Content of plant nutrients in vegetables depending on various lime materials used for neutralising bog peat

M. Järvan[1] and P. Põldma[2]

[1]Department of Field Crops, Estonian Research Institute of Agriculture, Teaduse 13, 75501 Saku, Estonia; e-mail: malle.jarvan@mail.ee
[2]Department of Horticulture, Estonian Agricultural University, Kreutzwaldi 64, 54014, Tartu, Estonia; e-mail: ppoldma@eau.ee

Abstract. The trials were performed in the years 1998–2000 in Saku (59°18'N, 24º39'E) in greenhouse conditions. The aim was to establish how lime materials used for the neutralisation of bog peat acidity (oil shale ash, clinker dust, limestone meal, dolomite meal and their mixtures), which changed significantly the contents of available Ca, K and Mg in the peat substrata, affect the mineral composition of vegetable leaves (lettuce, cucumber, tomato, paprika) and the mutual relationships between elements (K, Ca, Mg, P). In the case of all vegetables, a strong Ca and Mg antagonism occurred. The Mg content of plants was very sensitive to the Ca:Mg ratio in the lime material used for peat neutralisation. In the case of limestone meal, the tomato plants contained Mg 0.18–0.24% and cucumber plants 0.36–0.40%; in the case of dolomite meal, 0.66–0.71% and 0.78–0.90, respectively. The Ca and K contents of vegetables were somewhat less affected by the difference of lime materials than the Mg content. Abundant Mg in lime material increased P content in plants, a synergism between Mg and P occurred.

Lettuce grown on substrata neutralised with mixtures of limestone and dolomite meal contained less nitrates than that grown on substrata with clinker dust and oil shale ash. Too high K content in the substrate neutralised with clinker dust had a negative effect on the carotene content of lettuce.

Key words: peat substrate, limestone, dolomite, oil shale ash, cement clinker dust, tomato, cucumber, lettuce, pepper, mineral content in leaves, nitrate, carotene

INTRODUCTION

The mineral composition of plants characterises their nutrition conditions and indicates the yield potentials. The content of mineral elements is affected not only by the contents of elements in the nutrition environment but also by ratios between them, the environment's pH and several other factors. A classical tool for the evaluation of a plant's nutritional status is its leaf analysis, although some studies have indicated that the leaf analysis does not reflect the actual uptake of nutrients and their mutual relationships (Puustjärvi, 1985). The contents and ratios of nutrients differ in different parts of plants, the variations are particularly great between plant species.

The ratios between plant nutrients have a significant effect on the chemical composition of plants and thus also on the growth, development and yielding ability of crops. Improper nutrient ratios may disturb the uptake of certain elements and, in extreme cases, cause nutrient deficiency related diseases, which considerably reduce the marketability of vegetables. For example, an excessive amount of Ca antagonists K^+ and Mg^{2+} in the substrate may cause tipburn of lettuce (Thibodeau & Minotti, 1969; Ashkar & Ries, 1971; Barta & Tibbitts, 1991), which is up to date a major problem for lettuce growers. Also, in the case of tomato, excessive K and Mg inhibits the Ca uptake and causes blossom end rot, which is a result of Ca deficiency (Adams & Ho, 1993).

The nutrient uptake and chemical composition of vegetables are significantly affected by the following ratios between elements: Ca:Mg, Mg:K and Ca:K. As a rule, these three elements function as antagonists (Adams et al., 1978; Kirkby, 1979; Smith & Demchak, 1990; Jakobsen, 1993a; Yang et al., 1996; Järvan, 1999). While growing vegetables on peat substrata where the excessive acidity of bog peat has been neutralised by liming, the lime materials of different compositions have affected both the growth, development, yielding ability and the chemical composition of vegetables (Järvan, 1999 & 2001; Järvan & Teedumäe, 1999).

The aim of the present study was to identify how the different lime materials, which were used for neutralising the acidity of bog peat and which changed the content of available Ca, K, Mg in the substrata considerably (Järvan, 2004), affect the chemical composition of vegetables.

MATERIALS AND METHODS

The trials were carried out in a greenhouse in Saku in 1998–2000. Substrata were produced of bog peat, the pH_{KCl} of which was 3.0 in 1998 and 2000, and 3.2 in 1999. For the neutralisation of peat acidity, different carbonate materials (oil shale ash, clinker dust, limestone meal, dolomite meal and their mixtures) were used mainly at a rate of 8 kg per m³ of peat. In 1998, different lime material rates (6, 8 and 10 kg per m³) were tested. Trial variants are given in Tables 1–4.

Mineral fertilisers were applied to the neutralised peat of trial variants in 1998 and 1999 as a complex fertiliser at a rate of N125 P88 and K162 g per m³ of peat. The complex fertiliser contained the needed amount of microelements but no magnesium. In 2000 macro- and microelements were applied as simple fertilisers at a rate of N126 P91 K200 g/m³. As clinker dust contains a lot of potassium, no potassium was added to some variants, i.e. the effect of lime fertiliser was investigated on NP background.

After the substrata had become stable, their agrochemical indices were determined. Based on the analysis results, the dependence of the substrate's pH and content of available K, Ca and Mg on the type of the used lime material was studied (Järvan, 2004). Seedlings of vegetables were pricked out on the trial substrata. Lettuce was planted into 10 l containers, 10 plants in each container. Young tomato and cucumber plants were planted into 1 l pots, one plant made one replication. The lettuce trial had four replications, the tomato and cucumber trials 5–8 replications. Depending on the year, the plants were grown on substrata from the last days of April until the first decade of June, the length of the growth period being 24–32 days.

While harvesting the lettuce, the yield was weighed per container. In all replications of the trial variants, one half of three lettuce plants was cut, dried at 60ºC and milled later. Average plant samples were prepared for chemical analyses. In the case of lettuce, in the raw samples of each replication of all variants also dry matter, carotene and nitrate contents were determined, which were later recalculated into absolute dry matter.

Tomato and cucumber plants that had reached the outplanting stage were cut down (four from each trial variant) and weighed. Before that the development of blossom cluster of each plant was estimated on a 5-grade scale. The same system was used also for the estimation of the development and condition of tomato and cucumber roots. The effect of different lime materials on the growth and development of tomato and cucumber plants was identified (Järvan, 2001). All leaves were cut from the cut tomato and cucumber plants, they were dried and milled and average samples were prepared for chemical analyses. From dry-ashed plant samples K, Ca and Mg, and in the case of some trials also P, were determined in two replications. The analyses were made at the Chemistry Laboratory of ERIA. Tables 1–4 show the average results of two parallel analyses. The difference between the parallel analyses was 0–5.3%.

RESULTS AND DISCUSSION

There were no major differences in the content of mineral elements of lettuce grown on peat substrata neutralised with different lime materials (Table 1).

Table 1. The influence of lime materials used for neutralising of bog peat on the chemical content of lettuce (*Lactuca sativa L.*, variety 'Cheshunt') in 1998.

Lime material, rate per cubic metre, kg	Content in dry matter					
	carote-ne mg kg^{-1}	nitrate g kg^{-1}	P %	K %	Ca %	Mg %
NPK background						
Oil shale ash, 8 kg	423	36.0	0.72	7.47	1.25	0.41
Limestone +dolomite 1:1, 8 kg	412	20.0	0.87	6.14	1.24	0.45
Limestone +dolomite 2:1, 8 kg	416	26.8	0.88	6.22	1.34	0.42
Limestone +dolomite 3:1, 8 kg	403	22.3	0.87	6.22	1.25	0.41
Limestone +dolomite 1:1,10kg	449	25.2	0.87	6.14	1.14	0.45
Limestone +dolomite 2:1,10kg	453	25.6	0.88	5.89	1.18	0.43
Limestone +dolomite 3:1,10kg	448	25.5	0.84	6.22	1.38	0.41
Cement clinker dust, 6 kg	377	33.1	0.72	7.39	1.34	0.45
Cement clinker dust, 8 kg	404	41.2	0.62	7.68	1.13	0.43
Cement clinker dust, 10 kg	430	38.5	0.62	7.64	1.17	0.38
NP background						
Cement clinker dust, 6 kg	523	40.2	0.83	5.64	1.54	0.53
Cement clinker dust, 8 kg	504	41.1	0.71	6.31	1.39	0.50
Cement clinker dust, 10 kg	500	36.5	0.60	6.81	1.38	0.46
$LSD_{95\%}$	58	8.6				

Table 2. Influence of lime materials used for neutralising of bog peat on the mineral content of tomato and cucumber leaves in 1998.

Lime material, rate per cubic metre, kg	Content in dry matter, %			
	P	K	Ca	Mg
Tomato, variety 'Moneymaker'				
NPK background				
Oil shale ash, 8 kg	0.48	3.32	2.07	0.24
Limestone+dolomite 1:1, 8 kg	0.80	3.32	2.50	0.31
Limestone+dolomite 2:1, 8 kg	0.73	2.86	2.50	0.28
Limestone+dolomite 3:1, 8 kg	0.96	3.32	2.57	0.25
Limestone+dolomite 1:1, 10 kg	0.77	2.82	2.54	0.29
Limestone+dolomite 2:1, 10 kg	0.82	3.03	2.47	0.26
Limestone+dolomite 3:1, 10 kg	0.83	3.20	2.79	0.27
Cement clinker dust, 6 kg	0.54	3.57	2.25	0.25
Cement clinker dust, 8 kg	0.39	3.69	2.43	0.29
Cement clinker dust, 10 kg	0.33	3.69	2.29	0.27
NP background				
Cement clinker dust, 6 kg	0.85	2.66	2.32	0.29
Cement clinker dust, 8 kg	0.57	2.57	2.32	0.33
Cement clinker dust, 10 kg	0.38	2.99	2.68	0.33
Cucumber, variety 'Davista' F_1				
NPK background				
Oil shale ash, 8 kg	0.64	4.40	2.47	0.35
Limestone+dolomite 1:1, 8 kg	1.07	4.32	2.65	0.42
Limestone+dolomite 2:1, 8 kg	1.06	4.48	2.66	0.41
Limestone+dolomite 3:1, 8 kg	1.08	4.48	2.70	0.35
Limestone+dolomite 1:1, 10 kg	0.99	4.07	2.27	0.39
Limestone+dolomite 2:1, 10 kg	0.92	4.15	2.43	0.36
Limestone+dolomite 3:1, 10 kg	1.06	3.99	2.75	0.36
Cement clinker dust, 6 kg	0.75	4.56	2.40	0.37
Cement clinker dust, 8 kg	0.63	4.81	2.36	0.41
Cement clinker dust, 10 kg	0.61	4.90	2.42	0.45
NP background				
Cement clinker dust, 6 kg	1.03	4.15	2.68	0.42
Cement clinker dust, 8 kg	0.92	4.32	2.90	0.42
Cement clinker dust, 10 kg	0.61	4.56	2.77	0.46

When lime materials were used at a rate of 8 kg/m³, the dry matter of lettuce contained 0.62–0.88% of P, 6.14–7.68% of K, 1.13–1.25% of Ca and 0.41–0.45% of Mg. In the case of clinker dust, the K content of lettuce was highest; this was due to the high K content in clinker dust, because even in the substrate of this variant there was 1.3–2.1 times more K than in other variants (Järvan, 2004). At the same time, the lettuce of clinker dust variant contained less P and Ca, thus the antagonism between the elements occurred. However, in general the content of mineral elements in lettuce remained in all trial variants within the optimum limits, which are for lettuce grown on peat as following: P 0.5–1%, K 5–10%, Ca 1–2% and Mg 0.3–0.7% in dry matter (Kasvihuoneanalyysien…,1990). Claassens (1994) considers the optimum P content for lettuce to be 0.4–0.9% and he mentions that a higher P content may cause leaf abnormalities on certain lettuce varieties. When Ca content in the dry matter of lettuce leaves is at least 1%, it indicates that the plant takes from the substrate up a sufficient amount of Ca and there is no danger for tipburn of lettuce (Thibodeau & Minotti, 1969). For lettuce the optimum Ca:Mg ratio in leaves is considered to be 3.0 (Puustjärvi, 1985). In our trial variants, at a liming rate of 8 kg/m³, the above ratio was between 2.6 and 3.2.

The lime materials did not affect the dry matter content of lettuce, being between 4.71 and 4.96%. But there were the significant differences in nitrate and carotene contents, being respectively 986–1994 mg and 19.1–25.3 mg in kg raw material.

Table 3. Influence of lime materials used for neutralising of bog peat on the mineral content of tomato and cucumber leaves in 1999.

The rate of lime materials 8 kg per cubic metre peat

Lime material	Content in dry matter, %			
	P	K	Ca	Mg
Tomato, variety 'Moneymaker'				
NPK background				
Oil shale ash	0.60	2.86	3.25	0.58
Cement clinker dust	0.63	3.20	3.00	0.45
Limestone meal	0.88	3.61	2.68	0.18
Dolomite meal	0.90	2.53	1.82	0.71
Limestone + dolomite 1:1	0.88	3.49	2.39	0.40
Clinker dust + dolomite 1:1	0.75	3.90	2.54	0.44
Clinker dust + limestone 1:1	0.73	3.74	3.00	0.39
NP background				
Cement clinker dust	0.74	2.74	3.00	0.49
Clinker dust + dolomite 1:1	0.99	2.08	2.79	0.49
Clinker dust + limestone 1:1	0.96	2.28	3.00	0.44
Cucumber, variety 'Davista' F_1				
NPK background				
Oil shale ash	0.64	4.03	4.07	0.63
Cement clinker dust	0.66	4.69	3.14	0.45
Limestone meal	0.79	4.44	2.89	0.36
Dolomite meal	0.87	4.57	2.32	0.78
Limestone + dolomite 1:1	0.82	4.73	2.50	0.46
Clinker dust + dolomite 1:1	0.76	4.90	2.79	0.48
Clinker dust + limestone 1:1	0.75	5.15	3.22	0.36
NP background				
Cement clinker dust	0.81	4.73	4.43	0.49
Clinker dust + dolomite 1:1	1.00	4.07	3.64	0,54
Clinker dust + limestone 1:1	0.93	3.40	3.86	0.48

Table 4. Influence of lime materials used for neutralising of bog peat on the mineral content of tomato, cucumber and pepper leaves in 2000.

The rate of lime materials 8 kg per cubic metre peat

Lime material	Content in dry matter, %		
	K	Ca	Mg
Tomato, variety 'Moneymaker'			
NPK background			
Cement clinker dust	4.03	2.57	0.31
Limestone meal	3.71	2.36	0.24
Dolomite meal	3.76	1.39	0.66
Limestone + dolomite 1:1	4.13	1.82	0.45
NP background			
Cement clinker dust	3.51	2.93	0.37
Clinker dust + limestone 1:1	2.76	2.98	0.32
Clinker dust + dolomite 1:1	2.49	2.50	0.54
Cucumber, variety 'Davista' F_1			
NPK background			
Cement clinker dust	4.40	2.39	0.42
Limestone meal	3.45	2.75	0.40
Dolomite meal	3.20	1.69	0.90
Limestone + dolomite 1:1	3.34	2.50	0.74
NP background			
Cement clinker dust	3.49	3.04	0.51
Clinker dust + limestone 1:1	2.29	3.04	0.52
Clinker dust + dolomite 1:1	2.06	2.97	0.90
Pepper, variety 'Podarok Moldovi'			
NPK background			
Cement clinker dust	5.41	1.32	0.32
Limestone meal	5.13	1.36	0.34
Dolomite meal	4.50	0.98	0.59
Limestone + dolomite 1:1	4.61	1.07	0.47
NP background			
Cement clinker dust	4.87	1.50	0.37
Clinker dust + limestone 1:1	4.03	1.39	0.32
Clinker dust + dolomite 1:1	4.23	1.27	0.55

Lettuce grown on the substrata neutralised with carbonate rock meals contained less nitrates than that grown on substrata neutralised with clinker dust or oil shale ash. In the case of the latter lime materials, the accumulation of nitrates could be enhanced by the fact that they contained a considerable amount of K. A positive effect of K on the nitrate content of vegetables has been proved in earlier studies (Järvan, 1994). The carotene content of lettuce was higher, as a rule, when higher lime material rates (10 kg per m^3 on NPK background) were applied. Also a connection between the carotene content and K uptake became evident: when the substrate's K content exceeded significantly the optimum level (clinker dust on NPK background), the lettuce contained 16–39% less carotene than on the optimum K level (clinker dust on NP background).

In the case of tomato grown on peat substrate, the optimum Ca content in the dry matter of leaves is considered to be 1.5–3.0% (Kasvihuoneanalyysien….,1990). In our trials tomato leaves contained 2.1–3.2% of Ca (Tables 2–4). Plants grown on the peat neutralised with dolomite meal made an exception, their Ca content was on a critical level (1.4 and 1.8%). It has become evident that already a relatively short period of Ca deficiency (8–10 days) causes visual deficiency symptoms on tomato, inhibits the growth of stalk and destroys the apical meristem (Morard et al., 1990).

For greenhouse cucumber it is considered to be sufficient when the dry matter of leaves contains 2–6% of Ca (Kasvihuoneanalyysien….,1990). In our trials the cucumber leaves contained, depending on the lime material, 2.3–4.4% of Ca (Tables 2–4). Even in the case of cucumber the substrate neutralised with dolomite meal made an exception; in the trial of 2000 the plants grown on it contained only 1.7% of Ca. Such a Ca level can later result in acute Ca deficiency, the more serious expression of which is drying of young fruits and crooking of fruits.

The optimum Mg content for greenhouse cucumber is considered to be 0.5–1% in the dry matter of leaves and for tomato 0.3–0.6%, respectively (Kasvihuone-analyysien…., 1990). However, in the opinion of some authors the optimum Mg content of tomato leaves should be higher, i.e. 0.4–1.0% (Kolota & Biesiada, 1990). In our trials the Mg content of cucumber plants grown on the peat neutralised with different lime materials was within 0.35–0.90% and that of tomato plants 0.18–0.71%. At that the Mg content of leaves was very sensitive to the Mg content of the used lime material and substrate (Järvan, 2004): in the case of one-sided Ca uptake (limestone meal) the leaves contained very little Mg and in the case of one-sided Mg uptake (dolomite meal) several times more. Thus, there was a strong occurrence of Ca:Mg antagonism.

The optimum K content in the dry matter of leaves of greenhouse cucumber and tomato is considered to be 2.5–5% and 3–6%, respectively (Kasvihuoneanalyysien…., 1990). In our trials (on NPK background) the cucumber leaves contained 3.2–5.2% of K and tomato leaves 2.8–4.1%. Unlike the Mg content of plants, the K content did not react so strongly to the differences in nutrient contents of lime materials and substrate. Even in the plants grown on the substrata neutralised with clinker dust and fertilised with NPK basic fertiliser, in which the content of available K was too high for plants reaching up to 570 mg/l (Järvan, 2004), there was no significant increase in the K content.

The relationships between plant's Ca and P contents are complicated – they can be either antagonistic or synergistic (Demchak & Smith, 1990; Jakobsen, 1993b). In the case of Ca deficiency in growth substrate, the Ca and P contents in tomato plants have decreased (Morard et al., 1996). In our trials the antagonistic relationships of Ca and P became evident both in tomato and cucumber; the Ca content of plants grown on the peat neutralised with dolomite meal was considerably lower than in the case of other lime materials, but the P content was the highest (Table 3). The same trial showed, however, a synergistic effect between Mg and P. Even other researches have found that abundant Mg in peat substrate enhances the uptake of P by tomato (Kolota & Biesiada, 1990). Synergism between Mg and P has been found also on other vegetables (Demchak & Smith, 1990).

The Mg content of pepper plants is inversely proportional to the Ca and K content (Yang et al., 1996). The same tendency was evident also in our trial. On NPK background the Mg content of pepper grown on the substrata neutralised with limestone meal and clinker dust was the lowest (Table 4). Mg, containing one-sidedly in dolomite meal, increased the content of this element in plant leaves but inhibited Ca uptake. A trial performed on peat substrate in Poland showed that different levels and ratios of Ca and K did not significantly affect the growth of pepper plants and the dry matter content of crops (Malinovski & Starck, 1992).

Neutralisation of peat substrate with different lime materials affects not only the contents of basic nutrients in plants (K, Ca, Mg, P) but also the contents of micronutrients. The content of heavy metals (Pb, Cd, Zn, Ni, Cr) in vegetables did not depend on the heavy metal content of the used lime materials. However, on some occasions it depended on the level to which one or other lime material (rate 8 kg/m^3) could raise the substrate's pH. For example, on the substrate neutralised with dolomite meal (pH_{KCl} 5.6) the lettuce contained 18.5% more Cd and 30.3% more Zn than on the substrate neutralised with oil shale ash (pH_{KCl} 6.5), regardless the fact that with oil shale ash these heavy metals were applied to the substrate respectively 38 and 239% more than with the same amount of dolomite meal (Järvan, 1998).

CONCLUSIONS

The following conclusions can be drawn from the given research:

- The use of different lime materials for the neutralisation of bog peat acidity had a considerable effect on the mineral composition of vegetables grown on peat substrata.
- The broader was the Ca: Mg ratio of lime material, the lower was the Mg content of plants. The Ca:Mg antagonism was strongly expressed in the mineral composition of plants. The Mg content of tomato and cucumber plants depended considerably on the Mg content of lime material and the available Mg content in the growth substrate.
- Unlike the Mg content of plants, the K content did not react much to the differences in nutrient contents of lime materials and substrate.
- The use of lime materials with one-sided Ca or Mg content causes deviances in the optimum content of mineral elements of plants. On the peat substrate neutralised with pure limestone meal plants develop Mg deficiency and on the substrate neutralised with dolomite meal Ca deficiency. These can later disturb considerably the growth and development of plants and reduce the quality of yield.
- The use of Mg rich lime material improved the uptake of P by cucumber and tomato plants.
- Lettuce grown on the substrata neutralised with mixtures of limestone and dolomite meal contained less nitrates than that on substrata with clinker dust and oil shale ash.
- Too high K content in the substrate neutralised with clinker dust had a negative effect on the carotene content of lettuce.

ACKNOWLEDGEMENTS. This research work was partially supported by the Estonian Science Foundation (grant no. 3211). Many thanks to Mrs. Anne Kask, Mrs. Kira Männik and Mr. Helmo Niine for their careful analytical work.

REFERENCES

Adams, P., Graves, C. J. & Winsor, G. W. 1978. Some responses of lettuce, grown in beds of peat, to nitrogen, potassium, magnesium and molybdenum. *Journal of Horticultural Science,* **53,** 4, 275–281.

Adams, P. & Ho, L. C. 1993. Effects of environment on the uptake and distribution of calcium in tomato and on the incidence of blossom-end rot. *Plant & Soil,* **154**, 127–132.

Ashkar, S. A. & Ries, S. K. 1971. Lettuce tipburn as related to nutrient imbalance and nitrogen composition. *J. Amer. Soc. Hort. Sci.,* **96**, 448–452.

Barta, A. J. & Tibbitts, T. W. 1991. Calcium localisation in lettuce leaves with and without tipburn: comparison of controlled-environment and field-grown plants. *J. Amer. Soc. Hort. Sci.,* **116**, 5, 870–875.

Claassens, A. S. 1994. The influence of varying P concentrations on the yield and abnormalities of lettuce leaves. *South African Journal of Plant and Soil,* **11**, 3, 145–148.

Demchak, K. T. & Smith, C. B. 1990. Yield responses and nutrient uptake of broccoli as affected by lime type and fertilizer. *J. Amer. Soc. Hort. Sci.,* **115,** 5, 737–740.

Jakobsen, S. T. 1993a. Interaction between Plant Nutrients. III. Antagonism between Potassium, Magnesium and Calcium. *Acta Agric. Scand. Sect. B,* 43, 1–5.

Jakobsen, S. T. 1993b. Interaction between Plant Nutrients. IV. Interaction between Calcium and Phosphate. *Acta Agric. Scand. Sect. B,* 43, 6–10.

Järvan, M. 1994. *Factors affecting the nitrate content of vegetables.* Thesis D.Agr.sc., Tartu.

Järvan, M. 1998. Content of heavy metals in vegetables depending on different lime fertilizers. *Journal of Agricultural Science* IX, 3, 176–187 (in Estonian).

Järvan, M. 1999. Different lime fertilizers in nutrition of vegetables. In *Scientific works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture*, **18**, 3, 113–121.

Järvan, M. 2001. Growth and development of vegetable plants depending on various lime fertilizers. *Transactions of the Estonian Academic Agricultural Society,* **14**, 65–68 (in Estonian).

Järvan, M. 2004. Available plant nutrients in growth substrata depending on various lime materials used for neutralising of bog peat. *Agron. Journal,* **2**, 1.

Järvan, M. & Teedumäe, A. 1999. The effect of finely ground Estonian limestone and dolomite on the growth and chemical composition of greenhouse vegetables grown on peat substrate. *Proceedings of the Estonian Academy of Sciences. Biology/Ecology,* **48**, 3, 236–245.

Kasvihuoneanalyysien tulkintaopas. 1990. Viljavuuspalvelu OY, pp. 3–7.

Kirkby, E. A. 1979. Maximizing calcium uptake by plants. *Communic. Soil Sci. & Plant Analysis,* **10**, 1&2, 89–113.

Kolota, E. & Biesiada, A. 1990. Effect of magnesium fertilization on yield and mineral state of greenhouse tomatoes. *Folia Horticulturae,* **2**, 1, 41–52.

Malinowski, D. & Starck, J. R. 1992. Influence of changes in potassium and calcium levels and the ratio of these elements in the nutrition solution on the growth and yield of paprika. *Annals Warsaw Agric. Univ.,* 16, 25–24.

Morard, P., Pujos, A., Bernadac, A. & Bertoni, G. 1996. Effect of temporary calcium deficiency on tomato growth and mineral nutrition. *J. Plant Nutrit.,* **19**, 1, 115–127.

Puustjärvi, V. 1985. Kalsium/magnesium-suhde turveviljelyssa. *Puutarha,* 6, 378–379.

Smith, C. B. & Demchak, K. T. 1990. Tomato nutrient uptake as affected by limestone type. *Communic. Soil Sci. & Plant Analysis*, **21**, 13–16.

Thibodeau, P. O. & Minotti, P. L. 1969. The influence of calcium on the development of lettuce tipburn. *J. Amer. Soc. Hort. Sci.,* **94**, 372–376.

Yang, S. K., Kim, W. S., Kim, H. W. & Chung, G. C. 1996. Effect of Ca/K ratio in nutrient solution on the early growth and the mineral composition in the xylem sap and plant of pepper. *J. Korean Soc. Hort. Sci.,* **37**, 5, 622–626.