

Effect of liming on the value of magnesium sulphate and two dolomitic limestones as magnesium sources for ryegrass

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Abstract: The effect of liming on the fate of magnesium given as either magnesium sulphate (200 mg Mg/3.9 kg of soil) or two dolomitic limestones (1140 mg or 1320 mg Mg) in the soil and the values of these three as magnesium sources for ryegrass (*Lolium multiflorum*) were studied in pot experiment carried out over two growing seasons. The pH(CaCl₂) of the very fine sand used as growth base was raised from its initial value of 4.9 to either 5.7 or 6.5 by the addition of calcitic limestone (12 g or 24 g limestone/3.9 kg of soil, respectively). The magnesium sources were compared at these three levels of soil acidity.

At pH(CaCl₂) 6.5 about 20 % of the magnesium applied as magnesium sulphate was converted into a form not extractable in 1 M neutral ammonium acetate. This not extractable magnesium appeared to be utilized slowly by ryegrass, which may indicate that magnesium bound in various Al-Mg compounds in limed soil is to some extent available to plants.

At pH(CaCl₂) 5.7 and 6.5 around 70 % and 85 %, respectively, of the magnesium derived from dolomitic limestones was not extractable in neutral ammonium acetate. The ryegrass was unable to utilize this not extractable magnesium during the two-year experimental period.

On an acid soil the dolomitic limestones used were a more effective source of magnesium than magnesium sulphate, though on almost neutral soil there was little difference between the two, despite the large difference in the amount of magnesium applied.

Introduction

Acidity and a low content of magnesium available to plants are characteristic features of several types of Finnish mineral soils, with the exception of glacial clays. It has thus become customary to use liming agents containing magnesium to improve the condition of the soil.

USHERWOOD and MILLER (1967) found that the magnesium uptake by 30-day-old maize seedlings decreased in soil treated with either coarse or fine dolomitic limestone (about 20 % Mg) when the pH of the soil was raised from 5.3 to 6.7 by addition of CaCO₃. There was no change in the uptake of magnesium by maize grown under the same conditions on soil treated with

magnesium sulphate, hydrated lime (18.7 % Mg) or burnt lime (21 % Mg). In their study, WHITE and MUNRO (1981) found that the magnesium uptake by ryegrass from soil treated with magnesium sulphate (50 ppm Mg) or two levels of dolomitic limestone (50 and 240 ppm Mg) decreased by 12 %, 22 % and 11 %, respectively, when the soil with an initial pH of 5.5 was treated with 800 ppm Ca as CaCO_3 (4.5 t/ha lime).

Dolomitic limestone is less effective in neutralizing soil acidity than the same amount of calcitic limestone ground to the same degree of fineness (PERSSON 1976, HABY et al. 1979, JAAKKOLA and JOKINEN 1980). If the pH of soil containing only small amounts of plant available magnesium is raised by the application of calcitic limestone, the need for the addition of magnesium becomes even greater because some of the soil magnesium is converted in a form not extractable in neutral ammonium acetate (MCLEAN 1956, ADAMS and HENDERSON 1962, KAILA 1974, GROVE et al. 1981, JOKINEN 1981). Similarly, some of the readily-soluble magnesium applied to the soil is converted into the not extractable form (JUO and UZU 1977, JOKINEN 1981).

The purpose of this study was to investigate the effect of changes in soil acidity on the availability to ryegrass of magnesium given as either magnesium sulphate or two dolomitic limestones, and to compare these magnesium sources under the same conditions of soil acidity.

Material and methods

The material comprises the crops obtained from a pot experiment (acid very fine sand as growth base) performed outdoors, together with the results of plant and soil analyses. The pot experiment was carried out at the Institute of Agricultural Chemistry and Physics of the Agricultural Research Centre in 1979–80. The plant and soil samples were analysed at the Department of Agricultural Chemistry of the University of Helsinki.

Very fine sand, a Littorina soil, contains 72 % of fraction 20–200 μm and 10 % of fraction less than 2 μm , has a pH(CaCl_2) 4.9 and an effective CEC 5.1 me/100 g and contains 3.9 % organic carbon, in 1 M KCl extractable ($\text{Al}+\text{H}$) 0.78 me/100 g and Al 0.28 me/100 g, in 1 M neutral ammonium acetate extractable Mg 0.38 me, Ca 4.35 me and K 0.31 me per 100 g soil.

The experiment began by weighing 4.5 kg of damp soil (18 % of moisture, corresponding to 3.9 kg of air-dry soil) into Mitscherlich pots. Calcitic limestone was mixed with the soil in amounts of 0 g (Ca_0), 12 g (Ca_1) or 24 g (Ca_2) per pot and each amount of limestone was supplemented with the following magnesium treatments: no magnesium (Mg_0), 200 mg/pot Mg as magnesium sulphate (MgSO_4), 12 g/pot dolomitic limestone 2 (D 2) or dolomitic limestone 1H (D 1H). Each treatment was replicated four times.

The calcitic limestone and dolomitic limestone 2 were of about the same degree of fineness, while dolomitic limestone 1H was finely ground (Table 1).

The amounts of magnesium supplied by the dolomitic limestones (D 2 = 1140 mg/pot, D 1H = 1320 mg/pot Mg) were considerably greater than

Table 1. Properties of the calcitic limestone and dolomitic limestones.

	Calcitic limestone	Dolomitic limestone 2	Dolomitic limestone 1H
Fractions			
< 0.15 mm, %	64.1	55.0	100.0
0.15—2.00 mm, %	35.9	43.6	
> 2.00 mm, %	0.0	1.4	
Acid neutralizing capacity			
calculated as Ca, %	35.9	34.3	35.2
Extractable in 1 M HCl			
Ca, %	36.1	20.9	16.7
Mg, %	0.7	9.5	11.0

those supplied by magnesium sulphate, which means that the magnesium sources can best be compared in terms of the relative uptakes of magnesium. Applied to field conditions the smaller amount of limestone corresponds to liming of 5 t/ha and the higher amount to 10 t/ha, while the magnesium sulphate application is equivalent to about 90 kg/ha magnesium fertilization.

Magnesium content of the calcitic limestone (0.73 %) supplemented the magnesium content of the soil by 84 mg (Ca_1) or 168 mg (Ca_2). The amount of magnesium taken up by ryegrass from different sources was calculated for the different calcitic limestone levels as the difference from the soil which received no magnesium treatment.

It was possible to compare the three magnesium sources over almost the same pH(CaCl_2) range, as each of the treatments Ca_1 , Ca_1MgSO_4 , D 2 and D 1H received 12 g of limestone per pot. Similar comparisons were also possible with the higher amount of limestone (24 g/pot).

Ryegrass (*Lolium multiflorum*) was cultivated during the two growing seasons of the experiment and four crops were cut each season. The ryegrass was given sufficient quantities of the following nutrients: NH_4NO_3 , $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, KCl , H_3BO_3 , $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ and $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$. Nitrogen and potassium fertilizers were applied each year before sowing and after the second cut, while the other nutrients were mixed into the entire soil batch prior to sowing.

The crops were dried at 105 °C overnight and ground in a Willey mill in preparation for analysis. The eight crops obtained from each pot were analysed separately. The total calcium and magnesium contents of the plant samples were determined by wet combustion ($\text{H}_2\text{SO}_4:\text{HClO}_4:\text{HNO}_3 = 1:2:10$, SCHARRER and MUNK 1956) followed by atomic absorption spectrophotometric analysis of the solution.

Calcium and magnesium contents of the liming agents were determined from the HCl extract obtained by allowing 3 g of limestone to react with 125 ml of 1 M HCl for one hour on a boiling water bath. The same extract was used to titrate the amount of acid neutralized by the limestone; calculated as calcium, this gives the neutralizing capacity of the limestone.

At the end of the first growing season a soil sample was taken from each pot for determination of pH(CaCl₂). At the end of the second growing season soil samples of about half a litre were taken from the pots for analysis. The analyses were performed on samples dried at room temperature.

The soil was suspended in 0.01 M CaCl₂ solution in the proportions 1:2.5 by volume and the pH determined after allowing the suspension to equilibrate for four hours. The magnesium and calcium available to plants was extracted from the soil with 1 M neutral ammonium acetate. The effective CEC was determined as the sum of (Ca+Mg) and (Al+H) extractable in 1 M KCl (KAILA 1971).

The growing season 1979 was extremely wet. The volume of water that drained through the soil into the basin under the pot was so high (1000–1500 ml) at the end of the experiment that it could not be re-adsorbed into the soil. Because of this, the following procedure adopted for each pot: the volume of the water was measured, a sample was taken for determination of magnesium and calcium, and the water was then poured away. The results were used to calculate the amounts of calcium and magnesium leached out of the soil by the rainwater.

The reliability of the results was studied by analysis of variance (COCHRAN and COX 1966). Duncan's new multiple range test was used to test the significant differences between the various treatments. In the tables, the results provided with the same letter do not differ from each other ($P = 0.05$).

Results

The calcium and magnesium contents of the water that had drained through the soil at the end of the first growing season may indicate the susceptibility of these two nutrients to leaching from the soil treated with the various agents over a short space of time. The water contained about 9 % of the magnesium from magnesium sulphate and about 1 % of the magnesium from dolomitic limestone 2 (Table 2). Raising the pH(CaCl₂) of the soil did

Table 2. Calcium and magnesium (mg/pot) in the water leached through the soil at the end of the first growing season.

	Mg ₀	MgSO ₄	D 2	D 1H
Mg mg/pot				
Ca ₀	3 ^a	19 ^{cd}	15 ^{bc}	26 ^d
Ca ₁	2 ^a	12 ^{bc}	13 ^{bc}	13 ^{bc}
Ca ₂	7 ^{ab}	18 ^{cd}	9 ^b	9 ^b
Ca mg/pot				
Ca ₀	155 ^b	197 ^{cd}	119 ^a	111 ^a
Ca ₁	203 ^{cde}	234 ^{def}	234 ^{def}	166 ^{bc}
Ca ₂	241 ^{ef}	344 ^g	245 ^{ef}	252 ^f

not significantly affect the amount of magnesium removed from the soil along with the water. Below pH(CaCl₂) 6 the water contained about 2 % of the magnesium from dolomitic limestone 1H, but raising the pH(CaCl₂) considerably reduced this amount. Application of magnesium sulphate fertilizer appeared to increase the amount of calcium leached from both unlimed and heavily limed soils.

The pH(CaCl₂) of soils treated with calcitic limestone (Ca₁) was significantly higher than that of soils treated with the same amount of dolomitic limestones (Table 3). Dolomitic limestone 1H, which was more finely ground than the others, appeared to have increased the pH(CaCl₂) value at the end of the first growing period by less than had dolomitic limestone 2. Above pH(CaCl₂) 6, the capacity of the dolomitic limestones to neutralize soil acidity was significantly less than that of calcitic limestone.

When the dolomitic limestones were used, the effective CEC increased along with pH(CaCl₂), though significantly less than was the case when calcitic limestone was used (Table 3). Close to pH(CaCl₂) 6.5 the increase in effective CEC induced by dolomitic limestone 1H was smaller than that produced by dolomitic limestone 2. In the other treatments neither the application of magnesium sulphate nor the increase in the magnesium content

Table 3. Soil pH(CaCl₂), effective CEC (me/100 g soil), contents of magnesium and calcium extractable in 1 M neutral ammonium acetate (mg/100 g soil) and equivalent ratio Ca/Mg at the end of the experiments.

	Mg ₀	MgSO ₄	D 2	D 1H
pH(CaCl ₂)				
Ca ₀	4.5 ^a	4.5 ^a	5.5 ^b	5.4 ^b
Ca ₁	5.7 ^c	5.7 ^c	6.3 ^d	6.2 ^d
Ca ₂	6.5 ^e	6.5 ^e	6.7 ^f	6.7 ^f
Effective CEC me/100 g soil				
Ca ₀	5.5 ^a	5.4 ^a	7.6 ^b	7.4 ^b
Ca ₁	8.9 ^c	9.3 ^c	10.7 ^d	10.9 ^d
Ca ₂	12.4 ^e	12.5 ^e	14.4 ^g	13.2 ^f
Mg mg/100g soil				
Ca ₀	1.0 ^a	2.9 ^{ab}	10.7 ^f	16.8 ^g
Ca ₁	1.1 ^a	3.9 ^{bc}	6.8 ^e	10.7 ^f
Ca ₂	1.4 ^a	4.2 ^{bc}	4.8 ^{cd}	6.0 ^{de}
Ca mg/100 soil				
Ca ₀	76 ^a	73 ^a	128 ^c	113 ^b
Ca ₁	172 ^d	174 ^d	200 ^e	198 ^e
Ca ₂	245 ^f	241 ^f	277 ^g	252 ^f
Equivalent ratio Ca/Mg				
Ca ₀	27.1 ^f	9.6 ^b	4.5 ^a	2.5 ^a
Ca ₁	62.4 ^g	16.3 ^d	10.8 ^{bc}	6.9 ^{ab}
Ca ₂	65.0 ^g	21.5 ^e	21.3 ^e	15.5 ^{cd}

of the dolomitic limestone had any significant effect on the effective CEC.

Increasing the amount of calcitic limestone appeared to cause a slight increase at the end of the experiment in the amount of magnesium extractable in 1 M neutral ammonium acetate in the soils not treated with magnesium, since the calcitic limestone contained 0.73 % magnesium (Table 3). The same trend was observed with soils treated with magnesium sulphate. At the calcitic limestone levels Ca_0 and Ca_1 the addition of magnesium as dolomitic limestones increased the soil's content of magnesium extractable in ammonium acetate significantly more than when magnesium sulphate was applied. The increase in magnesium content was greater with dolomitic limestone 1H than with dolomitic limestone 2. Supplementing calcitic limestone (Ca_2) with dolomitic limestone did not have quite as favourable an effect on the magnesium content of the soil as the above-described. Increasing the pH($CaCl_2$) of the soil produced a sharp decrease in the neutral ammonium acetate extractable magnesium content of the soils treated with dolomitic limestones.

As a result of the different calcium contents of the liming agents, calcitic limestone raised the calcium content of the soil more than the same amount of the dolomitic limestones (Table 3). The differences in the calcium content of the soil brought about by the application of the dolomitic limestones may also be due to the differences in calcium content of these limestones.

The application of calcitic limestone (Ca_1) increased the equivalent ratio Ca/Mg to almost three times the value for unlimed soil and to more than ten times the value for soil treated with the same amount of dolomitic limestone 2 (Table 3). The dolomitic limestones decreased the ratio Ca/Mg significantly more than did magnesium sulphate at the Ca_0 and Ca_1 levels of calcitic limestone, though not at the Ca_2 level. The amount of magnesium per pot provided by the different magnesium sources was not the same.

Irrespective of the liming agent, liming in itself appeared to produce a significant increase in the total yield of ryegrass obtained from the eight cuts (Table 4.) The yields obtained with the magnesium sources studied were the same at each level of calcitic limestone. The yields obtained from the first cut without calcitic limestone were significantly higher than those obtained with the high amount of this lime (results not presented). It was not until the sixth and seventh cuts that the yields without calcitic limestone were significantly lower than those obtained with liming.

The mean magnesium content of stands grown with magnesium sulphate was not dependent on the amount of calcitic limestone (Table 4). The mean magnesium content of stands cultivated with dolomitic limestone 1H decreased significantly at every stage as the amount of calcitic limestone was increased from Ca_0 to Ca_2 . The supply of calcitic limestone decreased the mean magnesium content of the stands obtained with the dolomitic limestone, though there was no difference between the two amounts of calcitic limestone.

The mean calcium content of stands cultivated without calcitic limestone but with either magnesium sulphate or dolomitic limestone 1H was lower than that of plants produced with dolomitic limestone 2 (Table 4). The

Table 4. Total ryegrass yields (g/pot), mean magnesium and calcium contents (mg/g dry matter) of the stands (8 cuts) and the total magnesium uptake by ryegrass (mg/pot).

	Mg ₀	MgSO ₄	D 2	D 1H
Total yield g/pot dry matter				
Ca ₀	83.8 ^a	86.7 ^{ab}	91.0 ^{bc}	88.9 ^{bc}
Ca ₁	91.3 ^c	91.9 ^c	92.3 ^c	88.7 ^{bc}
Ca ₂	92.0 ^c	88.9 ^{bc}	91.7 ^c	91.8 ^c
Mg mg/g dry matter				
Ca ₀	1.7 ^a	2.5 ^{bc}	2.9 ^d	3.3 ^e
Ca ₁	1.8 ^a	2.4 ^b	2.5 ^{bc}	2.8 ^{cd}
Ca ₂	1.8 ^a	2.3 ^b	2.3 ^b	2.3 ^b
Ca mg/g dry matter				
Ca ₀	8.7 ^{ab}	8.0 ^a	9.2 ^b	8.3 ^a
Ca ₁	10.6 ^{cd}	10.1 ^c	10.2 ^c	10.3 ^c
Ca ₂	11.1 ^d	10.8 ^{cd}	10.8 ^{cd}	10.3 ^c
Mg uptake mg/pot				
Ca ₀	140 ^a	217 ^{cd}	264 ^f	294 ^g
Ca ₁	166 ^b	225 ^{cd}	234 ^{de}	244 ^e
Ca ₂	171 ^b	207 ^c	211 ^c	214 ^c

differences in the calcium contents of the stands brought about by the different magnesium sources were not significant at either of the two calcitic limestone levels.

The total amount of magnesium taken up by ryegrass crops without magnesium sources increased as the amount of calcitic limestone increased, since along with the calcitic limestone introduced into the soil 84 mg/pot or 168 mg/pot of magnesium (Table 4). The magnesium uptake by ryegrass grown with magnesium sulphate was independent of the soil acidity. When dolomitic limestones were used the magnesium uptake decreased as the pH(CaCl₂) of the soil increased. Without calcitic limestone the crops that took up most magnesium were those cultivated with dolomitic limestone 1H, though, close to pH(CaCl₂) 6.5, the magnesium uptake was independent of the magnesium source. Even the lower amount of calcitic limestone appeared to cancel out the differences between magnesium sources.

The recovery of magnesium from magnesium sulphate (the difference between magnesium treatment and no magnesium) was at Ca₀ and Ca₁ levels of calcitic limestone almost the same in both years (Table 5). In near neutral soil about 30 % of the total magnesium uptake occurred during the first year. The ryegrass took up about 35 % of the total magnesium uptake supplied by the dolomitic limestones at the Ca₀ and Ca₁ levels of calcitic limestone during the first growing season, whereas at pH(CaCl₂) 6.5 the uptake was divided evenly between the two years.

The apparent recovery of magnesium from the various sources was greatest when calcitic limestone was not used (Table 5). The ryegrass crops recovered a greater proportion of the magnesium from magnesium sulphate

Table 5. Apparent recovery of added magnesium (mg/pot) applied as magnesium sulphate or dolomitic limestones in the first and second growing season, and apparent recovery of the magnesium for the entire experimental period (%).

	Apparent recovery of magnesium applied as magnesium sulphate or dolomitic limestones									
	Mg mg/pot								% Total	
	1st year		2nd year		MgSO ₄	D 2	D 1H	MgSO ₄	D 2	D 1H
	MgSO ₄	D 2	D 1H							
Ca ₀	37 ^{b,c}	45 ^c	61 ^d	40 ^{bcd}	79 ^c	93 ^c	39 ^c	11 ^b	12 ^b	
Ca ₁	26 ^b	25 ^b	24 ^b	33 ^{abc}	43 ^{cd}	54 ^d	30 ^d	6 ^a	6 ^a	
Ca ₂	11 ^a	19 ^{ab}	21 ^{ab}	25 ^{ab}	21 ^a	22 ^a	18 ^c	4 ^a	3 ^a	

than from the dolomitic limestones. There were no differences in the apparent recovery of magnesium from the dolomitic limestones at the pH(CaCl₂) values studied.

When magnesium sulphate was used, the magnesium uptake by ryegrass from this magnesium source, plus the increase in neutral ammonium acetate extractable magnesium content of the soil, plus the magnesium contained in the water that drained through the soil was roughly the same at each of the pH(CaCl₂) values studied (Table 6). The proportion of magnesium not extractable in neutral ammonium acetate of the magnesium added as magnesium sulphate was greatest (22 %) in soil given the heavy liming (Ca₂).

About 50 % of the magnesium added as dolomitic limestones was not extractable in neutral ammonium acetate when the soil pH(CaCl₂) was not adjusted by the addition of calcitic limestone. The proportion of the not extractable magnesium of the added magnesium increased as the pH(CaCl₂)

Table 6. The proportion of magnesium added in the various sources found in the yields and the soil, leached out of the soil, and remaining in the soil in a form not extractable in 1 M neutral ammonium acetate (mg/pot, %).

		Added magnesium mg/pot	Magnesium uptake mg/pot	Leached magnesium mg/pot	Magnesium in soil extract. amm. acet. mg/pot	Total of analysed magnesium mg/pot	Magnesium in soil not extractable in ammonium acetate mg/pot	%
Ca ₀	MgSO ₄	200	77 ^c	16 ^b	74 ^a	167 ^a	33 ^a	17 ^b
	D 2	1140	124 ^d	12 ^b	378 ^e	514 ^c	626 ^c	55 ^d
	D 1H	1320	154 ^e	23 ^c	616 ^f	793 ^d	527 ^b	40 ^c
Ca ₁	MgSO ₄	200	59 ^{bc}	10 ^b	109 ^b	178 ^a	22 ^a	11 ^a
	D 2	1140	68 ^c	11 ^b	222 ^d	301 ^{ab}	839 ^d	74 ^f
	D 1H	1320	78 ^c	11 ^b	374 ^e	463 ^{bc}	857 ^d	65 ^e
Ca ₂	MgSO ₄	200	36 ^a	11 ^b	109 ^b	156 ^a	44 ^a	22 ^b
	D 2	1140	40 ^{ab}	2 ^a	132 ^b	174 ^a	966 ^e	85 ^g
	D 1H	1320	43 ^{ab}	2 ^a	179 ^c	224 ^a	1096 ^f	83 ^g

of the soil increased, reaching about 85 % around pH 6.5. If the experiment had been continued for longer than two years the proportion of not extractable magnesium derived from dolomitic limestones would have been lower than that found now at Ca_1 level of calcitic limestone, since the magnesium uptake by ryegrass during the second year was greater than during the first.

Discussion

The effect of dolomitic limestone 1H on the pH(CaCl_2) of the soil at the end of the first growing season was smaller than that of dolomitic limestone 2. At the end of the second growing period the two limestones had neutralized the soil almost equally effectively. Liming affects the pH of the soil more rapidly in a pot experiment than in field experiments (JAAKKOLA and JOKINEN 1980). The higher the magnesium content of the limestone the more finely ground it should be if the various types of limestone are to neutralize the soil to roughly the same extent, since dolomitic limestone dissolves more slowly than calcitic limestone in soil (MEYER and VOLK 1952, HABY et al. 1979). The ability of dolomitic limestones to neutralize soil whose pH(CaCl_2) had been raised to about 6.5 with calcitic limestone was virtually non-existent, despite the fact that it was finely ground (PEDERSEN 1978).

Liming increases the effective CEC of the soil since the number of negatively charged sites increases and calcium and magnesium occupy most of these sites (MUNS 1976). In this pot experiment the dolomitic limestones seemed to have a smaller effect on the effective CEC than the same amount of calcitic limestone. It has also been reported that the effective CEC of soil is not affected by either magnesium sulphate (GROVE et al. 1981, JOKINEN 1981) or magnesium carbonate (GROVE et al. 1981) because of the slight changes in the pH of the soil.

During the two years of this pot experiment about 20 % of the readily soluble magnesium applied as magnesium sulphate was converted into a form not extractable in neutral ammonium acetate at pH(CaCl_2) 6.5, and about 11 % at pH(CaCl_2) 5.7. Since the 1 M KCl extractable Al content of the soil was low (0.28 me/100 g soil, 5 % of the effective CEC) the formation of various not extractable Al-Mg compounds (HUNSAKER and PRATT 1970, McBRIDE 1978) or other reactions due to the high aluminium content of the soil (KINNIBURG et al. 1976, CHAN et al. 1979, GROVE et al. 1981) do not alone adequately explain the conversion of magnesium into a not in ammonium acetate extractable form.

At the end of the experiment 85 % of the magnesium applied as dolomitic limestones was not extractable in neutral ammonium acetate at the Ca_2 level of calcitic limestone. According to USHERWOOD and MILLER (1967) there were very small differences in the magnesium uptake by corn from hydrated lime, burnt lime and magnesium sulphate at all the five pH levels between 4.4 and 6.7. The magnesium uptake from two dolomitic limestones was signifi-

cantly lower than from the magnesium sources mentioned above. This may indicate that the magnesium from dolomitic limestones is to a greater extent converted to a not extractable form than from other magnesium sources at a high pH level. In addition to the very low solubility of dolomitic limestones (USHERWOOD and MILLER 1967) the formation of insoluble magnesium carbonates and phosphates may take place (LIEBHARDT 1979) in soils limed with calcitic limestone.

GROVE et al. (1981) found that the conversion of magnesium in soil into not in ammonium acetate extractable form takes place rapidly, within the space of 1–25 days. The results of this pot experiment also support this, since in unlimed soil the first-cut crops took up 5.2 mg/pot of the magnesium given as magnesium sulphate and 1.3 mg/pot of the magnesium when the soil was limed around $\text{pH}(\text{CaCl}_2)$ 5.7. Nevertheless, it appears that this not in neutral ammonium acetate extractable magnesium is gradually released and available to the plants. At around $\text{pH}(\text{CaCl}_2)$ 6.5 the magnesium uptake by ryegrass from magnesium sulphate was about twice as high during the second year as during the first. The uptake of magnesium on unlimed soil was the same in both years.

At about $\text{pH}(\text{CaCl}_2)$ 6.5 the ryegrass took up the same amount (mg/pot) of magnesium from both dolomitic limestones and magnesium sulphate, despite the fact that there was a marked difference in the amount of magnesium applied. The neutral ammonium acetate insoluble magnesium compounds from dolomitic limestones were not available to the ryegrass during the two years of the experiment, since the uptake of magnesium was the same in both years. In the absence of calcitic limestone the magnesium applied as dolomitic limestone was more easily available to the ryegrass during the second year than the first, and the total uptake of magnesium was considerably higher than in soil limed with calcitic limestone to around $\text{pH}(\text{CaCl}_2)$ 6.5. The results obtained at the Ca_1 level of calcitic limestone showed the same trend as those obtained without lime.

In terms of the magnesium supply and the amount of magnesium available to the plants, dolomitic limestones are better liming agents for acid soils than calcitic limestone and better sources of magnesium than magnesium sulphate. The magnesium fertilization applied to soils with a high pH should be in the form of magnesium sulphate, irrespective of the risk of the formation of magnesium compounds not extractable in neutral ammonium acetate because this insoluble magnesium is more readily available to the plants than when dolomitic limestone is used.

At the end of the first growing season there was a clear increase in the amount of calcium leached from both unlimed soil and from soil treated with calcitic limestone as a result of the application of magnesium sulphate. This is due to the formation of soluble gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) from the calcium ions either present in the soil or supplied with the liming agent and from the sulphate ions supplied in the magnesium sulphate.

The limestone sold in Finland bearing the name of magnesium containing calcitic limestone has an average magnesium content of 5 % (range 3–7 % Mg). The total limestone amount (24 g/pot) applied in this experiment in

treatments Ca₁D2 and Ca₁D1H contained 4.5 % and 6 % magnesium, respectively, while the treatments Ca₂D2 and Ca₂D1H (36 g/pot of lime) contained 2.3 % and 3 % magnesium, respectively. The results obtained with these treatments may give some indication of the effects of the magnesium containing calcitic limestone on the yield, the nutrient content of the crop and the properties of the soil.

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SELOSTUS

Kalkituksen vaikutus magnesiumsulfaatin ja dolomiittikalkkien arvoon raiheinän magnesiumin lähteestä

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Kaksi vuotta jatkuneessa astiakokeessa tutkittiin magnesiumsulfaattina (200 mg Mg/3,9 kg maata), dolomiittikalkki 2:na (1140 mg Mg) tai dolomiittikalkki 1H:na (1320 mg Mg) annetun magnesiumin arvoa raiheinän magnesiumin lähteestä sekä niiden vaikutusta kasveille käyttökelpoiseen magnesiumiin maassa. Maan pH(CaCl₂) kohotettiin alkuarvostaan (4,9) kalkkikivijauheella (12 g tai 24 g kalkkia/3,9 kg maata) 5,7:ään tai 6,5:een. Peltoviljelyyn sovellettuna dolomiittikalkkimäärit ja pienempi kalkkikivijauhemääri vastaavat 5 t/ha ja suurempi kalkkikivijauhemääri 10 t/ha kalkitusta. Magnesiumsulfaatissa tuli noin 90 kg/ha magnesiumia.

Kalkkikivijauheena tai dolomiittikalkkeina annettu kalkitus samoin kuin kalkkikivijauhe ja magnesiumsulfaatti yhdessä lisäävät raiheinän kokonaissatoa keskimäärin 8 %.

Ilman kalkkikivijauhetta kasvustojen (8 satoa) keskimääräinen magnesiumpitoisuus oli dolomiittikalkki 1H (3,3 mg/g kuiva-ainetta) käytettäessä merkitsevästi korkeampi kuin dolomiittikalkki 2:lla (2,9 mg/g) tai magnesiumsulfaatilla (2,5 mg/g) tuotetuissa sadoissa. Lähellä pH(CaCl₂) 6,5 kasvustojen keskimääräinen magnesiumpitoisuus (2,3 mg/g) oli riippumaton magnesiumin lähteestä.

Magnesiumsulfaattina annetusta magnesiumista oli lähellä pH(CaCl₂) 6,5 ammoniumasetaattiin (1 M, pH 7) uutumattomana noin 20 %. Raiheinä näytti käyttävän vähitellen hyväkseen uutumatonta magnesiumia päätellen siitä, että magnesiumin otto oli toisena vuotena suurempi kuin ensimmäisenä. Ilman kalkitusta magnesiumin otto oli kumpanakin vuotena lähes yhtä suuri. Kokonaisuudessaan magnesiumsulfaatista otettu magnesiummääri oli kalkitsemattomassa maassa suurempi kuin kalkitussa.

Dolomiittikalkkeina annettu magnesium oli voimakkaasti kalkkikivijauheella kalkitussa maassa lähes kokonaan (85 %) ammoniumasetaattiin uutumattomana. Kahden vuoden koejakson aikana raiheinä ei kyennyt käyttämään uutumatonta magnesiumia hyväkseen. Happamassa maassa dolomiittikalkkien magnesium tuli hitaasti raiheinän käyttöön, sillä ensimmäisen vuoden satojen ottama magnesiummääri oli noin 35 % koko koeajana otetusta määristä.

Korkean pH(CaCl₂)-luvun omaavalle maalle magnesiumlannoitus tulee antaa magnesiumsulfaattina ammoniumasetaattiin uutumattomien magnesiumyhdisteiden muodostumisesta huolimatta. Dolomiittikalkit taas ovat tehokkaita magnesiumin lähteitä happamissa maissa.