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THE EFFECT OF FINELY GROUND ESTONIAN LIMESTONE AND DOLOMITE ON THE GROWTH AND CHEMICAL COMPOSITION OF GREENHOUSE VEGETABLES GROWN ON PEAT SUBSTRATUM

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Abstract. Estonia has resources of limestone and dolomite with different calcium and magnesium contents, the meal of which can be used for neutralizing the growth substratums produced from bog peat and for supplying plants with sufficient quantities of magnesium. The effect of limestone and dolomite meal and their mixtures at ratios of 1 : 1 and 3 : 1, as well as oil shale ash on the growth, yield, and chemical composition of greenhouse vegetables (lettuce, tomato, and cucumber) was compared. The rate of lime fertilizer addition was set at 8 kg per cubic metre of peat. A too broad or too narrow Ca : Mg ratio in lime fertilizers inhibited the growth of plants and reduced the yield. Magnesium contained in dolomite meal had a positive effect on the synthesis of leaf pigments (chlorophyll, carotene) and also decreased the nitrate content in vegetables. The use of limestone and dolomite meal mixtures for neutralizing peat substratum increased the yields of lettuce and cucumber and improved the taste of tomatoes.

Key words: limestone and dolomite meal, peat substratum, neutralizing of soils, Ca : Mg ratio, greenhouse vegetables, yield, chemical composition, chlorophyll, carotene, nitrates.

INTRODUCTION

Estonia is overlain by abundant deposits of peat which are widely used for growing greenhouse vegetables. Vegetables are grown in a peat substratum, the acidity of which has usually been neutralized with oil shale ash. In order to provide plants with a source of magnesium, imported magnesium sulphate was added to the substratum. It is possible, however, to regulate the acidity of the substratum with several other domestic materials (Järvan, 1997a).

Carbonate rocks of commercial value are widespread in Estonia with more than half of the country being directly underlain by them. The rather thin Quaternary cover has permitted extraction since ancient times. Workable deposits occur at many levels (Fig. 1) and the country is well endowed with explored resources.

The chemical composition of carbonate rocks covers the full spectrum from pure limestone through pure dolomite, and it offers good prospects for liming purposes (Teedumäe, 1986). Until recently, dust ash from power stations and clinker dust from cement manufacture were used, but changing economic circumstances favour the application of locally produced limestone and dolomite. The relatively new trend towards the use of dolomite has resulted principally because of changes in agricultural practices which have given rise to considerable magnesium deficiences. Traditionally, magnesium was returned to the soil in the form of manure, but crop specialization and a fall in farming activity have reduced its availability.

Carbonate rocks are actively exploited today enabling a number of quarries to serve agricultural requirements (Teedumäe, 1997). In mining there are large volumes of production wastes which, after grinding to the required fineness, could provide suitable materials with both economic and environmental benefits. These products would be very suitable for liming acid soils and neutralizing growth media. By mixing limestone and dolomite meals it is possible to prepare mixtures with different Ca:Mg ratios for neutralizing peat, with the added benefit that the import of Mg-fertilizers can be reduced considerably or even entirely avoided (Järvan, 1997b).

The goal of the present study was to assess the effect of finely ground limestone, dolomite, and their mixtures on the agrochemical properties of peat substratum as well as the growth, development, yield, and chemical composition of greenhouse vegetables.

MATERIAL AND METHODS

The samples of aggregate were collected from three exploited deposits – Vasalemma, Anelema, and Rõstla (Fig. 1). The deposits were chosen considering the composition of rocks. The Vasalemma deposit represents the purest limestone. All limestones suitable for lime production (Fig. 1) are approximately of the same composition. The Anelema deposit represents the purest dolomite, distributed on the outcrop of the Jaagarahu Stage in the mainland of Estonia and on the Island of Muhu (Fig. 1). The argillaceous dolomite from the Rõstla deposit was chosen to assess the possible impact of terrigenous component, common to Estonian carbonate rocks. Their chemical composition and heavy metals content were determined by the Agricultural Chemistry Centre of the Estonian Department of Plant Protection. From these results, carbonate aggregates suitable for crop production were selected, delivered, and prepared for trials by crushing.

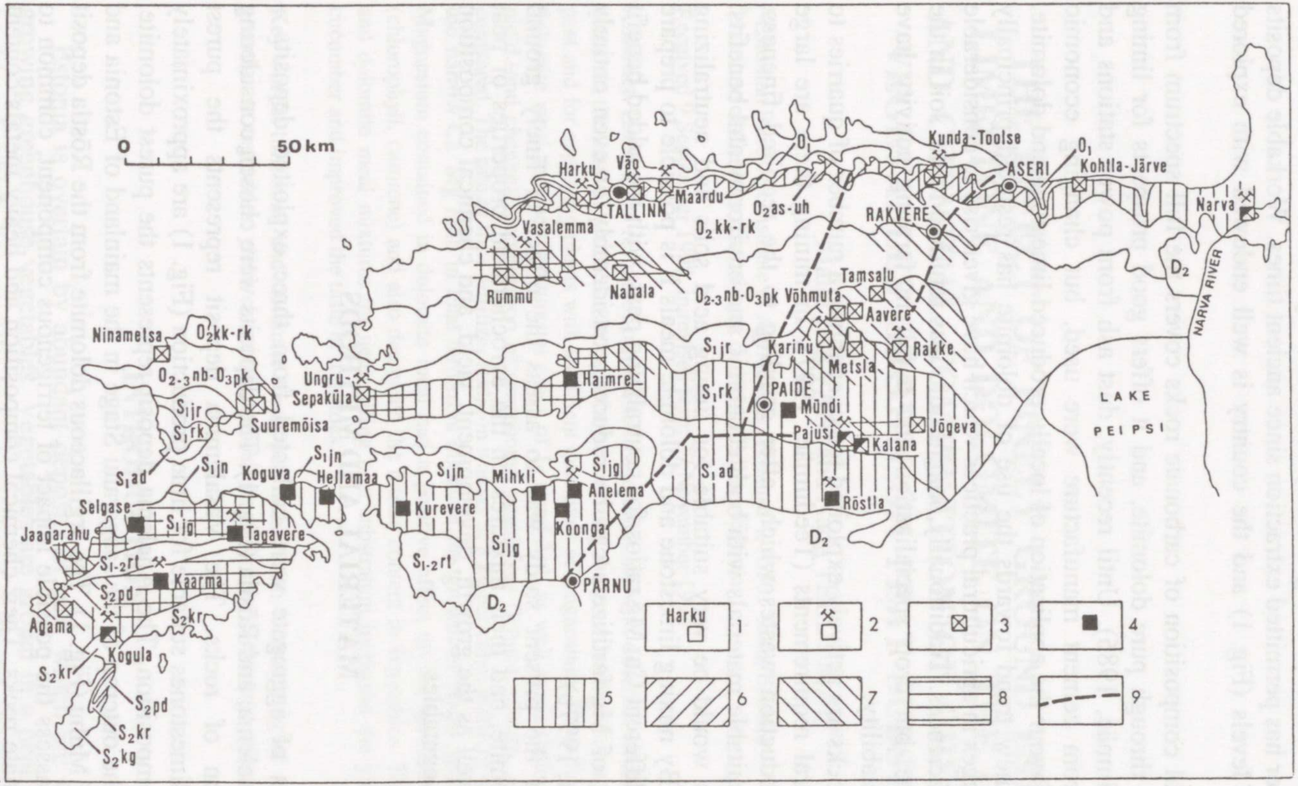

Fig. 1. Distribution of limestone and dolomite resources in Estonia.

1, deposit and its name; 2, deposit in exploitation; 3, limestone deposit; 4, dolomite deposit. Promising areas of carbonate rocks: 5, for construction purposes; 6, for cement production; 7, for lime production; 8, for facing and ornamental purposes; 9, zone of disturbances. Stratigraphical indices of the regional stages: O_1, Pakerort, Varangu, Volkhov, Kunda; O_2as-uh, Aseri, Lasnamäe, Uhaku; O_2kk-rk, Kukruse, Idavere, Jõhvi, Keila, Oandu, Rakvere; O_{2-3}nb–O_3pk, Nabala, Vormsi, Pirgu, Porkuni; S_1jr, Juuru; S_1rk, Raikküla; S_1ad, Adavere; S_1jn, Jaani; S_1jg, Jaagarahu; S_{1-2}rt, Rootsiküla; S_2pd, Paadla; S_2kr, Kuressaare; S_2kg, Kaugatuma; D_2, Middle Devonian.

The preliminary trials made in 1995 studied the effects of different fractions (1–2 mm and <0.5 mm) of seven mechanically crushed dolomite aggregates in peat's neutralization. The trial monitored the pH level and the Ca and Mg contents of the substrata at two weekly intervals. Further trials were then carried out using rock meals ground to 0.2 mm in a disintegrator mill.

The 1995 trials compared the effects of dolomite meals (Anelema and Rõstla) and oil shale ash on lettuce, cucumber, and tomato grown in a greenhouse. A control variant was established in which oil shale ash with a 0.4 kg/m^3 magnesium sulphate addition was used. Such oil shale ash application has been the most common Estonian practice for growing greenhouse vegetables. The lime fertilizer rate was the same for all the trial variants – 8 kg/m^3 peat. This rate of addition was also used for the 1996 trials.

The 1995 trial lime fertilizer variants and their Ca and Mg contents were as follows:

1. Anelema dolomite meal; Ca 18.7%, Mg 12.1%
2. Rõstla dolomite meal; Ca 18.4%, Mg 11.7%
3. Oil shale ash; Ca 29.0%, Mg 2.0%
4. Oil shale ash + 0.4 kg/m^3 magnesium sulphate (control)

The 1996 trials with greenhouse vegetables were performed in two series. The neutralization variants were similar in both series and were as follows:

1. Oil shale ash; Ca 28.8%, Mg 2.1%
2. Vasalemma limestone meal; Ca 33.9%, Mg 2.4%
3. Anelema dolomite meal; Ca 19.6%, Mg 11.5%
4. Limestone meal + dolomite meal, 1 : 1
5. Limestone meal + dolomite meal, 3 : 1

In the first series of trials lettuce, cucumber, and tomato plants were grown. These crops require a lower concentration of nutrients, therefore only 1.25 kg of complete fertilizer (N 10.1%, P 7.3%, K 16.1% + trace elements) was added per cubic metre. The same NPK fertilizer rate was used for the 1995 trials.

In the second series of trials, cucumber and tomato plants were grown from young plant stage to the end fruit stage. The substratum was enriched with 2.4 kg of complete fertilizer per cubic metre and during fruit bearing NK fertilizer was applied as a top-dressing.

The trials were performed as vegetation trials. For lettuce four replications with ten plants per vessel were made; for cucumber and tomato plants there were eight replications with one plant per vessel. Container trials were also carried out with fruit bearing cucumber and tomato plants in three replications with two plants per container.

The growth dynamics of the plants was studied and the average weight yield of lettuce, tomato, and cucumber plants determined. Both substratum and plant samples were collected for analysis. In the plant material the contents of chlorophyll, carotene, nitrates, nutrient elements, and heavy metals were determined. The fruits collected from the cucumber and tomatoes were analysed and the tomatoes were tasted twice.

RESULTS AND DISCUSSION

According to unpublished data by Malle Järvan the 1–2 mm fraction of crushed dolomite does not practically reduce the acidity in the peat substratum. The pH of the peat changed only by 0.11–0.24 units. Thus, it is apparent that, without prior grinding, it is not possible to use the fine fraction of dolomite production waste for regulating the growth medium of plants.

With the lime fertilizer rate of 8 kg/m^3, the <0.5 mm fraction reduced the peat's acidity on average by 1.65 pH units with Rõstla dolomite and by 1.85 pH units with Anelema dolomite; the same amount of oil shale ash as an average by 2.74 pH units. The pH of the peat was to all intents and purposes stabilized two weeks after the application of lime fertilizer.

The available Ca content in the substratum increased in the case of dolomite meal on average by 350 mg/L and in the case of oil shale ash by 690 mg/L, the increase of Mg content was respectively 260 and 130 mg/L.

The Ca:Mg ratio in the substratum has a considerable effect on the growth and development of plants because both elements act as antagonists. The Ca:Mg ratio must be optimal, neither too broad nor too narrow (Järvan, 1997a). For peat neutralization it is recommended to use a lime fertilizer in which the Ca:Mg ratio as carbonates is 6.5:1 (Rinkis & Nollendorf, 1977), i.e. as elements the ratio should be approximately 9:1.

In lime fertilizers used in the 1995 trials, the Ca:Mg ratios were as follows: in dolomite meals 1.5–1.6 (too narrow); in oil shale ash 14.5 (too broad); and in oil shale ash + magnesium sulphate 10.4 (almost optimum).

Because of different neutralization ability of lime fertilizers, the substratum's pH_{KCl} in dolomite meal variants was 5.5 and in oil shale ash variants 6.5–6.6 (Table 1). For vegetables grown in the given trials pH_{KCl} 5.5 on peat substratum is quite acceptable and according to literature it is even better if the pH_{KCl} is greater than 6.5. However, such differences in acidity will affect the uptake of some plant nutrients. In the above trials the effect was most evident in the uptake of phosphorus and heavy metals.

The trial results indicated that on peat neutralized with dolomite meals the weight of plants was considerably lower than in the control variant: for lettuce the average was 22.4% lower, for tomatoes 19.4%, and for cucumbers 20.3% (Table 1). The most probable reason for this difference is too narrow a Ca:Mg ratio. The trial results also indicated the necessity of further research into the possibilities of creating an optimum Ca:Mg ratio by mixing carbonate rock meals of different compositions.

As a positive feature of dolomite meals that contain magnesium, its effect on the synthesis of leaf pigments should be mentioned. According to Baumeister & Ernst (1978), a broader Ca:Mg ratio than normal leads to more carotenoids and less chlorophyll synthesized. In the case of a narrower ratio, this pattern is reversed. In the trials of 1995, the leaves of vegetables grown in the dolomite meal variants contained between 9.4 and 23.7% more chlorophyll, and lettuce contained 25.7%

more carotene than the control variant (Table 1). On the substratum neutralized with dolomite meal the lettuce contained on average 26.8% less nitrates.

The plants in dolomite meal variants contained more magnesium but less calcium due to the chemical composition of lime fertilizers. The differences in the plant's phosphorus content were probably caused by differences in the acidity of substrata. On the other hand, these might be caused also by a synergistic relationship between Mg and P. The concentration of Mg in a substratum strongly affects phosphorylation reactions (Mengel & Kirkby, 1987; Marschner, 1997). The higher K content in lettuce and cucumber leaves in the oil shale ash variants was due to the fact that this lime fertilizer contains considerable amounts of potassium.

Table 1. The effect of dolomite meal and oil shale ash on vegetables in 1995

	Anelema dolomite meal	Rõstla dolomite meal	Oil shale ash	Oil shale ash + $MgSO_4$ (control)
In the substratum				
pH_{KCl}	5.5	5.5	6.5	6.6
Ca, mg/L	1128	1062	2279	2016
Mg, mg/L	450	478	248	294
Ca : Mg	2.5	2.2	9.2	6.9
Lettuce (cv. Cheshunt)				
Weight, g	32.1	30.4	39.6	41.5
Chlorophyll, mg/kg	1900	1969	1607	1673
Carotene, mg/kg	34.0	36.5	28.7	28.0
Nitrate, mg/kg	2010	2294	3376	2938
P, % DM	1.17	1.18	0.70	0.76
K, % DM	8.65	8.73	14.5	10.9
Ca, % DM	0.99	0.90	1.02	1.09
Mg, % DM	1.26	1.11	0.67	0.75
Tomato plants (cv. Belõi naliv)				
Weight, g	43.7	43.6	53.6	50.4
Chlorophyll, mg/kg	6650	7011	5284	5522
P, % DM	0.87	0.88	0.42	0.45
K, % DM	5.28	5.68	5.13	5.55
Ca, % DM	1.50	1.55	2.45	2.50
Mg, % DM	0.98	1.18	0.79	0.86
Cucumber plants (cv. F_1NIIOH-412)				
Weight, g	42.6	38.3	50.0	50.8
Chlorophyll, mg/kg	6183	6179	5336	5652
P, % DM	0.70	0.72	0.52	0.52
K, % DM	5.53	5.83	6.65	6.40
Ca, % DM	1.60	1.55	2.45	2.30
Mg, % DM	1.26	1.49	0.78	0.79

The first trial series of 1996 involved the pricking of the plants into substrata two weeks after it had been prepared. By this time, the pH had more or less been stabilized, whereas Ca and Mg continued their transformation. After a further period of a month, the content of available Ca and Mg had increased considerably and the Ca:Mg ratio had narrowed in all substrata (Table 2).

Table 2. Properties of peat substratum in the first trial series of 1996, lime fertilizer rate 8 kg/m^3

Properties	Oil shale ash	Limestone meal	Dolomite meal	Limestone and dolomite meal 1 : 1	Limestone and dolomite meal 3 : 1
Two weeks after preparation					
pH_{KCl}	6.5	6.2	5.4	5.8	6.0
Ca, mg/L	2548	2856	1102	1848	2320
Mg, mg/L	192	123	440	235	180
Ca : Mg	13.3	23.2	2.5	7.9	12.9
Six weeks after preparation					
pH_{KCl}	6.5	6.2	5.6	5.9	6.2
Ca, mg/L	3240	3772	1656	2592	3110
Mg, mg/L	279	175	713	365	258
Ca : Mg	11.6	21.6	2.3	7.1	12.1

The trial results indicated that a unilateral excess of both Ca and Mg had a negative effect on the growth of lettuce, cucumber, and tomato plants because the weight of the plants was the lowest in the variants of pure limestone and dolomite meal (Table 3). When limestone and dolomite meal mixtures in the ratio 1:1 and 3:1 were used for peat neutralization, plant weights were significantly increased. An increase in plant weight for lettuce of up to 18.2% was observed, the figure for cucumber was up to 26.1% greater compared with plants grown in the variants containing pure dolomite meal.

Differences in lime fertilizers had no significant effect on the dry matter content of vegetables, nor on their nitrate content, which was rather low. As previously noted in the 1995 trial, the Mg rich fertilizer reduced the nitrate content in lettuce. The chlorophyll content of leaves was always highest in the variants with dolomite meal, whilst addition of dolomite meal to limestone meal also had a positive effect on chlorophyll synthesis.

When the meal mixtures 1:1 and 3:1 were used, the yield of cucumber was considerably higher than in variants with oil shale ash and limestone meal. However, no significant change in tomato yields occurred. There was, however, a significant change in the taste of tomatoes, which was confirmed by a second tasting. The highest grade for taste (on average 4.54) was given to tomatoes grown on the substratum which had been neutralized with oil shale ash, whilst the lowest grades (2.50 and 2.93) were recorded by those variants containing pure dolomite

Tabel 3. The effect of lime fertilizers on vegetables in 1996

Vegetable, phase of development, weight, chemical composition	Oil shale ash	Limestone meal	Dolomite meal	Limestone meal + dolomite meal	
				1 : 1	3 : 1
Lettuce (cv. Cheshunt)					
Weight, g	28.0	24.8	22.5	25.2	26.6
Chlorophyll, mg/kg	1986	1826	2097	2155	1878
Carotene, mg/kg	18.0	21.6	21.7	20.6	25.5
Nitrate, mg/kg	1193	1193	855	1015	844
P, % DM	0.82	0.93	1.05	0.89	0.97
K, % DM	8.30	6.97	6.23	6.56	6.91
Ca, % DM	1.35	1.54	1.21	1.31	1.42
Mg, % DM	0.45	0.40	0.63	0.45	0.42
Tomato (cv. F_1 Ida)					
Plant phase					
Weight, g	63.9	61.3	58.3	62.4	58.3
Chlorophyll, mg/kg	4248	4126	5000	4208	4192
P, % DM	0.43	0.59	0.69	0.61	0.53
K, % DM	4.22	2.21	2.07	2.37	2.08
Ca, % DM	2.19	2.48	1.57	2.07	2.22
Mg, % DM	0.30	0.23	0.62	0.38	0.31
Fruit phase					
Leaves					
P, % DM	0.59	0.91	1.01	0.94	1.01
K, % DM	4.08	2.83	3.04	2.87	2.70
Ca, % DM	2.70	2.70	2.82	2.73	3.09
Mg, % DM	0.58	0.48	0.89	0.58	0.62
Fruits					
Yield, kg per plant	2.48	2.38	2.62	2.55	2.34
Taste, points	4.54	2.93	2.50	3.21	3.66
Sugar, %	3.66	3.57	3.54	3.92	3.69
Organic acids, %	0.60	0.59	0.54	0.52	0.52
Nitrate, mg/kg	14.2	12.4	11.1	10.2	13.2
P, % DM	0.55	0.64	0.63	0.63	0.62
K, % DM	4.02	3.98	3.88	3.39	3.31
Ca, % DM	0.31	0.31	0.34	0.33	0.31
Mg, % DM	0.18	0.17	0.17	0.15	0.14
Cucumber (cv. F_1 Strema)					
Plant phase					
Weight, g	68.5	63.5	57.0	71.9	66.5
Chlorophyll, mg/kg	5663	5449	6020	5981	5753
P, % DM	0.57	0.75	0.92	0.77	0.78
K, % DM	3.74	1.98	2.09	1.88	2.29
Ca, % DM	3.40	4.30	2.77	3.94	3.86
Mg, % DM	0.42	0.46	1.17	0.83	0.58
Fruit phase					
Leaves					
P, % DM	0.48	0.60	0.67	0.65	0.61
K, % DM	2.19	1.73	1.73	2.01	1.71
Ca, % DM	6.49	7.27	7.27	7.64	7.66
Mg, % DM	0.73	0.76	1.54	1.05	0.98
Fruits					
Yield, kg per plant	2.14	2.10	2.30	2.49	2.46
Nitrate, mg/kg	17.1	11.8	14.7	16.6	13.6
P, % DM	0.74	0.82	0.86	0.91	0.92
K, % DM	4.92	4.53	4.54	4.86	4.87
Ca, % DM	0.65	0.60	0.59	0.62	0.70
Mg, % DM	0.40	0.34	0.39	0.36	0.36

and limestone meals. The use of mixtures improved the taste of tomatoes considerably, increasing also somewhat the sugar contents of fruits and reducing the contents of organic acids. It is known from previous research that these compounds have an effect on taste qualities in vegetables.

The same regularities were observed in the nutrient content of plant leaves as also noted in the 1995 trials. Differences in Ca and Mg contents of lime fertilizers were nearly always measurable in the leaves. In the variants with oil shale ash, leaves contained as a rule considerably less phosphorus and more potassium than variants with other lime fertilizers. However, differences in the mineral element content of tomato and cucumber fruit (with the exception of P content) were not as regular as in the leaves.

CONCLUSIONS

1. Application of the fine fraction (1–2 mm) of dolomite production waste for regulating the acidity of the peat substratum without prior grinding is inefficient.

2. The Ca:Mg ratio in the substratum has a considerable effect on the growth and development of plants. The unilateral excess of both Ca in limestone meal and Mg in dolomite meal compared with oil shale ash decreased the weight of lettuce, cucumber, and tomato plants.

3. When dolomite and limestone meal mixtures in the ratio 1:1 and 3:1 were used for peat neutralization, the weight of lettuce and cucumber plants and the yield of cucumber fruits were considerably higher than in the variants with pure limestone and pure dolomite.

4. Magnesium contained in dolomite meal had a positive effect on the synthesis of leaf pigments (chlorophyll, carotene), and also decreased the nitrate content in vegetables.

5. The nutrient (Ca, Mg, P, K) content of leaves varied significantly depending on the chemical composition of lime fertilizers. However, differences in the mineral element content of the tomato and cucumber fruits were not as regular as in the leaves.

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EESTI LUBJAKIVI JA DOLOMIIDI JAHUDE TOIMEST KASVUHOONEKÖÖGIVILJADE KASVULE JA KEEMILISELE KOOSTISELE TURVASSUBSTRAADIL

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Erineva keemilise koostisega lubiväetisi (lubjakivijahu, dolomiidijahu ja nende kindlas vahekorras segud, tolmpõlevkivituhk) kasutati happelisest rabaturbast valmistatud kasvusubstraatide neutraliseerimiseks. Uuriti nende lubiväetiste toimet turvassubstraadi agrokeemilistele parameetritele ning kasvuhoonekööginiljade (salat, kurk, tomat) kasvule, arengule, saagile ja keemilisele koostisele. Selgus, et kasvusubstraadis sisalduva kaltsiumi ja magneesiumi vahekord mõjutab oluliselt taimede kasvu ja arengut. Kaltsiumi liig (lubjakivijahus) või selle vaegus (dolomiidijahus) mõjusid negatiivselt. Lubjakivi- ja dolomiidijahu segudega neutraliseeritud substraatidel kiirenes salati ja kurgitaimede kasv, suurenes kurgi saagikus ning paranes tomati maitse. Lubiväetistes sisalduv magneesium soodustas lehepigmentide (klorofülli ja karotiini) sünteesi ning vähendas köögiviljade nitraatide sisaldust. Lubiväetiste keemiline koostis mõjutas mineraalainete sisaldust taimelehtedes, tomati ja kurgi viljades aga oluliselt mitte.