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Available plant nutrients in growth substrate depending on various lime materials used for neutralising bog peat

M. Järvan

Department of Field Crops, Estonian Research Institute of Agriculture, Teaduse 13, 75501 Saku, Estonia; e-mail: malle.jarvan@mail.ee

Abstract. In 1998–2000, the effect of local Estonian lime materials (oil shale ash, cement clinker dust, limestone meal, dolomite meal and their mixtures) used for neutralising acid bog peat on the contents of available plant nutrients (K, Ca, Mg) and on Ca:Mg, Ca:K, K:Mg ratios in peat substrate was investigated. The substrate were made on NPK and NP backgrounds. Lime materials, the Ca:Mg ratio of which varied between 3.4–16.7:1, were applied at a rate of 8 kg (in some variants 6 and 10 kg) per m³ peat. The substrate were analysed 2 and 4 weeks after their production.

The pH_{KCl} of growth substrate became stable almost within 2 weeks. Dolomite meals neutralised peat acidity approximately by 0.5–0.7 units less than the same rate of dusty lime fertilisers. The higher the Mg-content in lime material, the weaker its neutralising effect. While using a 1:1 mixture of limestone and dolomite meal, the content of available Mg in the substrate was sufficient for plant growth and it was possible to leave out the application of Mg-fertiliser to the substrate. The Ca:Mg ratio in growth substrate was considerably broader than in lime materials and depended significantly on the type of lime. The content of available Ca in substrate increased relatively more than that of available Mg. Under the effect of dusty lime fertilisers the Ca:Mg ratio had shifted in favour of Ca by 1.2–1.4 times, in the case of carbonate rock meals the preponderance of Ca had increased by 3.6–3.9 times. The best variants for neutralising peat acidity in the given research were as following: 1:1 mixture of limestone meal and dolomite meal and 1:1 mixture of clinker dust and dolomite meal. In these cases the contents of Ca, Mg and K and their mutual ratios in the substrate corresponded in the best way to the limit values needed for the optimum growth of greenhouse vegetables.

Key words: peat substrate, limestone, dolomite, oil shale ash, cement clinker dust, content and ratios of available Ca, Mg, and K

INTRODUCTION

In growing of greenhouse vegetables growth substrate made on the basis of bog peat are widely used. Estonian peat resources are large and at the present production volume – for heating, horticulture, etc. approximately a million tons per year – they last for many years to come. Horticultural peat is produced both for internal market and for export. Bog peat is acid; in Estonian bogs the pH_{KCl} of sphagnum peat is mainly between 2.6–3.4 (Orru & Orru, 2003). The content of plant nutrients in it is relatively low. The research results of Estonian bogs indicate the following nutrient contents in low-decomposition air-dry bog peat: MgO 0.85–2.3%, CaO 0.04–0.06% and P_2O_5 0.12–0.80% (Orru, 1992). Bog peat can be used as growth substrate only after neutralising the excessive acidity and adding macro- and microelements necessary for plant growth. The best Nordic specialists in the field of growth substrate have developed their fertilisation recommendations mainly for the peat substrate neutralised with dolomite lime (Puustjärvi, 1962 & 1973; Kaukovirta, 1971). In Estonia it was started to grow vegetables on peat substrate 40 years ago (Hiiop, 1969), whereas for several decades oil shale ash was almost exclusively used as lime fertiliser. But besides oil shale ash there are several other carbonate materials in Estonia suitable for neutralising the acidity. Thus for example cement production produces clinker dust as a by-product, mining of limestone and dolomite result in large amounts of finer stone fractions that are unsuitable for industrial use but can be utilised in agriculture. By mixing limestone and dolomite meals it is possible to prepare mixtures with different Ca:Mg ratios for neutralising peat, with the added benefit that the import of Mg-fertilisers can be reduced considerably or even entirely avoided (Järvan, 1997; Järvan & Teedumäe, 1999).

The aim of the given research was to identify the effect of neutralisation of acid bog peat with different lime materials on the content and ratios of available plant nutrients (K, Ca, Mg) in peat substrate.

MATERIALS AND METHODS

The research was conducted in greenhouse conditions in the years 1998–2000. As source material, low-decomposition sphagnum peat was used, the pH_{KCl} of which in A- and C-trials was 3.0 and in B-trials 3.2. Before preparing the substrate, the peat was sieved and particles with a size of 1 cm and bigger were removed. The amount of the prepared substrate was 0.25 m³ for all trial variants. For the neutralisation of peat acidity, different Estonian local lime materials (cement clinker dust, dolomite meal, limestone meal) and their mixtures were used. Clinker dust contained 30.1% Ca, 1.9% Mg and 4.2% K, neutralising capacity 82.4% $CaCO_3$. Dolomite meal and limestone meal contained respectively 19.6% and 33.9% of Ca, 12.6% and 2.8% of Mg, neutralising capacity was 96.7% and 99.5% $CaCO_3$. These were applied mainly at a rate of 8 kg/m³, in certain cases 6 and 10 kg/m³. Trial variants are presented in Tables 1–3. In each trial macro- and micronutrients were added in equal amounts. Potassium made an exception; it was not added to these variants in which the effect of lime fertilisers was compared on NP-background. In A- and B-trials to 1 m³ of peat (NPK-background) there was applied 1.25 kg of the Võru complex fertiliser that contained 10% of N, 7.3% of P and 12.6% of K and the required amount of micronutrients. For NP-background a test lot of the same fertiliser was used (without potassium). The Võru combined fertiliser does not contain magnesium. In C-trial there were mixed to peat macronutrients in the form of simple fertilisers and micronutrients in the form of chemical preparations in the conformity with the recipe developed for horticultural peat earlier at ERIA (Hiiop, 1969). After preparation the peat substrate were put into big plastic bags that were open from top and from where after a certain time mean samples were taken for substrate analysis. These substrate were also used as growth media in further trials.

Mean samples of substrate were taken two and four weeks after their preparation. Analyses were made in the chemical laboratory of ERIA. The pH_{KCl} of peat was determined electrometrically from 1 M KCl infusion. For the determination of Ca, Mg and K peat substrate were extracted in a solution of acid ammonium acetate (pH_{KCl} 4.65). The contents of available nutrients in peat were expressed in mg/l. Tables 1–3 present the mean results of two analyses. The Ca and Mg contents of lime materials, which served as a basis for Ca:Mg ratios given in the tables, were determined by the Agricultural Chemistry Centre of the State Department of Plant Protection.

RESULTS AND DISCUSSION

The growth and development of plants depend both on the nutrient content of substrate and the interaction between elements. Very important are Ca:Mg, Mg:K and Ca:K ratios. These three elements act as a rule as antagonists in the nutrient uptake (Adams et al., 1978; Kirkby, 1979; Steenhuizen, 1987; Kolota & Biesiada, 1990; Jakobsen, 1993a). Relationships between Ca and P are complicated – they could be either synergistic or antagonistic (Demchak & Smith, 1990; Jakobsen, 1993b).

The solubility of lime materials and their acid neutralising effect depend on the types of Ca and Mg compounds in them. The effect of carbonates is slower than that of oxides and hydroxides; their solubility depends significantly on the size of particles (Mengel & Kirkby, 1987; Turbas, 1996). The higher the Mg content in lime material, the slower and to a lesser extent it reduces the acidity of peat (Puustjärvi, 1985; Järvan, 2000). While regulating the acid reaction of growth media with Ca-carbonate, the Ca:Mg antagonism became evident both in the substrate and in the plants (Rusu et al., 1998). Such situation could, in addition to the reduced availability of Mg, also impede the mobility of other cations, in particular that of K.

In literature there is a great variety of different opinions on the subject what the optimum Ca:Mg ratio in a lime fertiliser and substrate or in nutrient solution should be. For example, in Finland it was earlier regarded necessary to use dolomite lime with Ca:Mg ratio ~2:1 for peat neutralisation, in later recommendations the ratio was ~3.4:1 (Puustjärvi, 1985). Latvian agrochemists (Rinkis & Nollendorf, 1977) regard the optimum ratio to be 5–8:1 (on average 6.5:1). In our trials lime materials and mixtures with very different Ca and Mg contents were used for peat neutralisation, the Ca:Mg ratio varied between 3.4 and 16.7 (Tables 1 and 2).

While analysing the substrate, it became evident that already two weeks after the preparation pH_{KCl} had become almost stable and did not change significantly thereafter. Oil shale ash and clinker dust at a rate of 8 kg/m³ increased the substrate's pH_{KCl} to 6.2–6.7. In the event of applying the same rate of dolomite meal the pH_{KCl} increased to 5.7–6.0, whereas the lime material with a broader Ca:Mg ratio neutralised the acidity somewhat better than that with a narrower Ca:Mg ratio. A higher rate of dolomite meal (10 kg/m³) did not significantly increase the pH_{KCl} any more. In neutralising with the 1:1 mixture of limestone meal and dolomite meal, the Mg content of substrate was 174–243 mg/l, i.e. on the level that more or less corresponds to the lower limit of the optimum for greenhouse crops (Kasvihuoneanalyysien …, 1990), and thus the application of Mg-fertilisation to the substrate is not necessarily required. To these trial variants, in which the Mg content in substrate remained below 150 mg/l, Mg-fertiliser must be applied. As to the nutrient content and interaction, the 1:1 mixture of limestone and dolomite meal is almost equal to the variant of oil shale ash, which in earlier days was predominantly used in peat cultivation in Estonia.

Table 1. Contents and relationships of available plant nutrients in peat substratedepending on various lime materials used for neutralising bog peat. Trial A (1998)

Lime material	Ca : Mg in lime	pH_{KCl}	Content in substrate, mg per litre			Ca : Mg	Ca : K	K : Mg
			K	Ca	Mg			
NPK background								
Oil shale ash, 8 kg/m^3	12.7	6.18±0.00	350±21	2,360±221	141± 12	16.7	6.7	2.5
Limestone + dolomite meal 1:1, 8 kg/m^3	3.7	5.66±0.02	282± 4	2,338±186	174±27	13.4	8.3	1.6
Limestone + dolomite meal 2:1, 8 kg/m^3	5.3	5.85±0.07	265±13	2,709±235	142±11	19.1	10.2	1.9
Limestone + dolomite meal 3:1, 8 kg/m^3	6.6	5.97±0.00	264±5	2,830±304	110±21	25.7	10.7	2.4
Limestone + dolomite meal 1:1, 10 kg/m^3	3.7	5.90±0.01	266±3	2,735±102	208±31	13.1	10.3	1.3
Limestone + dolomite meal 2:1, 10kg/m^3	5.3	5.94±0.06	258±7	3,390±273	142±20	23.9	13.1	1.8
Limestone + dolomite meal 3:1, 10 kg/m^3	6.6	5.95±0.07	262±0	3,598±254	115±17	31.3	13.7	2.3
Cement clinker dust, 6 kg/m^3	13.3	6.22±0.04	480±14	2,498±97	134±23	18.6	5.2	3.6
Cement clinker dust, 8 kg/m^3	13.3	6.59±0.12	566±26	3,133±178	170±10	18.4	5.5	3.3
Cement clinker dust, 10 kg/m^3	13.3	6.72±0.14	621±17	3,340±211	174±18	19.2	5.4	3.6
NP background								
Cement clinker dust, 6 kg/m^3	13.3	6.07±0.00	243±12	2,306±83	130±7	17.7	9.5	1.9
Cement clinker dust, 8 kg/m^3	13.3	6.35±0.04	302±19	2,768±196	148±27	18.7	9.2	2.0
Cement clinker dust, 10 kg/m^3	13.3	6.62±0.00	360±8	3,338±164	183±12	18.2	9.3	2.0

Table 2. Contents and relationships of available plant nutrients in peat substrate depending on various lime materials used for neutralising bog peat. Trial B (1999)

Lime material	Ca : Mg in lime	pH_{KCl}	Content in substrate, mg per litre			Ca : Mg	Ca : K	K : Mg
			K	Ca	Mg			
NPK background								
Without lime	–	3.33±0.19	238±23	540±21	32± 4	16.9	2.3	7.4
Oil shale ash, 8 kg/m^3	12.7	6.68±0.18	274± 4	2,398±192	158±25	15.2	8.8	1.2
Cement clinker dust, 8 kg/m^3	13.3	6.40±0.14	472±47	2,614±225	138±14	19.0	5.5	3.4
Limestone meal, 8 kg/m^3	16.7	5.84±0.00	252±15	2,794±278	87±21	32.1	11.1	2.9
Dolomite meal, 8 kg/m^3	1.6	5.25±0.05	261±35	1,516±110	572±166	2.7	5.8	0.5
Limestone + dolomite meal 1:1, 8 kg/m^3	3.7	5.36±0.14	260±2	2,017±184	243±22	8.3	7.8	1.1
Clinker dust + dolomite meal 1:1, 8 kg/m^3	3.4	5.61±0.06	376±5	1,840±164	285±38	6.5	4.9	1.3
Clinker dust + limestone meal 1:1, 8 kg/m^3	14.9	5.95±0.07	364±4	2,752±150	86±29	32.0	7.6	4.2
NP background								
Cement clinker dust, 8 kg/m^3	13.3	5.98±0.03	287±2	2,615±156	146±11	18.0	9.1	2.0
Clinker dust + dolomite meal 1:1, 8 kg/m^3	3.4	5.55±0.11	165±1	2,033±59	299±55	6.8	12.3	0.6
Clinker dust + limestone meal 1:1, 8 kg/m^3	14.9	5.78±0.00	155±6	2,953±191	89±23	33.2	19.1	1.7

Table 3. Contents and relationships of available plant nutrients in peat substrate depending on various lime materials used for neutralising bog peat. Trial C (2000)

Lime material	pH_{KCl}	Content in substrate, mg per litre			Ca : Mg	Ca : K	K : Mg
		K	Ca	Mg			
NPK background							
Cement clinker dust, 6 kg/m^3	5.07±0.10	294±27	1,340±40	97± 0	13.8	4.6	3.0
Cement clinker dust, 8 kg/m^3	5.75±0.21	315±21	2,012±37	125±7	16.1	6.4	2.5
Limestone meal, 8 kg/m^3	5.36±0.19	179±16	2,079±77	94±1	22.1	11.6	1.9
Dolomite meal, 8 kg/m^3	5.43±0.02	165±21	1,182±40	593±73	2.0	7.2	0.3
Limestone + dolomite meal 1:1, 8 kg/m^3	5.42±0.11	166±1	1,435±11	338±18	4.2	8.6	0.5
NP background							
Cement clinker dust, 6 kg/m^3	5.51±0.05	135±11	1,671±107	130±3	12.9	12.4	1.0
Cement clinker dust, 8 kg/m^3	6.18±0.04	180±22	1,975±71	137±3	14.4	11.0	1.3
Clinker dust + limestone meal 1:1, 8 kg/m^3	5.70±0.00	98±6	1,910±21	106±2	18.0	19.5	0.9
Clinker dust + dolomite meal 1:1, 8 kg/m^3	5.59±0.01	93±3	1,614±24	374±16	4.3	17.4	0.2

As clinker dust contains a lot of available K, the substrate neutralised with it could, in the case of conventional NPK-fertilisation, contain too much K. In the trial substrate the maximum K contents were 472–621 mg/l. Excessive K inhibits the uptake of other nutrients (Ca, Mg), worsening thus the nutrition conditions of plants. The optimum K content in peat substrate is considered to be 200–500 mg/l for tomato, 150–400 mg/l for cucumber and 150–300 mg/l for lettuce (Kasvihuoneanalyysien …, 1990). Trials have shown that the yielding ability and quality of lettuce are positively affected by increasing the K-rates only up to 200 mg/l (Adams et al., 1978). When in our trials K was excluded from the basic fertilisation (only NP + microelements were added), in the variants with clinker dust the substrate's K content was on normal level (240–369 mg/l).

The C-trial (Table 3), in which simple fertilisers were used for substrate preparation and microelements were given as chemicals, compared the agrochemical indices of peat substrate neutralised with different lime fertilisers also on different NPK and NP backgrounds. As physiologically acid fertilisers were used, the pH and Ca contents are slightly lower than in trials A and B. The lower K contents in substrate are probably also caused by different properties and rates of the used fertilisers.

Various factors affect the contents and ratios of available nutrients in peat substrate. These factors can include cation exchange capacity, lime, preplant fertilisers, and irrigation water sources (Argo, 1998). The pH_{KCl} of growth medium has also a direct influence. However, scientists are of quite different opinions on how and to what direction pH_{KCl} and nutrients, containing in the substrate or applied with fertilisers, affect each other's solubility (mobility) and mutual relationships.

By comparing Ca:Mg ratios in lime materials and growth substrate that were used for the neutralisation of peat (Tables 1 and 2), a regularity became evident, indicating that the ratio was much broader in the substrate than in lime materials. It means that the content of mobile Ca in substrate had increased somewhat more than that of mobile Mg. There is also a considerable difference between the types of lime materials. At the equal rate of lime (8 kg/m^3) in the case of using dusty lime fertilisers the Ca:Mg ratio had shifted in favour of Ca by 1.2–1.4 times, in the case of carbonate rock meals the preponderance of Ca had increased by 3.6–3.9 times. One of the reasons is probably the different solubility of Ca and Mg compounds. Of the Ca in oil shale ash and clinker dust, 90–98% dissolve in weak acids and, of Mg, 80–87% (Turbas, 1996). The carbonate rocks have also different solubility: unlike calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$] gives only a very weak reaction to weak hydrochloric acid (Berry et al., 1982).

What the ratios between elements for the optimum uptake by plants should be – scientists do not have common viewpoints on this matter. Probably there is no need to limit them because the interaction depends on different factors and specific conditions. If we proceed from the limit values of peat substrate analysis that are implemented in Finland, the following ratios are considered optimum for greenhouse vegetables: Ca:Mg $\cong$ 5 – 7:1, Ca:K $\cong$ 5 – 7:1, K:Mg $\cong$ 1:1 (Kasvihuoneanalyysien, 1990). Of the substrate studied in our trials in the conditions of 1999 (trial B), these recommendations were best met by the substrate neutralised with the 1:1 mixture of limestone meal + dolomite meal and the 1:1 mixture of clinker dust + dolomite meal and fertilised with NPK.

CONCLUSIONS

- Oil shale ash and clinker dust neutralised the acidity of bog peat better than the same rate of carbonate rock meals. The higher the Mg content in rock meal, the slower and to a lesser extent it neutralised the substrate.
- While neutralising peat with the 1:1 mixture of limestone meal and dolomite meal at a rate of 8 kg/m^3, the growth substrate contained a sufficient amount of available magnesium, which allowed us to leave out the application of Mg-fertiliser.
- In the peat substrate neutralised with clinker dust the potassium content could increase too much in the case of conventional NPK basic fertilisation. In this event it is possible to economise at the cost of K-fertiliser while preparing the substrate.
- In peat substrate the Ca:Mg ratio was much broader than in the lime fertilisers used for neutralisation and it depended significantly on the type of lime material.
- The mutual relationships between Ca, Mg and K met the optimum growth requirements of plants best in the peat substrate neutralised with the 1:1 mixture of limestone meal + dolomite meal and the 1:1 mixture of clinker dust + dolomite meal.

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