seed weight per plant was higher than in ‘Markiz’. Under a lower P fertilisation there was recorded a decreasing 1000 seed weight (more than 8%) and seed weight per plant (almost 13%), while self-completing ‘Markiz’ increased the seed weight per plant by 13%.

When exposed to a decreased K dose, stems were longer, the first pod was set up higher (Table 7) and the seed weight per plant dropped insignificantly. ‘Markiz’ stems were longer, 15% lower 1000 seed weight and 28% seed weight per plant than those of ‘Teo’.

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Table 6. Some biometrics and seed weight per plant in yellow lupin cultivars studied exposed to varied phosphorus fertilisation doses

Cultivar	P fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Teo	1P	56.7 A	44.9 A	5.2 A	2.9 A	128 C	1.86 B
Markiz	1P	68.9 B	59.1 B	3.9 A	2.8 A	98 A	1.07 A
Teo	¼ P	57.0 A	44.7 A	5.5 A	2.5 A	117 B	1.62 AB
Markiz	¼ P	69.9 B	60.9 B	4.4 A	2.6 A	107 A	1.23 AB
Mean for cultivars							
Teo		56.9 A	44.8 A	5.3 A	2.7 A	123 B	1.74 B
Markiz		69.4 B	60.0 B	4.1 A	2.7 A	102 A	1.15 A
Mean for P fertilisation							
1P		62.8 A	52.0 A	4.5 A	2.9 B	113 A	1.47 A
¼ P		63.5 A	52.8 A	4.9 A	2.5 A	112 A	1.42 A

A, AB, B, C - Homogenous groups according to Fisher test

Table 7. Some biometrics and seed weight per plant in yellow lupin cultivars studied exposed to varied potassium fertilisation doses

Cultivar	K fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Teo	1K	51.2 A	39.9 A	3.3 A	2.6 A	140 B	2.03 B
Markiz	1K	63.4 C	51.9 C	4.7 AB	2.7 A	112 A	1.40 A
Teo	¼ K	56.8 B	45.8 B	5.5 B	2.6 A	121 A	1.77 AB
Markiz	¼ K	68.9 D	56.3 D	5.3 AB	2.4 A	111 A	1.33 A
Mean for cultivars							
Teo		54.0 A	42.8 A	4.4 A	2.6 A	131 B	1.90 B
Markiz		66.2 B	54.1 B	5.0 A	2.6 A	111 A	1.36 A
Mean for K fertilisation							
1K		57.3 A	45.9 A	4.0 A	2.7 A	126 A	1.72 A
¼ K		62.9 B	51.0 B	5.4 A	2.5 A	116 A	1.55 A

A, AB, B, C, D - Homogenous groups according to Fisher test

Table 8. Some biometrics and seed weight per plant in yellow lupin cultivars studied exposed to varied magnesium fertilisation doses

Cultivar	Mg fertilisation	Plant height, cm	Height of 1st pod setting	Number of pods per plant	Number of seeds per pod	1000 seed weight, g	Seed weight per plant, g
Teo	1Mg	51.2 A	40.4 A	6.0 B	2.7 A	125 A	2.09 B
Markiz	1Mg	64.8 B	51.8 B	5.9 B	2.4 A	119 A	1.52 AB
Teo	¼ Mg	55.4 A	44.5 A	4.8 AB	2.4 A	123 A	1.34 A
Markiz	¼ Mg	72.4 C	63.5 C	3.8 A	2.5 A	123 A	1.14 A
Mean for cultivars							
Teo		53.3 A	42.4 A	5.4 A	2.5 A	124 A	1.72 A
Markiz		68.6 B	57.7 B	4.8 A	2.5 A	121 A	1.33 A
Mean for Mg fertilisation							
1Mg		58.0 A	46.1 A	5.9 B	2.5 A	122 A	1.81 B
¼ Mg		63.9 B	54.0 B	4.3 A	2.4 A	123 A	1.24 A

A, AB, B, C - Homogenous groups according to Fisher test

Decreased Mg doses significantly increased the plant height by 5.9 cm and the first pod was set up higher, the number of pods was considerably lower and the seed weight per plant – was lowered by about 31%. Under a Mg shortage, the cross-cultivar differences concerned only the plant height and the first pod setting height (Table 8).

DISCUSSION

Fertilising results from a necessity to supplying plant with minerals indispensable to a normal course of vital processes [19]. An improper supply of plants over their development in macro- and microelements decreases the yield, which also deteriorates the chemical composition of seeds, their anatomy and physiological properties [5]. The agricultural yield depends on the course of photosynthesis as well as the transport and distribution of assimilates [15,18]. The intensity of photosynthesis can be disturbed by almost every unfavourable environmental factor [17].

The key role in photosynthesis, transport and distribution of assimilates is played by ions of nitrogen, potassium and phosphorus. A shortage of these components leads to a disturbed plant development [18]. The present results confirmed the above statement; the plants of both tested pea forms showed a lowered intensity of photosynthesis when exposed to a shortage of phosphorus and potassium. In the yellow lupin forms tested the intensity of photosynthesis depended on the plant development phase. A higher intensity was observed in plants over filled-pod stage than over 3-7–leaf phase. Starck [20] reports on young plants showing a low photosynthetic production. Young leaves of developing seedlings are not fully autotrophic. Initially they are acceptors of assimilates, importing carbon compounds. A growth of leaf blade coincides with an intensifying CO_2 assimilation and decreasing intensity of respiration; hence changes in physiology, biochemistry and even anatomy, which transform a developing leaf from assimilates acceptor into donor. A maximum net photosynthesis in bean leaves is recorded when the leaf blade reaches about 70 – 80% of its final size. Similarly in soybean, along with increasing leaf blade, the intensity of photosynthesis increases. However over leaf and all-plant ageing the intensity decreases [20].

The stress caused by shortages of phosphorus and potassium also decreased the intensity of photosynthesis. In research reported by Orczyk [16] into rape breeding lines and cultivars such decreased was due to thermal stress. The varied fertilisation with phosphorus and potassium did not differentiate the seed weight per plant in pea. Also mean values for cultivars showed that the cultivars tested, namely 'Jaspis' and 'RRRbRb' yielded similarly. Also Fordoński and Rutkowski [3] claim that increased mineral fertilisation with N, P and K in field experiments did not show a significant effect on higher faba bean yielding. The optimal and lowered to ¼ of the phosphorus and potassium dose did not result in significant changes in the seed weight per yellow lupin plant. Out of all the cultivar types compared, significantly higher yielding was observed in 'Teo'. The reports by Bieniaszewski [1] also show that the yellow lupin traditional cultivar 'Juno' yielded higher, by over 20% than the self-completing 'Markiz'. Similarly the research conducted by Wilczek [22] showed that the effect of varied doses of fertilisation with the basic macroelements did not have a significant effect on yellow lupin seed yield.

In the present research fertilising pea with a lowered dose of magnesium significantly decreased the seed weight per plant and the number of seeds per pod. There was also observed a decreasing trend in the seed weigh in 'Jaspis' and 'RRRbRb' when exposed to a shortage of this macroelement. However mean values of seed weight per plant for the forms tested did not differ significantly. A similar reaction was recorded in the yellow lupin genotypes studied. A magnesium dose lowered to ¼, as compared to the control with the top magnesium dose in 'Teo' and in 'Markiz' decreased the seed weight per plant which did not show significant differences across yellow lupin cultivars in objects fertilised with magnesium. The yellow lupin forms differed in their plant height and the height of setting the first pod. 'Markiz' plants were higher and its first pod was set higher that in 'Teo'. Wojnowska et al. [23] studied also the effect of magnesium fertilisation on some morphological features in lupins and showed that it decreased the number of pods in plants tested, inhibited the growth in lupins, decreased also the height of setting the first pod. The authors observed that the seed yield of the lupins studied when exposed to magnesium fertilisation was significantly lowered as compared with the object fertilised with phosphorus and potassium.

CONCLUSIONS

1. The pea form tested under mineral stress showed lowered intensity of photosynthesis.
2. The yellow lupin cultivars, traditional 'Teo' and self-completing 'Markiz' at the filled-pod stage showed a higher intensity of photosynthesis yet a lower transpiration than in the 3-7– true leaf phase.
3. A decrease in the seed weight per plant in the legume forms and species studied was noted only when plants were treated with ¼ of the magnesium dose.
4. Lowering the fertilisation dose of phosphorus and potassium to ¼ did not result in a significant decrease in the seed weight per plant both in 'Jaspis', 'RRRbRb' pea and in 'Teo' and 'Markiz' yellow lupin cultivars.

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