Agronomy Research **2**(1), 71–82, 2004

About the effect of the contents and ratios of soil's available calcium, potassium and magnesium in liming of acid soils

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Abstract. Soils in Estonia are characterised by washing out, i.e. leaching, of calcium carbonates and magnesium carbonates. Calcium losses from the arable layer may amount 150–500 (600) kg ha^{-1} a year, resulting in excessive concentration of free hydrogen ions in the soil solution, and therefore these soils require liming. Relatively high doses of lime fertilisers have to be used in order to eliminate harmful acidity of the soils. Clinker dust, oil shale ash and milled limestone are the materials widely used as lime fertilisers at present. Soils in Estonia are often poor in both potassium and magnesium, and that is why clinker dust, which is relatively rich in potassium, has been a particularly valued lime fertiliser. Magnesium deficiency is being alleviated by adding dolomite meal to milled limestone. However, a non-uniform mixing of these lime fertilisers does not ensure their sufficiently homogeneous consistence. Large doses of lime fertilisers, which are not uniformly mixed, have a variable effect on the contents and ratios of calcium, potassium and magnesium in the soil. The trials showed that, as a result of an incorrect use of lime fertilisers, both calcium-to-magnesium and potassium-to-magnesium ratios in the soil may change to the detriment of plants, leading to lower yields.

Key words: acid soils, lime fertilisers, calcium, magnesium, potassium; yield; red clover (*Trifolium pratense L.*), Italian ryegrass (*Lolium multiflorum Lam. ssp. italicum* (A. Br.) Volkart)

INTRODUCTION

Soil fertility is affected by various processes to be taken into account in plant production. Washing out, or leaching, of calcium carbonates and magnesium carbonates is one of these processes characterising soils in Estonia. The leaching process began after ice sheets had retreated, and the process continues at present (Kask, 1996). Calcium losses from the arable layer may amount to 150–500 (600) kg ha^{-1} a year (Reintam et al., 1970; Turbas & Lauk, 1982; Loide, 2002). Calcium is being replaced by hydrogen ions, resulting in soil acidification. In order to reduce soil acidity, soil liming is required so that free hydrogen ions could be replaced by Ca ions again.

Extensive research on soil liming began in Estonia in 1939, lead by Prof. O. Hallik. The work was continued by in-depth studies carried out by E. Turbas and several other researchers. Soil liming is an issue that is continuously relevant today and in the future, because of soil re-acidification. In the years 1964–1990, oil-shale ash and, to a lesser extent, clinker dust were used as the principal lime fertilisers. Dust-like lime fertilisers served also as the main magnesium-containing fertilisers back in these years. A dose of 5 tons per hectare incorporated an amount of magnesium in the soil, which more or less satisfied a cycle of crop rotation (ca 130 kg ha^{-1}). Currently, according to the data of 2002. The percentage breakdown of used lime fertilisers is as follows: clinker dust 89%, oil-shale ash 7%, milled limestone 3.1%, etc. (Põllumajandus…, 2002). Although somewhat less magnesium is incorporated in the field with clinker dust, as compared to oil-shale ash, clinker dust is highly valued for its high potassium content. Milled limestone is poor in magnesium. Thus less magnesium is being incorporated in the soil with lime fertilisers today than it used to be. And that is why consideration should be given, more than hitherto, to supplying field crops and grass crops with magnesium. Magnesium deficiency is now tackled by enriching the lime fertilisers to be incorporated in the soil, with magnesium-containing dolomite meal. Thus soil liming has to do with adding to the plant requisite nutrient supplies as well, yet this does not depend on the content in the soil of the given nutrient alone.

Lime fertilisers incorporate a large quantity of several nutrients in the soil at a time, such as calcium, magnesium, potassium, etc., which produce a strong effect on the nutrient content in the soil solution and thereby also on nutrient ratios. All soils, included acid soils, have most varying nutrient contents and ratios (Ca, Mg, K in particular), therefore, using lime fertilisers without consideration of this fact may shift the balance between the nutrients to the detriment of the plants. There was noted the role of calcium-to-magnesium ratio for the nutrient assimilation process for many field crops (Gedroits, 1955; Kedrov-Zichman, 1947). Prof. O. Hallik also emphasised the role of magnesium in lime fertilisers (1965), because magnesium in large doses of lime fertilisers reduces calcium antagonism. Plants produce higher yields at a certain calcium-to-magnesium ratio and potassium-to-magnesium ratio. References in the literature to this effect are most varied since different determination methods have been used. It appears from soil nutrient contents determined from various extractions that different solutions have different calcium and magnesium percentages for the same soil. Meaning that when such data is compared with that of other researchers, consideration must be given to the extraction solutions used for determining the results. Our trials produced higher yields when Ca:Mg ratios remained within the range of 10-20:1, and most often within the range of 15:1 (Ca and Mg determined by AL method). A ratio narrower than that or a wide ratio produced lower yields (Loide, 1996). Due to the differences between the extraction solutions, data comparisons require that coefficients should be used that allow switching from one method to another. We applied this to calcium and magnesium, and compared the numerical values of optimum Ca:Mg ratios reported by the Estonian and Finnish researchers. These values coincided (15:1). In Finland, lime fertilisers are selected with consistent regard to the soil's Ca:Mg ratio. In Estonia, too, a lime fertiliser should be selected for soil liming with regard to the soil's calcium-to-magnesium ratio. Often, when a soil is acidic and poor in magnesium, a magnesium fertiliser may further narrow the soil's Ca:Mg ratio, because calcium content is low. The overly narrow Ca:Mg ratio in the soil has an adverse effect on the yield, so the efficiency of lime fertilisers may turn out to be lower than expected. Consequently, such soils require that their calcium content should be increased first, regardless of their magnesium-deficiency. This article attempts to show the range of available calcium, potassium and magnesium contents and ratios in the soils which require liming; the effect of lime fertilisers on such contents and ratios; and how this, in turn, affects crop yields.

Soil liming should also give consideration to the soil's potassium content. Besides the potassium content, other researchers have indicated soil's potassium-to-magnesium ratio (K:Mg). The literature suggests that a K:Mg ratio of 3:1, or a little wider, is a favourable ratio for plants (Döring, 1974; Kurki, 1982). Here, too, data from various authors should be compared in consideration of the extraction solution used to determine the fertiliser requirement, as we did with magnesium. In Germany, for instance, fertiliser requirement is determined by using double lactate method for potassium and $CaCl_2$ solution as an extraction for magnesium, and the numerical values of optimum K:Mg ratios for various granulometric compositions are as follows: 2.0:1 in sandy soils; 1.8:1 in sandy loam soils; 1.7:1 in loamy soils; 1.2:1 in clay soils; and as much as 3.6:1 in peat soils (Kundler et al., 1989). The coefficients that enable switching from one method to another were used and it was found that, given the extractions used in Estonia to this day to determine fertiliser requirements, the calculated numerical values of K:Mg ratios could be the following: 1.2:1 in sandy soils; 1:1 in sandy loam soils and loamy soils; 0.7:1 in clay soils; and 2.2:1 in peat soils (Loide, 2001). Soils in Estonia suffer from potassium deficiency, and even more than from magnesium deficiency. Arable land in Estonia has an average K:Mg ratio of 0.3:1, which indicates excessive predominance of magnesium in relation to potassium, which is also the case with magnesium-poor soils (Loide, 1999). It means that the deficiency of potassium as a principal nutrient should be seen as a rather serious issue for soils in Estonia because the plants that suffer from potassium deficiency do not develop sufficient collenchyma cells and bast bundles and are therefore less resistant to plant lodging. Thus the wide use of clinker dust for soil liming is fully justified. However, clinker dust liming incorporates a large quantity of potassium in the soil at a time (ca 175 kg ha^{-1} in the case of a 5 t ha^{-1} dose), which may upset the balance of K:Mg ratio in the opposite direction, unless magnesium is added at the same time. This is particularly important for very low-magnesium sandy loam soils and sandy soils.

Järvan (2003 a, b) recommends to increase lime fertiliser's magnesium content by adding dolomite meal to milled limestone in the relation 1/3 to 1/2 of the liming norm, i.e. 1.5–2.5 t ha^{-1} of dolomite meal, and to clinker dust 1/2 of the liming norm, i.e. 2.5 t ha^{-1} of dolomite meal. Thus this mix incorporates in the soil: 220–275 with dolomite meal (Mg 11%) + 30–40 kg ha^{-1} with lime stone (Mg 1.5%) or with clinker dust (Mg 1.6%), totalling 250–300 kg Mg ha^{-1}. Estimations show that in this case the magnesium dose incorporated in the soil at a time is rather large. Regrettably, lime fertiliser mixing practice (mechanical, by a bucket) produces a non-uniform mix, so that here and there concentrations, which affect the soil in an undesirable direction (local over or under dosing) occur in the soil. Below there has been made an attempt to address a few more problems encountered in soil liming, in addition to what has been researched to date.

MATERIALS AND METHODS

This research has used data from the database containing agrochemical values of Estonia's main soil categories (Calcaric Cambisols, Cambisols and Luvisols and Haplic Podzols, a total of 479 soil samples) to characterise acid soils; besides fertiliser requirement, the uptake capacity (T) of soil was determined. A field trial was designed to examine the effect of soil liming on the dynamics of available calcium-to-magnesium (Ca:Mg) and potassium-to-magnesium (K:Mg) ratios and identify the need to take this effect into account. Different doses of lime fertilisers (clinker dust and dolomite meal) were used to effect soil's available potassium, calcium and magnesium contents. The field trial was conducted on a moderately acid (pH_{KCl} 4.9–5.2) loamy soil at Kuusiku in the years 1996–2001. The agrochemical values of the experimental field soil were P_{DL} 25–35 and K_{DL} 60–75 mg kg^{-1}as determined from double lactate extract; Ca_{AL} 1200–1400 and Mg_{AL} 80–110 mg kg^{-1} as determined from ammonium lactate extract. The trial included the following variants: reference; clinker dust - 3 and 5 t ha^{-1}; dolomite meal - 2.5; 5 and 10 t ha^{-1}. Crops: red clover (*Trifolium pratense L.*); Italian ryegrass (*Lolium multiflorum Lam. ssp. italicum* (A. Br.) Volkart) 2 years; spring barley (*Hordeum vulgare L.*). The trial plot sized 30 m^2, four replications. Agrochemical values of the soil were determined before fertilising and after harvesting (pH_{KCl}, P_{DL}, K_{DL}, Ca_{AL}, $Mg_{AL)}$. In order to identify magnesium assimilation from the lime fertilisers, soil samples were taken concurrently with plant samples in the barley sprouting phase in Year 5. Chemical composition of the red clover and Italian ryegrass yields and of the barley sprouts (crude protein by the Kjeldhal method; P, K, Ca, Mg by dry ashing method) was determined at the Plant Material Control Centre. Also the dry-matter yields of red clover and first-year Italian ryegrass were determined.

The variance, correlation and regression analyses of the Microsoft Excel computation programme were used for mathematical processing of the data.

RESULTS AND DISCUSSION

Soil texture has an important role in the assessment of soil characteristics. The uptake capacity of soil, which is an indicator of soil fertility, depends on the texture composition of the soil. As the percentage of clay particles and colloids contained in the soil increases, the content of plant nutrients bound by these particles and colloids increases as well. Thus the soil's nutrient binding capacity dictates how easily the nutrients not bound by soil particles can be washed out of the soil (from fertilisers, lime fertilisers included). This should be kept in mind when dealing with fertiliser doses to be incorporated in soil.

In Table 1 there have been presented the agrochemical values of the soils of different texture, either requiring or not requiring liming, which indicate that acid sandy soils have uptake capacity and available calcium and magnesium contents lower than expected. The Ca:Mg ratio of sandy soil is also too narrow as far as plant nutrition is concerned – 2-8:1 (average 5.6:1). On the average, sandy loam soils, loamy soils and clay soils contain more calcium and magnesium than sandy soils, and their uptake capacity is higher, too. In sandy loam soils and loamy soils, Ca:Mg ratio widens as the percentage of clay particles increases. However, there are soils among sandy loam soils and loamy soils, whose Ca:Mg ratio is too narrow for plants. Usually, gleyed and gley soils are such soils. Gleyed and gley soils are characterised by topsoil enrichment with magnesium, owing to capillary soil water. Therefore, the available magnesium content of such soils is markedly higher than usual (400–700 mg kg^{-1}), yet their available calcium content is often low and acidity high. That is why these soils need liming. Rather generous liming of such soils with magnesium-containing lime fertilisers causes further narrowing of the soil's Ca:Mg ratio. For such soils, preference should be given to milled limestone over e.g. clinker dust.

Table 1. Overview of a few agrochemical characteristics of soils that require liming and soils that do not require liming.

Texture	Item	Ca_{AL} mg kg^{-1}	Mg_{AL} mg kg^{-1}	K_{DL} mg kg^{-1}	Ca:Mg	K/Mg	T mg/ekv kg^{-1}
			Soils that require liming *				
Sand, n=15	Mean	370	70	80	5.6:1	0.96:1	94
	Min-max	150–800	40–110	0.1–580	2–8:1	0.01–5.8:1	60–120
Sandy loam, n=24	Mean	695	160	80	5.9:1	0.72:1	138
	Min-max	200–1,550	50–550	8–270	1.4–13:1	0.08–3.8:1	60–320
Loam, n=30	Mean	1200	220	95	6.8:1	0.61:1	179
	Min-max	400–2,400	50–700	17–280	2–15:1	0.09–2.6:1	80–300
Clay, n=20	Mean	1650	540	130	3.3:1	0.30:1	268
	Min-max	500–4,400	190–850	25–200	2–8:1	0.10–0.74:1	100–420
			Soils that do not require liming				
Sand, n=40	Mean	2790	370	73	8:1	0.33:1	250
	Min-max	250–10,000	50–850	1–470	2–30:1	0.01–2.3:1	60–740
Sandy loam, n=125	Mean	2100	264	111	9:1	0.75:1	180
	Min-max	350–10,000	70–850	1–290	1.2–23:1	0.01–2.5:1	60–580
Loam, n=216	Mean	3440	370	102	11:1	0.48:1	270
	Min-max	260–10,000	50–900	1–470	2–29:1	0.01–3.0:1	60–800
Clay, n=9	Mean	6,400	7700	100	8:1	0.14:1	400
	Min-max	3,700–9,500	600–850	25–240	6–11:1	0.03–1.3	120–760

* - liming requirement was determined based on the soil texture and acidity

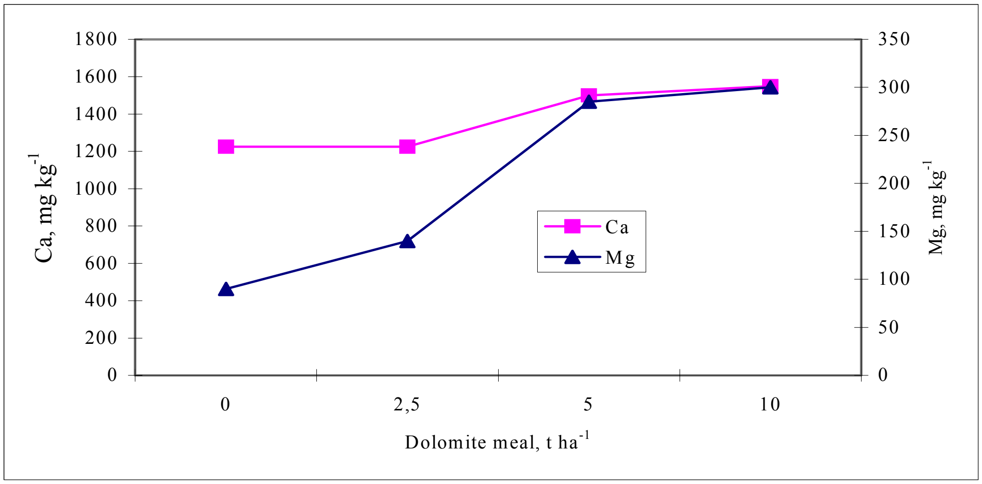


Fig. 1. Dolomite meal effect on the soil's available calcium and magnesium contents in 1 year after the distribution; $P > 0.05$: Ca = 277; Mg = 167.

y= - 0.0978x+24.641; $R^2 = 0.827$; $r = -0.909$**, $n = 15$

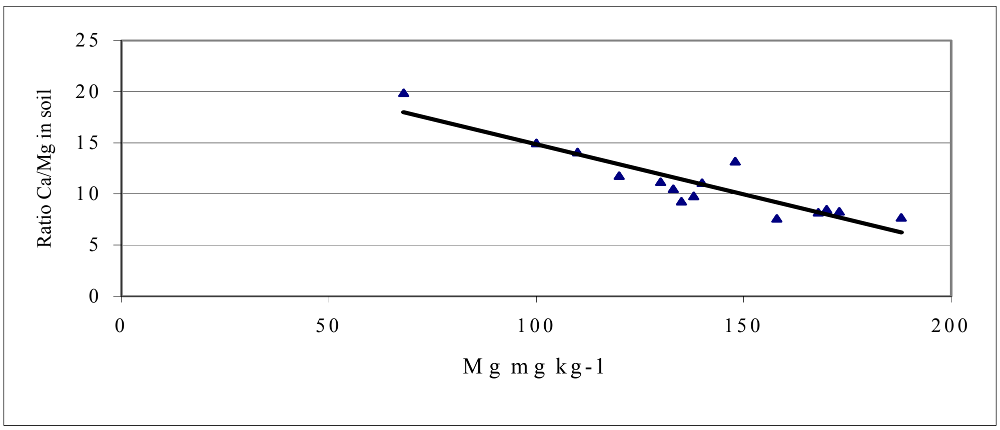
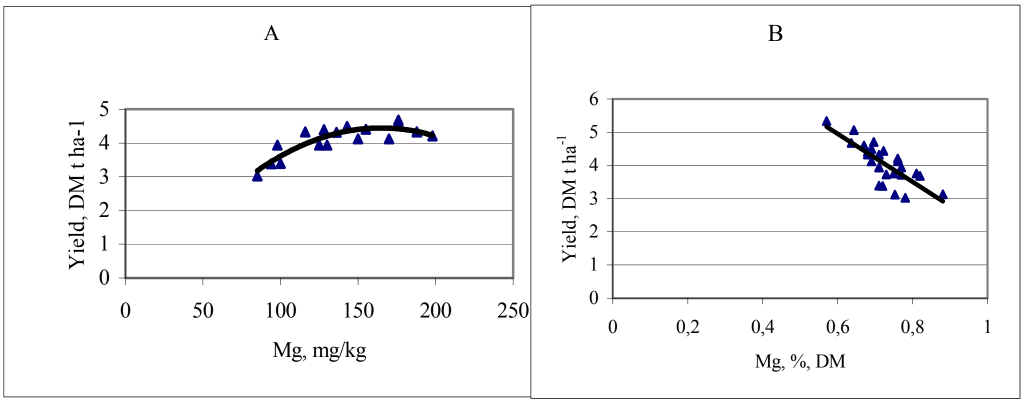


Fig. 2. Effect of the available magnesium content, increased by lime fertiliser incorporated in the soil, on the soil's Ca:Mg ratio in the Effect-Year 2 of the lime fertiliser.

Potassium-to-magnesium ratio has a very wide variation range as well, from excessive predominance of potassium to excessive predominance of magnesium. Therefore, this is another value to be taken into account in soil liming.

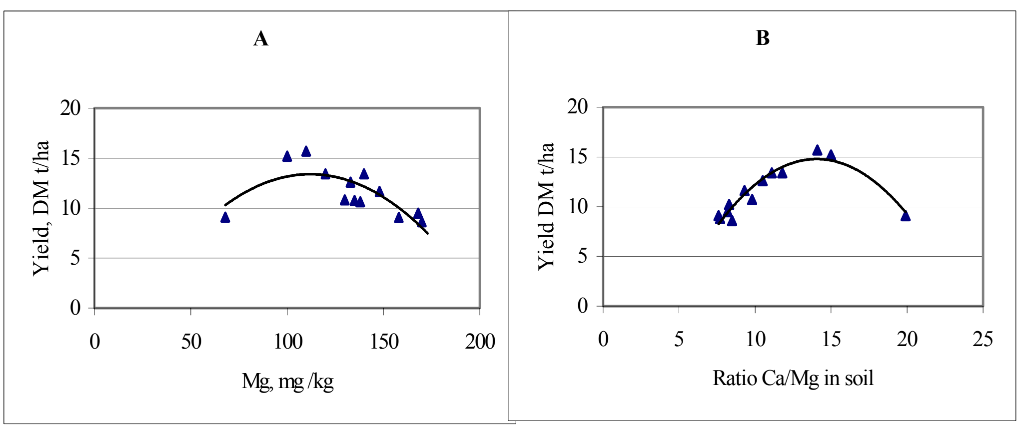
Fig. 1 shows how pure dolomite meal, incorporated in the soil, affects the available calcium and magnesium contents in the soil. It appears that the dolomite meal doses of 5 and 10 t ha^{-1} substantially increased the soil's available magnesium content from 90 to 300 mg kg^{-1} in the period from autumn to autumn; available calcium increased by about the same amount. As a result, however, Ca:Mg ratio narrowed in the soil (up to 5:1 in this trial in Year 1). In the following years, Ca:Mg ratio began to widen again in connection with a relatively more rapid decrease in magnesium content. By the end of Year 2 of lime fertiliser effect (Fig. 2), the available magnesium content in the arable layer had dropped to 190 mg kg^{-1} and Ca:Mg ratio had widened to 8:1 (r = -0.909**[1], n = 15; [1] – significance-threshold of the correlation coefficient here and hereinafter: * - 0.05; ** 0.01). A clinker dust dose of 3 t ha^{-1} proved most favourable for the soil's Ca:Mg ratio in this trial, maintaining the ratio within the optimum range (13-16:1) both in Effect-Year One and Effect-Year Five. A clinker dust dose of 5 t ha^{-1} widened Ca:Mg ratio to 18:1, from which point onwards magnesium requirement begins to increase in order to maintain the balance with calcium.



A-y = $-0.000x^2 + 0.0657x-0.9689$; R^2=0.762; r=0.725**, n=18;

B-y = $-7.2111x + 9.2707$; R^2= 0.6127, r = 0.783**, n = 28,

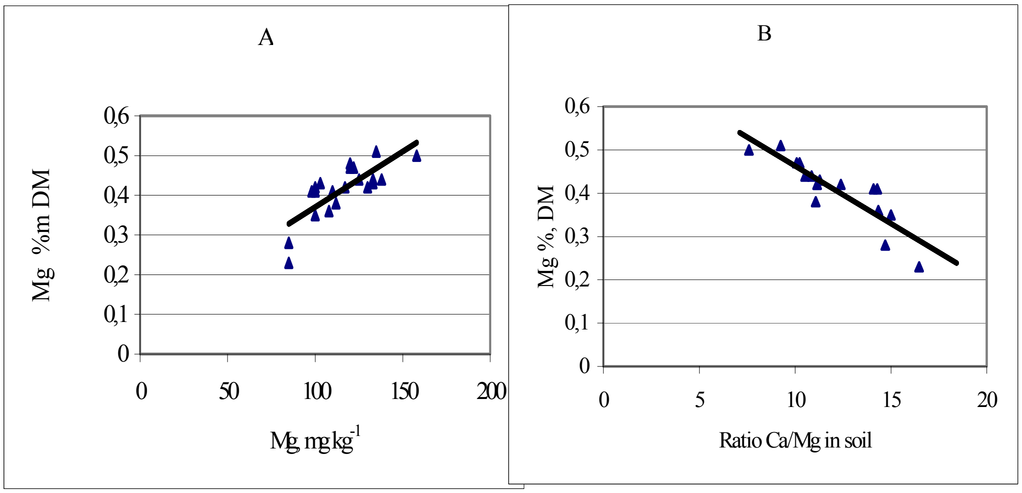
Fig. 3. A, B. Regression correlations between the red clover yield and the soil's available magnesium content (A) and the magnesium contained in the yield (B).



A-y = $-0.0016x^2 + 0,3573x – 6.6203$, R^2 = 0.613, n = 13;

B- y = $-0.1566x^2 + 4.4029x – 16.164$, R^2 = 0.913, n = 13

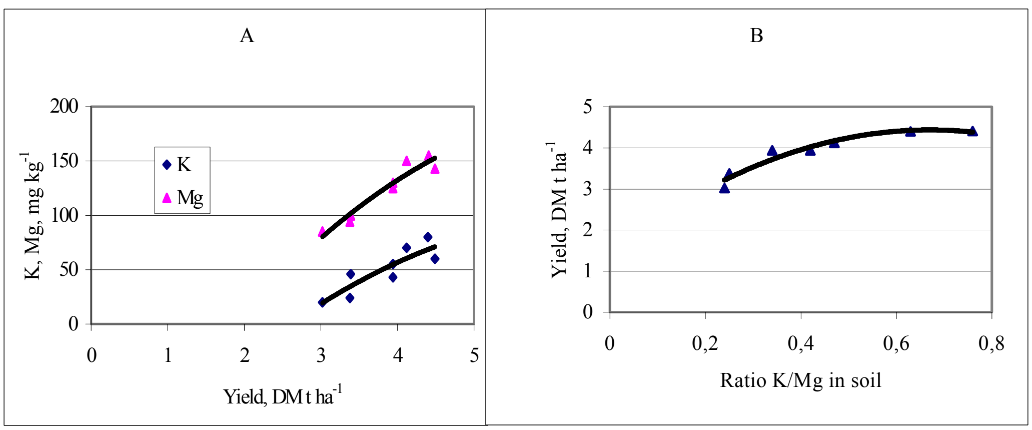
Fig. 4 A, B. Correlations between the ryegrass yield and the soil's magnesium content (A) and Ca:Mg ratio (B).



A-y = 0.0028x + 0.0892, R^2 = 0.599, r = 0.744**, n= 21;

B-y = -0.0266x + 0.7288; R^2 = 0.764, r = -0.874*, n = 16

Fig. 5 A, B. Linear correlations between the soil's magnesium content and the ryegrass yield's magnesium content (A), and between the soil's Ca:Mg ratio and the magnesium content of ryegrass (B).



A-y-Mg = -7.9925x^2 + 109.28x – 176.93, R^2 = 0.926, r = 0.960**, n = 7

A-y-K = -5.7876x^2 + 78.585x – 165.11, R^2 = 0.767, r = 0.874**, n = 7

B-y = -6.594x^2 + 8.8404x + 1.4739, R^2 = 0.931, r = 0.889**, n = 7

Fig. 6 A, B. Regression correlations between the red clover yield in clinker dust liming, and the available potassium and magnesium contents (A) and K:Mg ratio (B).

Study of the effects of soil's different calcium and magnesium contents and ratios on red clover and Italian ryegrass yields produced the following findings. Red clover yield (Fig. 3 A) increased as the soil's available magnesium content increased (up to

26% extra yield), until a content of 200 mg kg^{-1} was reached. A further increase in the soil's magnesium content caused the yield to begin decreasing. The red clover plants assimilated well the available magnesium contained in the soil, and magnesium percentage in the dry matter was relatively high - 0.57–0.88%. It is reported in the literature that 0.21–0.6% of magnesium in dry matter is the optimum magnesium content for red clover at the beginning of flowering (Bergmann & Neubert, 1976). So it appears that the soil contained too much magnesium assimilatable by the plants and this had a negative effect on the plants. Already Kedrov-Zichman (1937) explained in his research the adverse effect of magnesium excess on plants. The conclusion was that the dominance of one cation in the nutrient solution may be harmful even if the absolute nutrient quantities are such that plants tolerate the nutrients well when they are in balance. This phenomenon became known as cation antagonism. Cation antaganism plays an important role in the life of both plant and animal organisms (Pryanishnikov, 1950). The studies showed that different nutrients have different harmful and protective effect levels. Magnesium has a stronger toxic effect whereas calcium has a stronger protective effect. In principle, any cation may have a toxic as well as a protective effect (to a greater or lesser extent) since such effects are dictated by quantitative ratios. In the trial examined here, as we saw before, Ca:Mg ratio was too narrow (5:1) in the soil rich in magnesium or, in other words, calcium and magnesium contents were not in balance. Therefore, the yield and the yield's magnesium content (Fig. 3 B) showed a negative correlation only, with a good likelihood ($r = -0.783^{**}$, $n = 28$).

In Year Two of the trial the Italian ryegrass was used as the test crop. It appeared that the yield depended both on the magnesium content (Fig. 4 A) and Ca:Mg ratio (Fig. 4 B) in the soil, expressed in quadratic correlations. Here the highest hay yields (63% of extra yield) were produced by the soil which contained 90–120 mg kg^{-1} of available magnesium and had a Ca:Mg ratio of 13-15:1. The estimated magnesium content of the soil was closer to low in this variant, yet the Ca:Mg ratio was close to the optimum. Whereas the soils that had a much higher available magnesium (160–170 mg kg^{-1}) but much narrower Ca:Mg ratio (8-9:1) produced even lower yields than the soils that were magnesium-poor (70 mg kg^{-1}), had not been exposed to lime fertilisers and had a wide (20:1) Ca:Mg ratio. Thus compared to a wide Ca:Mg ratio, a narrow Ca:Mg ratio is even more harmful, caused by magnesium non-balanced by calcium and therefore toxic for plants (root system). Other magnesium fertiliser trials on red clover produced similar results (Loide, 1996). Data on the chemical analysis of plant material indicated that the plants' magnesium content increased as the soil's magnesium content increased (Fig. 5 A). Ryegrass grown on a non-limed soil (Mg 80 mg kg^{-1}) contained 0.3% of magnesium in dry matter. The plants that had grown on a soil richer in magnesium (170 mg kg^{-1}) contained 0.5% of magnesium in dry matter. Magnesium content of the yield was in positive correlation with the soil's available magnesium content, with a good likelihood. Narrowing of the soil's Ca:Mg ratio did not inhibit magnesium assimilation by the plants either (Fig. 5 B). The effect of the magnesium incorporated in the soil with lime fertiliser (dolomite meal) could be observed also in Year 5 of the trial. Sprouting-phase barley plants in the liming variant contained 0.23–0.25% of magnesium in the dry matter, whereas reference plants contained 0.21% (correlation coefficient of magnesium contents in the soil and in the plants: r = 0.875**, n = 14). This proves that an incorrect use of lime fertilisers may have a subsequent negative effect lasting for several years.

Therefore soil liming should give due consideration to the soil's calcium and magnesium contents and the quantities of calcium and magnesium to be incorporated in the soil. It has been established that the signs and symptoms caused by the predominance of magnesium are displayed, primarily, in the root growth zone. Namely, characteristic diseases in the plant root growth zone have been reported in the case of calcium deficiency and magnesium predominance: cells break down, cell walls become slimy. Apparently the pectins and lipoids, impregnating cell walls, together with calcium produce slightly soluble and slightly swelling compounds, so that the plants develop normal roots and stronger roots than in the case of non-balanced magnesium, potassium or sodium excess (Pryanichnikov, 1950). Thus the magnesium doses to be incorporated in the soil, recommended in practice and based on the dolomite meal norms (250–300 kg ha^{-1}), firstly jeopardise the physiological balance of the soil. This is particularly true in the case of non-uniform mixing and fertiliser distribution. Secondly, magnesium is more mobile than calcium and leaches to the lower soil layers more rapidly, to remain unavailable for the plants and inefficient. That is why large Mg doses to satisfy plants' magnesium requirement are not recommended (the maximum quantity is 190 kg ha^{-1}, recommended for sandy soils with very low magnesium content only).

The study of the effect of potassium-to-magnesium ratio on the yields produced the following findings. The red clover yield (Fig. 6 A) correlated well with potassium and magnesium incorporated in the soil with clinker dust. An increase in both potassium content and magnesium content in the soil contributed to an increase in the yield. The regression correlation between K:Mg ratio and the yield indicated that the yield and K:Mg ratio were in good correlation (r = 0.889**, n = 7) and that the yield increased until a K:Mg ratio of 0.6-0.7:1 was reached (Fig. 6 B). This is relatively close to the appropriate ratio calculated for the plants, which is 1:1 for the given conditions (loamy soil). As the potassium content increases further, the yield begins to decrease, unless magnesium is added in order to maintain a K:Mg balance.

Thus soil liming with various lime fertilisers should take into account the characteristics of the soil in a comprehensive manner to take advantage of the lime fertiliser potential in the best way possible. Similarly important is a uniform distribution of the lime fertiliser, because large doses affect soil characteristics extensively and for a long time. In the end, this reduces the positive effect of lime fertilisers and may, in the worst case, even produce a negative effect. The physiological balance of nutrients in the soil is another value that requires consideration. As shown above, the physiological balance of plants depends on the soil's Ca:Mg ratio. Magnesium deficiency usually comes with an excessively wide Ca:Mg ratio, so the field crops produce low yields. Even higher losses in yields may be brought about by magnesium excess in the soil, unbalanced with calcium, i.e. by a too narrow Ca:Mg ratio. This should be taken into account when using dolomite meal to increase soil's magnesium content. Cation unbalance may be encountered with potassium in clinker dust liming, too. This is particularly relevant to magnesium-poor sandy loam soils and sandy soils, to where magnesium should be added in such cases. One should also consider whether the use of lime fertiliser solutions is always expedient, especially where it cannot be ensured that individual lime fertiliser components are accurately dosed and uniformly distributed. As regards easily leachable cations such as potassium and magnesium, the bigger their quantities in the soil, the larger the quantities removed from the soil with the yield and by leaching. However, with lower lime fertiliser doses at shorter intervals (3–4 years instead of 5–7 years) a larger nutrient-starved surface could be covered. Indeed, since it is necessary to distribute twice a year over 6–8 years, the distribution costs increase to some extent. Nevertheless, nutrient losses decrease; a more extensive surface gets a better supply of nutrients; "major shock" periods caused by lime fertilisers to the soil environment ease up; soil liming becomes ever more environmentally friendly, etc. In particular, this could be an option for clinker dust. Clinker dust contains potassium, which field crops so badly need, in the form of potassium sulphate. Potassium sulphate, however, is highly soluble in water and therefore easily leachable from soils that have a lower uptake capacity. This makes loss of a large portion of sulphur likely. Plants (cruciferous and leguminous crops in particular) miss sulphur badly in many soils today.

CONCLUSIONS

Soil liming must maintain or improve in the soil the physiological balance of nutrients necessary for plant life. Lime fertilisers incorporate in the soil large quantities of several nutrients that plants need (Ca, K, Mg, S, microelements), altering thereby not only the contents but also the ratios of these nutrients in the soil. Calcium-to-magnesium ratio should be given particular consideration. Plants need magnesium, however, care should be taken not incorporate with lime fertilisers too much magnesium in relation to calcium in the soil. A too narrow calcium-to-magnesium ratio (less than 10:1, determined by AL method) or, in other words, magnesium excess that is not balanced with calcium, deteriorates the physiological characteristics of plant root system which, in turn, reduces field crop yields. At first, it is recommended to use lower-magnesium lime fertilisers, i.e. milled limestone, for such soils that require liming, are low in both calcium and magnesium and have a Ca:Mg ratio of less than 10:1. Only later on, when the soil's calcium content is higher and Ca:Mg ratio wider (over 15:1), it is recommended to incorporate also more magnesium in the soil with lime fertilisers. The magnesium doses to be incorporated in the soil should be based on the recommendations on fertiliser requirement and avoid exceeding these unreasonably.

In the soil liming process, more consideration should be given also to the soil's potassium content and potassium-to-magnesium ratio. Loamy soils produced a higher red clover yield when their potassium-to-magnesium ratio was 0.6-0.7:1 (K_{DL} and Mg_{AL} methods). Based on the data from the literature, recalculated by using the coefficient that allows to switch from one determination method to another, the following indicative K:Mg ratios (K_{DL} and Mg_{AL} methods) are suggested: 1.2:1 in sandy soils; 1:1 in sandy loam soils and loamy soils; 0.7:1 in clay soils; and 2.2:1 in peat soils. Roughly, the arable land in Estonia has an average K:Mg ratio of 0.3:1, indicating that, containing in the soil, magnesium excessively dominates in relation to potassium, also in magnesium-poor soils. Therefore, the potassium deficiency of Estonia's soils should be seen as a serious obstacle for achieving higher yields. Note should be taken also of the fact that potassium-starved plants have weaker cell walls and are less resistant to lodging. Therefore, the use of clinker dust for soil liming is most justified. However, large potassium quantities should be incorporated in the magnesium-poor soils with due regard to the potassium-to-magnesium balance and, if required, magnesium content should be increased in the soil.

Uniform distribution is particularly important in lime fertiliser distribution. This applies to single-type lime fertilisers and all the more to their mixes. Non-uniform material distribution means that in some places nutrient concentrations occur, which are many times higher or lower than the norms prescribe. In either case, the efficiency of the lime fertiliser decreases. Separate use of individual lime fertiliser components allows more accurate consideration of soil characteristics and more uniform distribution. Soils in Estonia are characterised by rather high potassium and magnesium deficiency and therefore, besides competent use of lime fertilisers to reduce soil acidity, attempts should be made to supply the plants with potassium and magnesium in a physiologically correct ratio and in a sustainable manner.

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