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# SOIL MAGNESIUM AND FERTILIZER MAGNESIUM UPTAKE BY RYEGRASS ON NINE MINERAL SOILS AT TWO AMMONIUM NITRATE LEVELS I. MAGNESIUM UPTAKE

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JOKINEN, R. 1981. **Soil magnesium and fertilizer magnesium uptake by ryegrass on nine mineral soils at two ammonium nitrate levels I. Magnesium uptake.** Ann. Agric. Fenn. 20: 231—243. (Agric. Res. Centre, Inst. Agric. Chem. and Phys. SF-31600 Jokioinen, Finland.)

A study was made in the form of a pot experiment to determine the effect of the amount of nitrogen fertilizer ($N_1$ = 1500 mg/pot, $N_2$ = 3000 mg/pot per year N as $NH_4NO_3$) on the magnesium uptake by ryegrass (*Lolium multiflorum*) from nine soils. The magnesium given as $MgSO_4 \cdot 7H_2O_1$ (Mg = 200 mg/pot per year Mg) was also studied. The soils were taken from the plough layer of cultivated lands. The clay fraction (< 0,002 mm) in the soils varied from 4,4 % to 64,3 % and the exchangeable magnesium content (extractable in 1 M ammonium acetate, pH 7) from 0,11 to 6,53 me/100 g soil.

An increase in ammonium nitrate level usually caused an increase in the soil magnesium uptake by ryegrass. In coarse mineral soils (less than 30 % clay) the magnesium uptake did, however, decrease in the second growing season and the yield was decreased in the third period because of the poor magnesium resources of the soil.

The magnesium uptake by ryegrass depended on changes in the magnesium content of the yield more clearly than on changes in the size of the yield.

Annual application of magnesium sulphate raised the magnesium uptake by plants at the lower nitrogen level only in coarse mineral soils, and in none of the soils it had any effect on the size of the yield. At higher nitrogen level magnesium fertilization raised the yields and magnesium uptake significantly in seven of the nine soils. The exceptions were sandy clay and heavy clay, where not even the magnesium content of the yield increased with magnesium fertilization. The higher level of nitrogen fertilization would appear to create a need for magnesium fertilization in silty clays as well as in coarse mineral soils.

Ryegrass took up at most 19 % or 39 % of the fertilizer magnesium in coarse mineral soils at the two nitrogen levels, respectively, 12 % or 62 % in silty clays and 14 % in sandy clays and heavy clay.

Index words: Soil magnesium, fertilizer magnesium, pot experiment, ryegrass, ammonium nitrate, magnesium content, magnesium uptake, K/(Ca + Mg), finesand, very finesand, muddy silt, silty clay, sandy clay, heavy clay.

## INTRODUCTION

In their studies of nitrogen fertilization SALONEN et al. (1962) stated that raising the amount of nitrogen given as calcium nitrate (15,5 % N) from 0 to 46,5 kg/ha affected the magnesium content of the timothy hay yield only seldom in field experiments. In the pot experiments by FIEDLER (1960) increasing the amount of nitrogen raised the magnesium content of ryegrass if there was sufficient magnesium in the soil, but in soils with little magnesium the magnesium content of yields did not alter.

Modern grassland cultivation relies on the extensive use of nutrients in form of fertilizers. Large amounts of nitrogen rise the magnesium content of yields (STEEN 1968) while decreasing the nutrient recources of the soil, as has clearly been demonstrated (SILLANPÄÄ and RINNE 1975, JOKINEN 1979 b, PENNY et al. 1980). An increase in the amount of nitrogen fertilizer may lead to the disappearance of the magnesium in the soil, even in soils where the magnesium resources appear to be sufficient.

The purpose of this pot experiment study was to determine the availability of the magnesium resources in certain Finnish mineral soils for ryegrass at two nitrogen fertilization levels. In addition to the amount of magnesium taken up by ryegrass, attention was paid to the size and magnesium content of the yield. A study was also made of the effect of magnesium given as magnesium sulphate on the properties of yields and the soil.

## MATERIAL AND METHODS

Nine soils from the plough layer of cultivated lands were taken for the pot experiment. Soils with different clay content and magnesium content were sought for the experiment. The soils were sifted with a 1 cm sieve and kept damp in plastic sacks with the exception of three soils, which were almost air dry at the start of the experiment.

Detailed information on the properties of the soils is given in the soil analysis section of the study (JOKINEN 1981). Muddy silt is a Littorina-soil and the clays are glacial soils. Silty clay (8) had probably been treated with lime in the years preceding the experiment because its pH value was high.

Italian ryegrass (*Lolium multiflorum*, var. Barmultra) was cultivated in the experiment. Each soil was cultivated until the plants ceased to grow satisfactorily, but very finesand and silty clays for two years only, even though there may have been a yield in the following growing season too.

The soils were weighed into Mitscherlich-pots (calculated at a 3 % moisture level) and the ryegrass crops were harvested as follows:

| Soil | Locality | Soil kg/pot | Exchangeable Mg me/100 g | Number of cuttings |
|---|---|---|---|---|
| 1. Finesand.. .. | Ruukki | 5,52 | 0,11 | 11 |
| 2. Finesand .... | Mikkeli | 4,82 | 0,57 | 12 |
| 3. Very finesand | Toholampi | 5,39 | 1,25 | 8 |
| 4. Muddy silt .. | Ylistaro | 3,80 | 0,55 | 11 |
| 5. Silty clay.. .. | Laukaa | 4,03 | 1,00 | 8 |
| 6. Sandy clay .. | Anjala | 5.17 | 1,95 | 16 |
| 7. Sandy clay .. | Vantaa | 5,06 | 4,30 | 12 |
| 8. Silty clay .... | Anjala | 4,70 | 2,80 | 8 |
| 9. Heavy clay .. | Jokioinen | 4,50 | 6,53 | 20 |

The magnesium uptake of ryegrass from various soil types and the apparent recovery of fertilizer magnesium (Mg = 200 mg/pot Mg, as $MgSO_4 \cdot 7H_2O$) were studied at two nitrogen fertilizer levels ($N_1$ = 1500 mg/pot, $N_2$ = 3000 mg/pot N, as $NH_4NO_3$). There were thus four treatments per soil and a total of 12 pots, the treatments being repeated in triplicate. The whole study comprised 108 pots.

The following amounts of other nutrients were given per pot:

| | | |
|---|---|---|
| 400 mg P | .............. | (as $Ca(H_2PO_4)\cdot H_2O$) |
| 1500 mg K | .............. | (as KCl) |
| 2 mg B | .............. | (as $H_3BO_3$) |
| 13 mg Cu | .............. | (as $CuSO_4\cdot 5H_2O$) |
| 16 mg Mn | .............. | (as $MnSO_4\cdot 4H_2O$) |
| 11 mg Zn | .............. | (as $ZnSO_4\cdot 7H_2O$) |
| 4 mg Mo | .............. | (as $Na_2MoO_4\cdot 2H_2O$) |

All these nutrients were given per growing season, and the nutrients were mixed with the soil in each pot in spring, at the start of the growing season. The nitrogen and potassium fertilizers were given in two stages: 2/3 in the spring and 1/3 after the second cut. The ratio between the nitrogen and potassium given as fertilizer was 1 : 1 on average at the lower nitrogen level and 2 : 1 at the higher level.

In order to guarantee the growth soil was treated with lime ($CaCO_3$, lab. reag.) as follows:

| | First lime treatment | Second lime treatment |
|---|---|---|
| 1. Finesand ..... | 2,4 g/pot Ca | 4,8 g/pot Ca |
| 2. Finesand ..... | 2,4 » » | 2,4 » » |
| 4. Muddy silt .... | 7,2 » » | 4,8 » » |
| 6. Sandy clay .... | 2,4 » » | 2,4 » » |
| 7. Sandy clay .... | 2,4 » » | 4,8 » » |
| 9. Heavy clay .... | 2,4 » » | 2,4 » » |

Very finesand and silty clays, included in the experiment for two years, were not limed.

Ryegrass was resown each spring (250 mg of seeds per pot) and the seeds were covered with 1/4 litre of fertilized soil. The seedlings were not thinned after sprouting. The crop was cut about 1 cm above the soil surface.

As the pots were outdoors throughout the experiment, the plants got all the rain falling during the growing season. Any water collecting in the dishes under the pots was fed back to the plants daily and additional deionized water was given as necessary. The pots were covered for the winter.

The yields were treated and the total calcium, magnesium and potassium contents were determined from ash obtained by dry combustion in accordance with previous pot experiments (Jokinen 1977 a and b). The results are expressed as mg/g of dry matter.

As there were different amounts of soil in the pots, the soils were compared by expressing the yields and their nutrient uptakes per 100 g of soil.

The significant differences in individual annual yields and in nutrient uptakes were not tested, the main item of interest being the total annual yield and nutrient uptake. Changes in magnesium contents were observed yield by yield.

The results were tested by analysis of variance and the significance of differences between treatments by Duncan's new multiple range test (Steel and Torrie 1960). The significances are expressed at 0,001***, 0,01** and 0,05* levels. In the tables the results in one and the same line marked with the same letter do not deviate from one another significantly ($P = 0,05$).

The dependences between various factors were studied by linear correlation analysis. Stepwise regression analysis based on the sums of least squares (Draper and Smith 1966, Searle 1971) was used in studying variables affecting magnesium uptake or the ratios between nutrients.

## RESULTS

### Yields

Of the 3—4 annual yields, the first and third were larger than the second and fourth (the results are not presented), because the nitrogen fertilization was given in the spring and after the second cut. At the higher nitrogen level the difference between yields was clearer than at the lower nitrogen level.

The annual yields (g/100 g of soil) obtained without magnesium fertilization were to begin significantly greater at level $N_2$ than at level $N_1$ in all soils (Table 1). In the third year large doses of nitrogen led to a marked reduction in the yield

Table 1. Effect of magnesium and nitrogen treatments on the yield of ryegrass (g dry matter/100 g of soil) on diverse soils.

| Soil Year | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| 1. Finesand | | | | |
| 1st | 0,76$^{a}$ | 0,74$^{a}$ | 0,88$^{ab}$ | 0,99$^{b}$ |
| 2nd | 0,53$^{a}$ | 0,47$^{a}$ | 0,99$^{b}$ | 0,91$^{b}$ |
| 3rd | 0,38$^{b}$ | 0,39$^{b}$ | 0,14$^{a}$ | 0,56$^{c}$ |
| Total | 1,67$^{a}$ | 1,60$^{a}$ | 2,01$^{b}$ | 2,46$^{c}$ |
| 2. Finesand | | | | |
| 1st | 1,00$^{a}$ | 0,97$^{a}$ | 1,18$^{b}$ | 1,20$^{b}$ |
| 2nd | 1,12$^{a}$ | 1,05$^{a}$ | 1,46$^{b}$ | 1,54$^{b}$ |
| 3rd | 0,57$^{a}$ | 0,56$^{a}$ | 0,86$^{b}$ | 0,80$^{b}$ |
| Total | 2,69$^{a}$ | 2,58$^{a}$ | 3,50$^{b}$ | 3,54$^{b}$ |
| 3. Very finesand | | | | |
| 1st | 0,97$^{a}$ | 0,94$^{a}$ | 1,22$^{b}$ | 1,33$^{c}$ |
| 2nd | 0,73$^{ab}$ | 0,91$^{b}$ | 0,58$^{a}$ | 0,87$^{b}$ |
| Total | 1,70$^{a}$ | 1,85$^{a}$ | 1,80$^{a}$ | 2,20$^{b}$ |
| 4. Muddy silt | | | | |
| 1st | 1,36$^{a}$ | 1,33$^{a}$ | 1,67$^{b}$ | 1,75$^{c}$ |
| 2nd | 0,91$^{a}$ | 0,85$^{a}$ | 1,28$^{b}$ | 1,51$^{b}$ |
| 3rd | 1,17$^{b}$ | 1,23$^{b}$ | 0,29$^{a}$ | 1,15$^{b}$ |
| Total | 3,44$^{a}$ | 3,41$^{a}$ | 3,24$^{a}$ | 4,41$^{b}$ |
| 5. Silty clay | | | | |
| 1st | 1,35$^{a}$ | 1,28$^{a}$ | 1,53$^{b}$ | 1,93$^{c}$ |
| 2nd | 0,93$^{ab}$ | 1,06$^{b}$ | 0,81$^{a}$ | 1,33$^{c}$ |
| Total | 2,28$^{a}$ | 2,34$^{a}$ | 2,34$^{a}$ | 3,26$^{b}$ |
| 6. Sandy clay | | | | |
| 1st | 1,08$^{a}$ | 1,11$^{a}$ | 1,62$^{b}$ | 1,74$^{b}$ |
| 2nd | 1,14$^{a}$ | 1,09$^{a}$ | 1,74$^{b}$ | 1,73$^{b}$ |
| 3rd | 0,67$^{a}$ | 0,60$^{a}$ | 1,00$^{b}$ | 1,04$^{b}$ |
| 4th | 0,99$^{ab}$ | 0,94$^{a}$ | 0,99$^{ab}$ | 1,03$^{b}$ |
| Total | 3,88$^{a}$ | 3,74$^{a}$ | 5,35$^{b}$ | 5,54$^{c}$ |
| 7. Sandy clay | | | | |
| 1st | 1,28$^{ab}$ | 1,06$^{a}$ | 1,56$^{c}$ | 1,49$^{bc}$ |
| 2nd | 1,16$^{a}$ | 1,17$^{a}$ | 1,65$^{b}$ | 1,70$^{b}$ |
| 3rd | 0,56$^{a}$ | 0,55$^{a}$ | 0,97$^{b}$ | 1,04$^{b}$ |
| Total | 3,00$^{a}$ | 2,78$^{a}$ | 4,18$^{b}$ | 4,23$^{b}$ |
| 8. Silty clay | | | | |
| 1st | 1,21$^{a}$ | 1,16$^{a}$ | 1,43$^{b}$ | 1,78$^{c}$ |
| 2nd | 0,94$^{ab}$ | 1,02$^{b}$ | 0,77$^{a}$ | 1,51$^{c}$ |
| Total | 2,15$^{a}$ | 2,18$^{a}$ | 2,20$^{a}$ | 3,29$^{b}$ |
| 9. Heavy clay | | | | |
| 1st | 1,30$^{a}$ | 1,35$^{ab}$ | 1,60$^{b}$ | 1,61$^{b}$ |
| 2nd | 1,38$^{b}$ | 1,28$^{a}$ | 2,05$^{c}$ | 2,00$^{c}$ |
| 3rd | 0,63$^{a}$ | 0,61$^{a}$ | 1,16$^{b}$ | 1,17$^{b}$ |
| 4th | 1,17$^{ab}$ | 1,11$^{a}$ | 1,45$^{c}$ | 1,30$^{b}$ |
| 5th | 1,09$^{a}$ | 1,07$^{a}$ | 1,45$^{b}$ | 1,54$^{b}$ |
| Total | 5,57$^{a}$ | 5,42$^{a}$ | 7,71$^{b}$ | 7,62$^{b}$ |

compared with the lower in finesand (1) and muddy silt. In sandy clay (7) and heavy clay ryegrass produced a significantly greater yield in every year with the larger nitrogen amount. The total yield obtained over the whole experimental period did not depend on the amount of nitrogen fertilization in very finesand, muddy silt and silty clays.

Magnesium fertilization did not significantly affect the ryegrass yield in any of the nine soils with the smaller nitrogen amount. Nor was it possible in finesands and muddy silt containing little $CaCl_2$ (0,01 M) or ammonium acetate (1 M, pH 7) extractable magnesium, to demonstrate the need for magnesium fertilization by means of greater yields in three growing seasons. At higher nitrogen level magnesium fertilization significantly increased the yield in very finesand, muddy silt and silty clays from the first test year onwards. In finesand (1) magnesium did not have any marked positive effect until the third growing season.

The total yield over the whole experimental period increased significantly with magnesium fertilization at the higher nitrogen level in six of the nine soils (finesand 1, muddy silt, sandy clay 6, silty clays 5 and 8). This increase in yield was quantitatively and relatively greatest in muddy silt and silty clays and smallest in sandy clays.

In the year 1974 experiment included finesand (2), muddy silt, sandy clays and heavy clay. In all these, smaller yields were obtained in that year than in other years. The 1974 growing season was cool, the effective temperature sums being smaller than in other years.

## Magnesium content

An increase in nitrogen fertilization increased the average magnesium content of ryegrass significantly in the first three cuts (Table 2). Application of magnesium had a significant positive effect on the magnesium content of ryegrass in all cuts. At the higher nitrogen level magnesium fertilization increased the magnesium content more sharply than at the lower nitrogen level (Mg $\times$ N *) in the first and second cuts.

The magnesium content of ryegrass appeared to be lowest at the start of the growing season, and at the lower nitrogen level it rose slowly to the fourth cut. With the larger nitrogen amount the magnesium content of the third cut was higher than that of the others. On heavy clay the difference between the magnesium contents of different cuts was slight.

The average magnesium content of all the cuts on very finesand appeared to be higher than on the other soil types (Table 2). In this soil the proportion of the $CaCl_2$ extractable magnesium of that extractable in ammonium acetate (pH 7) was high. The lowest magnesium contents were observed in the cuts on finesand (1) and muddy silt.

Table 2. Effect of magnesium and nitrogen treatments on the magnesium content (Mg mg/g dry matter) of ryegrass in different cuts or on diverse soils, on average.

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| 1st cut | 1,62$^{a}$ | 1,89$^{b}$ | 1,90$^{b}$ | 2,41$^{c}$ |
| 2nd » | 1,59$^{a}$ | 1,86$^{b}$ | 2,46$^{c}$ | 3,22$^{d}$ |
| 3rd » | 2,14$^{a}$ | 2,62$^{b}$ | 2,64$^{b}$ | 3,41$^{c}$ |
| 4th » | 2,32$^{a}$ | 2,86$^{b}$ | 2,31$^{a}$ | 2,93$^{b}$ |
| 1. Finesand | 0,89$^{a}$ | 1,71$^{b}$ | 0,87$^{a}$ | 2,49$^{c}$ |
| 2. Finesand | 1,57$^{a}$ | 2,06$^{b}$ | 1,61$^{a}$ | 2,73$^{c}$ |
| 3. Very finesand | 3,46$^{a}$ | 4,04$^{ab}$ | 4,08$^{ab}$ | 4,77$^{b}$ |
| 4. Muddy silt | 1,14$^{a}$ | 1,76$^{b}$ | 1,10$^{a}$ | 2,37$^{c}$ |
| 5. Silty clay | 2,24$^{a}$ | 2,71$^{a}$ | 2,70$^{a}$ | 3,94$^{b}$ |
| 6. Sandy clay | 1,89$^{a}$ | 2,04$^{a}$ | 2,41$^{b}$ | 2,73$^{c}$ |
| 7. Sandy clay | 2,11$^{a}$ | 2,35$^{ab}$ | 2,52$^{bc}$ | 2,64$^{c}$ |
| 8. Silty clay | 1,94$^{a}$ | 1,94$^{a}$ | 2,40$^{b}$ | 2,45$^{b}$ |
| 9. Heavy clay | 2,29$^{a}$ | 2,46$^{a}$ | 3,10$^{b}$ | 3,32$^{b}$ |

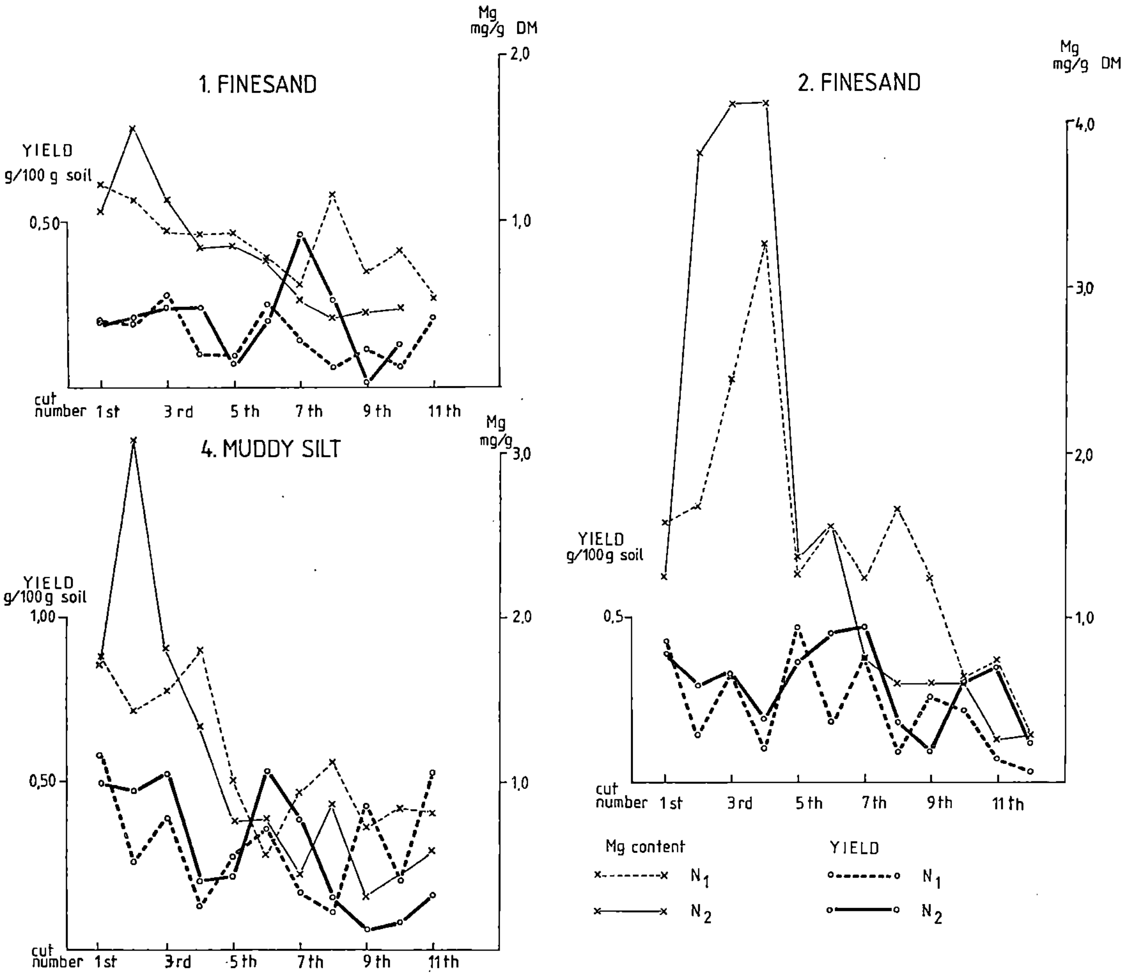


Fig. 1. Yield (g dry matter/100 g soil) and magnesium content (Mg mg/g dry matter) of ryegrass cuts at two ammonium nitrate levels on finesands and muddy silt.

In the last growing season ryegrass showed clear signs of magnesium deficiency without magnesium fertilization on finesand (1) and muddy silt. The signs were more severe at level $N_2$ than at level $N_1$.

An increase in the amount of nitrogen without the use of magnesium fertilization did not seem to change the average magnesium content of cuts significantly on the coarse mineral soils (1—4), but the magnesium content of the cuts obtained on clay soils (6—9) rose significantly. The results on silty clay (5) were similar to those on coarse mineral soils.

The magnesium content of cuts produced without magnesium at the higher nitrogen level dropped below that of cuts obtained with the lower nitrogen level on the finesands and muddy silt before the corresponding changes in the size of the yields were noticeable (Fig. 1).

When given in addition to the smaller nitrogen amount, magnesium fertilization increased the magnesium content of the cuts significantly on the finesands and muddy silt only. With the larger amount of nitrogen the positive effect of magnesium fertilization was significant on the coarse mineral soils, silty clay (5) and sandy clay (6). The increase in the magnesium content of

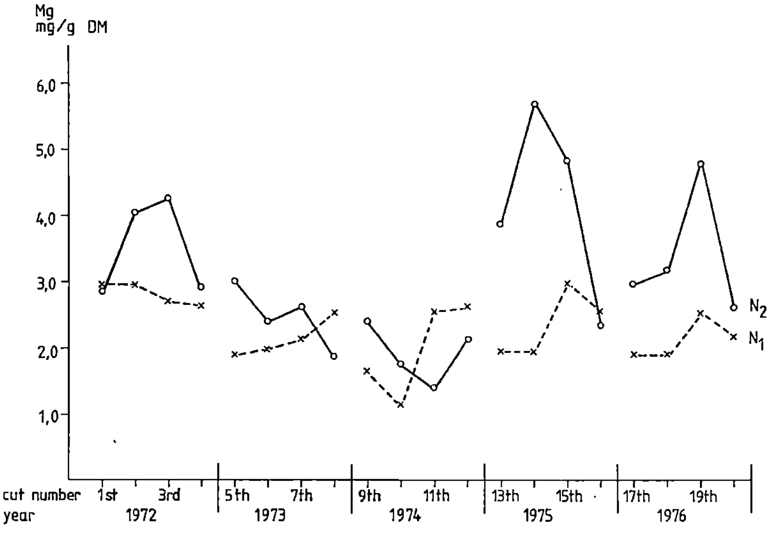


Fig. 2. The magnesium content of ryegrass (Mg mg/g dry matter) in different cuts on heavy clay soil at two ammonium nitrate levels without magnesium fertilization.

cuts due to the application of magnesium fertilization was sharper in the yields on the finesands and muddy silt obtained with the larger nitrogen amount than with the smaller amount (Mg × N **).

The magnesium content of the cuts varied from year to year, as is indicated by the magnesium contents of the cuts on heavy clay included throughout the experiment (Fig. 2). In the warm 1975 growing season the magnesium content of cuts was higher than in the cool 1974 season. The effect of liming on the magnesium content was possible not as marked as that of the cool weather, since the magnesium content of the cuts in the 1973 growing season was only about 1 mg/g higher than that of cuts the following year.

The negative correlation between the magnesium and potassium contents of cuts was smallest in the first cut (r = — 0,14*, n = 324) and greatest in the fourth cut (r = —0,42***, n = 294). There was a negative correlation between the magnesium and calcium contents, and this too was smallest in the first cut (r = — 0,29***) and greatest in the fourth (r = — 0,48***).

## Magnesium uptake

The dependence of the magnesium uptake on the yield size and magnesium content for each cut was as follows:

| Cut | | Yield g/100 g soil (r) | Mg mg/g of DM (r) | $R^2$ |
|---|---|---|---|---|
| 1st | (n = 324) .... | 0,81*** | 0,81*** | 0,94 |
| 2nd | (n = 324) .... | 0,71*** | 0,77*** | 0,92 |
| 3rd | (n = 321) .... | 0,66*** | 0,82*** | 0,94 |
| 4th | (n = 294) .... | 0,65*** | 0,58*** | 0,89 |

In the first three cuts the magnesium uptake appeared to follow changes in the magnesium content more clearly than changes in the yield. The magnesium uptake by the fourth cut was affected more by changes in the yield than by changes in the magnesium content.

Without magnesium fertilization, increasing the amount of nitrogen increased the magnesium uptake by ryegrass on sandy clays and heavy clay every year (Table 3). Even in the fifth year (16th—20th cuts) ryegrass was still taking up almost as much magnesium on the heavy clay as in the first year. On finesand (1) the magnesium uptake did not increase in any year, and on the other coarse mineral soils and silty clays in the first year only. The depletion of magnesium in the soil may be one reason for the reduction in magnesium uptake as the experiment proceeded.

Magnesium fertilization significantly increased the amount of magnesium removed with yields at the lower nitrogen level on the coarse mineral soils. At the higher nitrogen level the magnesium uptake increased on the coarse mineral soils and silty clays and in some years also on the sandy clays. Judging from the magnesium uptake, coarse mineral soils and silty clays appear to benefit from the magnesium fertilization.

The apparent recovery of fertilizer magnesium ($Mg_1$—$Mg_0$) seemed to be higher on the coarse mineral soils and silty clays than on the sandy clays and heavy clay (Table 4). On silty clay (5) the fertilizer magnesium uptake at the higher nitrogen level was very great, 61,9 %. On the other soils the corresponding value was at most 39,7 %. At the lower nitrogen level at most 19,0 % of the fertilizer magnesium was taken up on the coarse mineral soils.

Table 3. Effect of magnesium and nitrogen treatments on the magnesium uptake (Mg mg/100 g of soil) by ryegrass on diverse soils, on average.

| Soil Year | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| 1. Finesand | | | | |
| 1st .......... | 0,80$^{a}$ | 1,22$^{b}$ | 1,02$^{ab}$ | 2,50$^{c}$ |
| 2nd ......... | 0,42$^{a}$ | 0,56$^{a}$ | 0,55$^{a}$ | 1,01$^{b}$ |
| 3rd ......... | 0,20$^{a}$ | 0,85$^{b}$ | 0,06$^{a}$ | 2,38$^{c}$ |
| Total | 1,42$^{a}$ | 2.63$^{b}$ | 1,63$^{a}$ | 5,89$^{c}$ |
| 2. Finesand | | | | |
| 1st .......... | 2,05$^{a}$ | 2,31$^{a}$ | 3,68$^{b}$ | 4,47$^{c}$ |
| 2nd ......... | 1,50$^{a}$ | 1,92$^{b}$ | 1,66$^{ab}$ | 4,29$^{c}$ |
| 3rd ......... | 0,53$^{a}$ | 0,85$^{b}$ | 0,36$^{a}$ | 1,15$^{c}$ |
| Total | 4,08$^{a}$ | 5,08$^{b}$ | 5,70$^{c}$ | 9,91$^{d}$ |
| 3 Very finesand . | | | | |
| 1st .......... | 2,99$^{a}$ | 3,14$^{a}$ | 5,49$^{b}$ | 6,48$^{c}$ |
| 2nd ......... | 2,17$^{a}$ | 3,43$^{b}$ | 1,65$^{a}$ | 3,44$^{b}$ |
| Total | 5,16$^{a}$ | 6,57$^{b}$ | 7,14$^{b}$ | 9,92$^{c}$ |
| 4. Muddy silt .. | | | | |
| 1st .......... | 2,21$^{a}$ | 2,39$^{b}$ | 3,46$^{c}$ | 4,52$^{d}$ |
| 2nd ......... | 0,76$^{a}$ | 1,02$^{a}$ | 0,89$^{a}$ | 2 15$^{b}$ |
| 3rd ......... | 0,92$^{a}$ | 3,13$^{b}$ | 0,15$^{a}$ | 3,99$^{c}$ |
| Total | 3,89$^{a}$ | 6,54$^{b}$ | 4,50$^{a}$ | 10,66$^{c}$ |
| 5. Silty clay | | | | |
| 1st .......... | 2,60$^{a}$ | 2,86$^{a}$ | 4,01$^{b}$ | 7,05$^{c}$ |
| 2nd ......... | 1,98$^{a}$ | 2,88$^{b}$ | 1,79$^{a}$ | 4,91$^{c}$ |
| Total | 4,58$^{a}$ | 5,74$^{a}$ | 5,80$^{a}$ | 11,96$^{b}$ |
| 6. Sandy clay | | | | |
| 1st .......... | 2,30$^{a}$ | 2,32$^{a}$ | 3,82$^{b}$ | 4,33$^{c}$ |
| 2nd ......... | 1,83$^{a}$ | 1,97$^{a}$ | 3,55$^{b}$ | 3,88$^{c}$ |
| 3rd ......... | 1,02$^{a}$ | 0,97$^{a}$ | 1,63$^{b}$ | 1,76$^{b}$ |
| 4th ......... | 2,02$^{a}$ | 2,17$^{a}$ | 3,58$^{b}$ | 4,71$^{c}$ |
| Total | 7,17$^{a}$ | 7,43$^{a}$ | 12,58$^{b}$ | 14,68$^{c}$ |
| 7. Sandy clay | | | | |
| 1st .......... | 2,96$^{a}$ | 2,56$^{a}$ | 5,51$^{b}$ | 4,89$^{b}$ |
| 2nd ......... | 2,43$^{a}$ | 2,62$^{a}$ | 4,26$^{b}$ | 4,67$^{c}$ |
| 3rd ......... | 0,93$^{a}$ | 0,95$^{a}$ | 1,60$^{b}$ | 2,03$^{c}$ |
| Total | 6,32$^{a}$ | 6,13$^{a}$ | 11,37$^{b}$ | 11,59$^{b}$ |
| 8. Silty clay | | | | |
| 1st .......... | 2,41$^{a}$ | 2,46$^{a}$ | 3,05$^{b}$ | 4,37$^{c}$ |
| 2nd ......... | 1,73$^{a}$ | 1,72$^{a}$ | 1,90$^{a}$ | 3,97$^{b}$ |
| Total | 4,14$^{a}$ | 4,18$^{a}$ | 4,95$^{b}$ | 8,34$^{c}$ |
| 9. Heavy clay | | | | |
| 1st .......... | 3,70$^{a}$ | 4,03$^{a}$ | 5,76$^{b}$ | 6,03$^{b}$ |
| 2nd ......... | 2,85$^{a}$ | 2,76$^{a}$ | 5,34$^{b}$ | 5,36$^{b}$ |
| 3rd ......... | 1,04$^{a}$ | 1,24$^{a}$ | 2,19$^{b}$ | 2,55$^{c}$ |
| 4th ......... | 2,87$^{a}$ | 2,82$^{a}$ | 6,18$^{b}$ | 6,40$^{b}$ |
| 5th ......... | 2,30$^{a}$ | 2,27$^{a}$ | 5,07$^{b}$ | 5,40$^{b}$ |
| Total | 12,76$^{a}$ | 13,12$^{a}$ | 24,54$^{b}$ | 25,74$^{b}$ |

Table 4. The apparent recovery of fertilizer magnesium ($Mg_1$—$Mg_0$, mg/100 g soil, %) on diverse soils.

| | Fertilization Mg mg/ 100 g soil | Apparent recovery of fertilizer Mg mg/100 g soil | | % | |
|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | $N_1$ | $N_2$ |
| 1. Finesand . | 10,87 | 1,21 | 4,26 | 10,8 | 39,5 |
| 2. Finesand . | 12,45 | 1,00 | 4,21 | 8,0 | 33,7 |
| 3. Very finesand...... | 7,42 | 1,41 | 2,78 | 19,0 | 37,5 |
| 4. Muddy silt | 15,79 | 2,65 | 6,16 | 16,7 | 39,0 |
| 5. Silty clay . | 9,93 | 1,16 | 6,16 | 11,7 | 61,9 |
| 6. Sandy clay | 15,47 | 0,26 | 2,10 | 1,6 | 13,6 |
| 7. Sandy clay | 11,81 | —0,19 | 0,22 | | 1,6 |
| 8. Silty clay . | 8,51 | 0,04 | 3,39 | 0,4 | 39,7 |
| 9. Heavy clay | 22,22 | 0,36 | 1,20 | 1,7 | 5,4 |

### Potassium content and potassium uptake

In the whole material, the average potassium content of different cuts seemed to be highest in the first cut and lowest in the fourth (Table 5). Neither magnesium fertilization nor an increase in the amount of nitrogen fertilization affected the potassium content of the first cut. At the higher nitrogen level the potassium content of the second and third cut receiving magnesium fertilization was lower than the potassium content of the cuts from other treatments. The same also was observed in the average potassium content of all cuts on finesand (1), muddy silt and silty clay (8).

The ryegrass took more potassium from the soil than had been added in fertilization. The higher nitrogen amount given together with magnesium fertilization increased the yield on finesand (1), very finesand, muddy silt and silty clays and the amount of potassium removed with yields so strongly that the potassium in the soil and that given as fertilizer were insufficient. This may be the reason for the marked reduction in the potassium content of the yield.

### Calcium content and calcium uptake

Changes in the calcium content of the different ryegrass cuts were not as clear as in the case of the magnesium or potassium contents (Table 6). The last cut seemed to contain slightly more calcium than the other cuts.

Table 5. Effect of magnesium and nitrogen treatments on the potassium content (K mg/g dry matter) and potassium uptake (K mg/100 g soil) by ryegrass in different cuts or on diverse soils, on average.

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ | Total K-fertilization mg/ 100 g |
|---|---|---|---|---|---|
| | K mg/g DM | | | | |
| 1st cut .... | 47,7$^{a}$ | 51,2$^{a}$ | 49,5$^{a}$ | 50,8$^{a}$ | |
| 2nd » .... | 38,1$^{b}$ | 37,2$^{b}$ | 38,8$^{b}$ | 33,5$^{a}$ | |
| 3rd » .... | 34,4$^{c}$ | 35,6$^{c}$ | 30,7$^{b}$ | 25,4$^{a}$ | |
| 4th » .... | 27,4$^{b}$ | 27,7$^{b}$ | 21,8$^{a}$ | 20,3$^{a}$ | |
| 1. Finesand . | 42,2$^{b}$ | 38,4$^{ab}$ | 40,9$^{b}$ | 32,9$^{a}$ | |
| 2. Finesand . | 33,8$^{a}$ | 38,0$^{a}$ | 33,7$^{a}$ | 34,5$^{a}$ | |
| 3. Very finesand...... | 23,0$^{a}$ | 26,0$^{a}$ | 25,2$^{a}$ | 19,0$^{a}$ | |
| 4. Muddy silt | 35,7$^{b}$ | 36,0$^{b}$ | 38,5$^{b}$ | 29,4$^{a}$ | |
| 5. Silty clay . | 35,1$^{b}$ | 35,3$^{b}$ | 33,1$^{ab}$ | 25,1$^{a}$ | |
| 6. Sandy clay | 41,4$^{b}$ | 42,2$^{b}$ | 33,2$^{a}$ | 33,4$^{a}$ | |
| 7. Sandy clay | 38,9$^{a}$ | 39,2$^{a}$ | 40,6$^{a}$ | 41,2$^{a}$ | |
| 8. Silty clay . | 46,2$^{b}$ | 44,7$^{b}$ | 47,6$^{b}$ | 33,4$^{a}$ | |
| 9. Heavy clay | 39,5$^{b}$ | 39,2$^{b}$ | 33,6$^{a}$ | 34,3$^{a}$ | |
| | K uptake mg/100 g soil | | | | |
| 1. Finesand . | 70,5$^{ab}$ | 69,6$^{a}$ | 76,3$^{bc}$ | 81,1$^{c}$ | 67,9 |
| 2. Finesand . | 100,2$^{a}$ | 108,8$^{b}$ | 121,8$^{c}$ | 126,4$^{c}$ | 108,9 |
| 3. Very finesand...... | 53,6$^{ab}$ | 56,6$^{b}$ | 52,1$^{a}$ | 52,1$^{a}$ | 56,6 |
| 4. Muddy silt | 125,7$^{a}$ | 124,5$^{a}$ | 124,6$^{a}$ | 138,3$^{b}$ | 98,7 |
| 5. Silty clay . | 94,6$^{a}$ | 95,9$^{ab}$ | 93,4$^{a}$ | 99,4$^{b}$ | 74,4 |
| 6. Sandy clay | 173,8$^{a}$ | 173,7$^{a}$ | 201,7$^{b}$ | 211,0$^{c}$ | 101,5 |
| 7. Sandy clay | 134,5$^{a}$ | 126,6$^{a}$ | 182,2$^{b}$ | 186,3$^{b}$ | 103,8 |
| 8. Silty clay . | 105,8$^{a}$ | 105,9$^{a}$ | 109,1$^{a}$ | 132,7$^{b}$ | 63,8 |
| 9. Heavy clay | 243,0$^{a}$ | 236,2$^{a}$ | 276,7$^{b}$ | 275,7$^{b}$ | 150,0 |

Doubling the amount of nitrogen fertilization significantly increased the calcium content of all cuts. The negative effect of magnesium fertilization on the calcium content of the third and fourth cuts at the higher nitrogen level may be a consequence of the rise in the magnesium content of the cuts.

Magnesium fertilization appeared to decrease the calcium content of cuts slightly on all soils, though the average calcium content dropped significantly only in the cuts on silty clay (8). This soil was not limed at all during the experiment.

Ryegrass took up less calcium on very finesand and silty clays than on the other soils, because these soils were included in the experiment for only two years and were not limed at all. The amounts of calcium taken up on the finesands

Table 6. Effect of magnesium and nitrogen treatments on the calcium content (Ca mg/g dry matter) and calcium uptake (Ca mg/100 g soil) by ryegrass in different cuts or on diverse soils, on average.

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ | Ca applied mg/100 g |
|---|---|---|---|---|---|
| | Ca mg/g DM | | | | |
| 1st cut | 6,08[a] | 5,65[a] | 7,40[b] | 6,97[b] | |
| 2nd » | 5,88[a] | 5,77[a] | 8,27[b] | 8,02[b] | |
| 3rd » | 5,47[a] | 5,39[a] | 8,00[c] | 7,28[b] | |
| 4th » | 7,89[ab] | 7,79[a] | 9,03[c] | 8,73[b] | |
| 1. Finesand | 6,26[a] | 5,69[a] | 8,10[b] | 7,82[b] | |
| 2. Finesand | 8,03[a] | 7,84[a] | 11,40[b] | 10,11[b] | |
| 3. Very finesand | 7,13[ab] | 6,41[a] | 8,52[b] | 6,88[ab] | |
| 4. Muddy silt | 6,86[a] | 6,19[a] | 8,94[b] | 8,62[b] | |
| 5. Silty clay | 6,25[a] | 5,70[a] | 8,75[b] | 7,12[ab] | |
| 6. Sandy clay | 6,39[a] | 6,69[a] | 8,96[b] | 8,78[b] | |
| 7. Sandy clay | 5,93[a] | 6,03[a] | 6,83[a] | 6,64[a] | |
| 8. Silty clay | 5,10[a] | 5,00[a] | 7,31[c] | 6,12[b] | |
| 9. Heavy clay | 5,56[a] | 5,40[a] | 6,93[b] | 6,97[b] | |
| | Ca uptake mg/100 g soil | | | | |
| 1. Finesand | 10,0[a] | 8,5[a] | 15,9[b] | 18,8[c] | 130,4 |
| 2. Finesand | 19,8[a] | 18,5[a] | 39,7[c] | 35,3[b] | 99,6 |
| 3. Very finesand | 10,0[a] | 9,9[a] | 12,3[b] | 13,1[b] | |
| 4. Muddy silt | 23,8[b] | 21,4[a] | 26,2[c] | 36,6[d] | 315,6 |
| 5. Silty clay | 12,1[a] | 11,3[a] | 15,7[b] | 19,7[c] | |
| 6. Sandy clay | 25,0[a] | 24,3[a] | 46,3[b] | 47,1[b] | 92,8 |
| 7. Sandy clay | 17,3[a] | 15,8[a] | 29,9[b] | 27,9[b] | 142,4 |
| 8. Silty clay | 10,9[a] | 10,6[a] | 15,7[b] | 20,0[c] | |
| 9. Heavy clay | 29,8[a] | 28,5[a] | 52,3[b] | 52,1[b] | 106,8 |

were also small, even though the soils were limed.

The significant increase in calcium uptake caused by magnesium fertilization at the higher nitrogen level is probably a consequence of the increase in the yield, for the calcium content appeared to decrease.

## Equivalent ratios of nutrients

The potassium to magnesium ratio was highest in the first cut, as was the potassium content, and lowest in the fourth cut (Table 7). The correlation between the K/Mg ratio and the potassium or magnesium content in the different cuts were as follows:

| K/Mg | Mg mg/g DM | K mg/g DM | |
|---|---|---|---|
| | | r | $R^2$ |
| 1st cut | —0,74*** | 0,25** | 0,57 |
| 2nd » | —0,68*** | 0,47** | 0,54 |
| 3rd » | —0,69*** | 0,33** | 0,48 |
| 4th » | —0,71*** | 0,39** | 0,51 |

Table 7. Effect of magnesium and nitrogen treatments on the equivalent ratio K/Mg in different cuts or on diverse soils, on average

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| 1st cut | 11,0[b] | 8,4[a] | 12,4[b] | 7,3[a] |
| 2nd » | 8,7[c] | 6,9[b] | 8,5[c] | 4,2[a] |
| 3rd » | 6,5[c] | 4,9[b] | 7,1[c] | 3,4[a] |
| 4th » | 4,3[b] | 3,4[a] | 4,7[b] | 2,8[a] |
| 1. Finesand | 15,9[b] | 7,7[a] | 17,0[b] | 6,0[a] |
| 2. Finesand | 8,3[b] | 6,5[ab] | 13,8[c] | 5,5[a] |
| 3. Very finesand | 3,2[a] | 2,8[a] | 3,0[a] | 1,9[a] |
| 4. Muddy silt | 10,7[b] | 7,0[ab] | 17,5[c] | 4,9[a] |
| 5. Silty clay | 6,0[b] | 5,0[ab] | 5,0[ab] | 3,1[a] |
| 6. Sandy clay | 7,1[b] | 6,8[b] | 5,0[a] | 4,5[a] |
| 7. Sandy clay | 5,7[a] | 5,5[a] | 5,3[a] | 5,0[a] |
| 8. Silty clay | 7,9[b] | 7,7[b] | 6,6[b] | 5,1[a] |
| 9. Heavy clay | 5,6[b] | 5,2[b] | 3,8[a] | 3,9[a] |

Table 8. Effect of magnesium and nitrogen treatments on the equivalent ratio K/(Ca+Mg) in different cuts or on diverse soils, on average

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| 1st cut | 3,33[b] | 3,26[b] | 2,81[a] | 2,64[a] |
| 2nd » | 2,50[c] | 2,39[c] | 1,83[b] | 1,53[a] |
| 3rd » | 2,12[c] | 2,06[c] | 1,49[b] | 1,28[a] |
| 4th » | 1,58[c] | 1,24[b] | 1,00[a] | 0,91[a] |
| 1. Finesand | 2,98[b] | 2,54[ab] | 2,40[ab] | 1,96[a] |
| 2. Finesand | 2,08[b] | 2,06[b] | 1,58[a] | 1,50[a] |
| 3. Very finesand | 1,34[a] | 1,35[a] | 1,26[a] | 0,98[a] |
| 4. Muddy silt | 2,39[b] | 2,31[b] | 2,13[b] | 1,52[a] |
| 5. Silty clay | 2,16[a] | 2,11[a] | 1,79[a] | 1,43[a] |
| 6. Sandy clay | 2,37[b] | 2,40[b] | 1,54[a] | 1,51[a] |
| 7. Sandy clay | 2,36[a] | 2,25[a] | 2,04[a] | 2,02[a] |
| 8. Silty clay | 2,89[b] | 2,88[b] | 2,21[a] | 1,95[a] |
| 9. Heavy clay | 2,38[b] | 2,28[b] | 1,57[a] | 1,53[a] |

The negative correlation between the magnesium content and the K/Mg was closer than the positive correlation between the potassium content and this ratio.

The magnesium fertilization made it possible to reduce the ratio significantly in the yields on the finesands, muddy silt and silty clay (8). Increasing the amount of nitrogen without magnesium fertilization increased the K/Mg in the cuts on finesand (2) and muddy silt and reduced it in cuts on sandy clay (6) and heavy clay.

The K/(Ca+Mg) ratio seemed to be highest in the first cut and decreased during the growing season (Table 8).

The correlations between the nutrient contents and the K/(Ca+Mg) in different cuts were as follows:

| K/(Ca+Mg) | Ca mg/g DM | Mg mg/g DM | K mg/g DM | |
|---|---|---|---|---|
| | | r | | $R^2$ |
| 1st cut ...... | —0,72*** | —0,64*** | 0,30** | 0,90 |
| 2nd » ...... | —0,51*** | —0,75*** | 0,51*** | 0,85 |
| 3rd » ...... | —0,64*** | —0,57*** | 0,86*** | 0,90 |
| 4th » ...... | —0,75*** | —0,57*** | 0,88*** | 0,90 |

In the first cut the variations in K/(Ca+Mg) depended most clearly on the changes in the calcium content, in second cut on those in magnesium content, and in the other cuts on the changes in the potassium content.

Increasing the amount of nitrogen fertilization reduced the ratio K/(Ca+Mg) in all cuts. Magnesium fertilization reduced the ratio significantly in the third and fourth cuts, though only at the higher nitrogen level.

The K/(Ca+Mg) ratio appeared to be smallest in the cuts on very finesand, but the difference between other soils seemed to be small. With magnesium fertilization the ratio decreased significantly only in cuts on muddy silt at the higher nitrogen level. Increasing the amount of nitrogen reduced the K/(Ca+Mg) in the cuts on finesand (2), sandy clay (6), silty clay (8) and heavy clay, regardless of the magnesium fertilization.

## DISCUSSION

The nutrient uptake of plants in a pot experiment is more efficient than in the field, because the plants' water requirement is quaranteed by daily watering, the plants' roots form a dense network extending throughout the soil, and nutrients are supplied in fertilization in 4—10 times the quantity applied in field cultivation.

The magnesium contents, the equivalent ratios K/Mg and K/(Ca+Mg) in the ryegrass of this pot experiment were higher than the values obtained in field experiments for timothy grassland yields at the silage stage and in the aftergrowth (Jokinen 1979 a).

The magnesium content of ryegrass was lowest in the first cut and highest in the third or fourth cut, provided there was sufficient magnesium in the soil. Similar results were obtained by Todd (1961) in pot experiments and Penny et al. (1980) in field experiments studying the magnesium content of timothy cut several times during the growing season. Mayland and Grunes (1974), on the other hand, obtained the opposite results with *Agropyron desertorum*. In this pot experiment the differences in the magnesium contents of different cuts were small if the magnesium resources in the soil were low.

The chief reason for the low magnesium content of the first cut was probably the high potassium content of the plants (McIntosh et al. 1973). The yields produced without magnesium fertilization had more than 11 times the equivalent amount of potassium compared with magnesium, and even in yields that did receive magnesium there was more than 7 times the amount. The equivalent ratio K/(Ca+Mg) was also highest in the first cut. In addition to the high potassium content the antagonism between the ammonium and magnesium ions may be one reason for the low magnesium content of the first cut (Claasen and Wilcox 1974), because according in the preliminary results of incubation experiments performed in the laboratory, at most 30 % of the ammonium ions of ammonium nitrate had nitrified in seven weeks (the time between sowing and the first cut in the pot experiment).

In the soil in which a magnesium deficiency limited the magnesium uptake by ryegrass, a reduction in the magnesium content of yields was observed in the second growing season and the size of the yield decreased in the third growing season. A similar results was obtained by Shadfan (1976) in his pot experiment with ryegrass. The magnesium content of the plants, rather than the yield, would thus seem to indicate a pending magnesium deficiency provided that the change in the magnesium content is observed over several growing seasons. According to

JANSSON (1971) the high nutrient content of plants is not always an indication of a sufficient nutrient supply, because the reason for the high nutrient content may be a small yield due to a shortage of nutrients. In exhaustive cropping experiments the magnesium uptake by plants no doubt express the amount of magnesium available for plants in the soil better than does the magnesium content of plants (SALMON and ARNOLD 1963). The correlation between the magnesium uptake by ryegrass and the magnesium content of cuts was closer in the first cut than the corresponding correlation between magnesium uptake and yield.

On the finesand and muddy silt soils the ryegrass yield and its magnesium uptake decreased in the last two years of the experiment more sharply at the higher nitrogen level than at the lower level. The signs of magnesium deficiency observed in the plants and the low magnesium content of cut indicated that an insufficient supply of magnesium restricts the growth and magnesium uptake of ryegrass. At the end of the experiment the exchangeable magnesium content in the soils was only 0,44—1,73 mg/100 g of soil, while the equivalent ratio Ca/Mg was extremely high (JOKINEN 1981). In addition to the magnesium deficiency, the large amount of calcium in relation to magnesium may have hindered the magnesium uptake by ryegrass (FINE and SHANNON 1976, MORGAN and JACKSON 1976).

When double the guantity of nitrogen fertilization was applied, the ryegrass took up almost twice the amount of magnesium on sandy clays and heavy clay than at the lower nitrogen level. On these soils the magnesium content of the cuts also rose significantly as a result of an increase in the amount of nitrogen fertilization (FIEDLER 1960, GEORGE and THILL 1979). The increase in magnesium uptake caused by heavy nitrogen fertilization is connected with the metabolism of plants (HANSEN 1972, COX and REISENAUER 1973). On the finesands and muddy silt containing little magnesium the magnesium uptake by ryegrass did not depend on the amount of nitrogen fertilization, and contrary to the investigations of FIEDLER (1960), the magnesium content of ryegrass fell.

Magnesium fertilization increased the ryegrass yield, its magnesium uptake and magnesium content on coarse mineral soils and silty clays. The apparent recovery of fertilizer magnesium was also greater on these soils than on sandy clays and heavy clay. According to PRINCE et al. (1947), the greater the magnesium fertilizer requirement, the higher the recovery of fertilizer magnesium. Even the silty clays of this pot experiment would thus appear to need magnesium fertilization. An explanation for the results is sought in the soil analysis in part II of this report (JOKINEN 1981). On the sandy clays and heavy clay magnesium fertilization did not increase the magnesium uptake or magnesium content of ryegrass. The magnesium uptake on heavy clay was in the 20th cut almost as high as in the 1st cut, and the apparent recovery of fertilizer magnesium was at most 14 %. In their pot experiments, KAILA and KETTUNEN (1974) also observed that heavy clay contains an abundance of magnesium available for plants.

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## SELOSTUS

# Kahden typpilannoitemäärän vaikutus raiheinän kykyyn ottaa maan magnesiumia ja lannoitteen magnesiumia yhdeksästä kivennäismaasta I. Raiheinän magnesiumin otto.

Raili Jokinen

Maatalouden tutkimuskeskus

Astiakokeilla selviteltiin kahden typpilannoitemäärän ($N_1$ = 1500 mg/ast, $N_2$ = 3000 mg/ast N vuodessa, $NH_4NO_3$:na) vaikutusta raiheinän (*Lolium multiflorum*) magnesiumin ottoon yhdeksästä kivennäismaasta. Tutkimuksen kohteena olivat sekä maassa oleva että lannoituksena annettu magnesium ($Mg_1$ = 200 mg/ast Mg vuodessa, $MgSO_4 \cdot 7H_2O$:na). Raiheinää kasvatettiin 2—5 vuotta ja sato korjattiin 8—20 kertaa. Maat astiakokeisiin otettiin viljeltyjen maiden muokkauskerroksesta. Maiden savespitoisuus (fraktio alle 0,002 mm) vaihteli 4,4—64,3 % ja vaihtuva (1 M ammoniumasetaatti, pH 7) magnesiumpitoisuus 0,11—6,53 me/100 g maata.

Raiheinän ottaman magnesiumin määrä näytti olevan positiivisessa vuorosuhteessa selvemmin sadon magnesiumpitoisuuteen kuin sadon määrään.

Savimaissa ammoniumnitraattimäärän lisäys tehosti raiheinän magnesiumin ottoa lähes poikkeuksetta. Karkeissa kivennäismaissa magnesiumin otto väheni toisena kasvukautena ja sato pieneni kolmantena kasvukautena suuremman typpimäärän tasolla maan magnesiumrajojen niukkuuden vuoksi.

Vuosittainen magnesiumlannoitus lisäsi raiheinän magnesiumin ottoa pienemmän typpimäärän tasolla vain karkeissa kivennäismaissa, mutta raiheinän satoon magnesiumlannoitus ei vaikuttanut yhdessäkään maassa. Suurempaa typpimäärää käytettäessä magnesiumlannoitus lisäsi raiheinän satoa ja magnesiumin ottoa merkitsevästi seitsemässä maassa yhdeksästä. Hietasavissa ja aitosavessa ei edes sadon magnesiumpitoisuus kohonnut magnesiumlannoituksella.

Runsas typpilannoitus näytti lisäävän magnesiumlannoituksen tarvetta karkeiden kivennäismaiden lisäksi myös happamassa hiesusavessa.

Lannoituksena annetusta magnesiumista raiheinä otti eri typpilannoitustasoilla karkeissa kivennäismaissa enintään 19 % tai 39 %, hiesusavissa 12 % tai 62 % sekä hietasavissa ja aitosavessa 14 %.

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# SOIL MAGNESIUM AND FERTILIZER MAGNESIUM UPTAKE BY RYEGRASS ON NINE MINERAL SOILS AT TWO AMMONIUM NITRATE LEVELS II. MAGNESIUM CONTENT OF SOILS

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The effects on the soil characteristics of the magnesium uptake from soil sources and from magnesium fertilizer ($Mg_1$ = 200 mg/pot per year Mg, as $MgSO_4 \cdot 7H_2O$) was studied at two ammonium nitrate levels ($N_1$ = 1500 mg/pot $N_2$ = 3000 mg/pot per year N) in a pot experiment.

The primary source of magnesium for ryegrass appeared to be exchangeable soil magnesium, since the correlation between the magnesium uptake and the soil magnesium content extractable in 1 M neutral ammonium acetate was high (r = 0,97**, n = 18). The correlation between magnesium uptake and the soil magnesium content extractable in 1 M KCl was also close (r = 0,95**), as was the correlation between magnesium uptake and the magnesium extractable in 0,01 M $CaCl_2$ (r = 0,94**).

On three clay soils the increase in magnesium uptake as the amount of nitrogen fertilizer was increased caused a significant decrease in the exchangeable (pH 7) soil magnesium content and in the magnesium content extractable in 0,01 M $CaCl_2$. This was not observed on two other clay soils, possibly because of magnesium fixation, or in three coarse mineral soils because of the poor magnesium resources of the soil.

In the case of limed soils, the change in the exchangeable magnesium content of the soil during the experiment was greater than the amount of magnesium removed along with the yields. Some of the soil and of fertilizer magnesium was fixed not extractable in ammonium acetate. At the higher nitrogen level the ryegrass might have taken up fixed magnesium.

Index words: Soil magnesium, fertilizer magnesium, pot experiment, ryegrass, ammonium nitrate, magnesium content, magnesium fixation, Ca/Mg, finesand, very finesand, muddy silt, silty clay, sandy clay, heavy clay.

## INTRODUCTION

In the earlier study (JOKINEN 1981 a) it was stated that an increase in the amount of nitrogen fertilizer increased the magnesium uptake by ryegrass on sandy clays and heavy clay. In the case of coarse mineral soils there was no increase in magnesium uptake, a finding would seem to indicate that this type of soils contains little magnesium that can be used by the plants.

In addition to the shortage of available magnesium, the magnesium uptake may be influenced by a high calcium to magnesium ratio too (SIMSON et al. 1979) and, in acid soils, by a high concentration of aluminium (HUETT and MENARY 1980).

The purpose of this study was to investigate on some Finnish mineral soils the dependences of the magnesium resources of these soils on the magnesium uptake by ryegrass, and the effect of the nitrogen fertilizer level on the fate of soil magnesium and of fertilizer magnesium in the soil.

## MATERIAL AND METHODS

The pot experiment consists of nine mineral soils from the plough layer of cultivated area (Table 1). Four of the nine soils are coarse mineral soils (less than 30 % clay fraction < 0,002 mm) and five of them clay soils (over 30 % clay fraction). Muddy silt is a Littorina soil.

Detailed information of the pot experiment, which this study is based on, has been presented earlier (JOKINEN 1981 a). At the end of the experiment a soil sample was taken from each pot by removing two sectors (c. 1/2 litre) from opposite sides of the clump of soil and mixing them. A subsample about 1/2 litre was retained for analysis. The soil samples was left to dry at room temperature.

All soil analyses were carried out at the same time. The soil was analysed both at the start and at the end of the experiment. Prior to analysis the soils were ground to pass a 2 mm sieve.

— pH was determined from a suspension in 0,01 M $CaCl_2$ (1: 2,5 v/v) after allowing the suspension to equilibrate overnight.
— Organic carbon contents were determined by digestion the sample in a mixture of concentrated sulphuric acid and potassium dichromate followed by colorimetric determination (Hitachi), with references prepared from oxalic acid.
— Particle size distribution was determined by means of the pipette method (ELONEN 1971).

Table 1. The properties of the soils in the pot experiment.

| | 1 Fine-sand | 2 Fine-sand | 3 Very fine-sand | 4 Muddy silt | 5 Silty clay | 6 Sandy clay | 7 Sandy clay | 8 Silty clay | 9 Heavy clay |
|---|---|---|---|---|---|---|---|---|---|
| $pH(CaCl_2)$ | 4,4 | 5,1 | 5,0 | 3,9 | 4,5 | 5,6 | 5,0 | 6,1 | 5,6 |
| Org. C % | 1,9 | 4,7 | 3,0 | 6,1 | 5,7 | 4,5 | 5,6 | 2,8 | 5,2 |
| Particle size distribution, % | | | | | | | | | |
| < 0,002 mm | 4,4 | 4,5 | 11,7 | 25,4 | 30,9 | 36,4 | 43,8 | 45,1 | 64,3 |
| 0,002— 0,02 » | 7,2 | 15,4 | 42,3 | 40,4 | 55,0 | 41,0 | 24 5 | 42,9 | 13,8 |
| 0,02 — 0,06 » | 32,3 | 23,8 | 37,4 | 24,9 | 10,5 | 11,6 | 15,0 | 8,2 | 4,8 |
| 0,06 — 0,20 » | 54,8 | 32,8 | 6,4 | 6,4 | 2,1 | 4,3 | 12,2 | 1,6 | 5,7 |
| 0,20 — 2,00 » | 1,3 | 23,5 | 2,2 | 2,9 | 1,4 | 6,7 | 4,5 | 2,2 | 11,4 |
| Neutral ammonium acetate (1 M) extr. | | | | | | | | | |
| $Ca^{2+}$ me/100 g soil | 1,09 | 6,86 | 3,75 | 2,99 | 6,61 | 14,13 | 11,39 | 18,58 | 18,71 |
| $Mg^{2+}$ » | 0,11 | 0,57 | 1,25 | 0,55 | 1,00 | 1,95 | 4,30 | 2,80 | 6,53 |
| $K^+$ » | 0,24 | 0,32 | 0,18 | 0,38 | 0,51 | 1,13 | 0,59 | 0,77 | 1,15 |
| $Na^+$ » | 0,05 | 0,15 | 0,11 | 0,25 | 0,13 | 0,23 | 0,24 | 0,22 | 0,77 |
| Ca/Mg | 9,9 | 12,0 | 3,0 | 5,4 | 6,6 | 7,2 | 2,6 | 6,6 | 2,9 |
| Effective cation exchange capacity me/100 g soil | 3,0 | 7,8 | 5,7 | 9,6 | 9,4 | 14,8 | 15,6 | 19,7 | 23,9 |
| Mg mg/100 g extr. 1 M KCl | 1,21 | 5,70 | 15,06 | 4,90 | 11,36 | 21,23 | 50,06 | 30,88 | 73,95 |
| Mg » » 0.01 M $CaCl_2$ | 1,10 | 4,53 | 12,25 | 4,53 | 8,63 | 14,00 | 31,75 | 17,75 | 40,25 |
| (Al+H) me/100 g » 1 M KCl | 1,94 | 0,64 | 0,78 | 6,60 | 2,24 | 0,23 | 0,76 | 0,26 | 0,36 |

The soil types were named in accordance with the »soil triangle» approved in Finnish agriculture (SILLANPÄÄ 1976).

— Exchangeable cations were extracted in 1 M ammonium acetate (pH 7). In a centrifuge tube was weighed 10 g of soil, 50 ml of the extractant solution added and the tube was shaken for 1 h before being centrifuged for 10 min (2500 rpm). The clear supernatant was decanted off and filtered through a hard filter paper. This process was repeated three more times, and all the filtrates were combinated. The calcium and magnesium contents of filtrate were determined by atomic absorption spectrophotometry (Varian 1200) after eliminating the interference by 1500 ppm Sr. The potassium and sodium contents were determined by flame photometry (EEL).

— To determine the effective cation exchange capacity 10 g of soil was extracted with 1 M KCl as in the determination of exchangeable cations. The (Al+H) content of the filtrate was determined by titrating a 50 ml aliquot with 0,01 M NaOH (phenolphthalein as indicator) until a red colour persisted, after which the aluminium content was determined by titrating with 0,01 M HCl (10 ml 4 % NaF added) to just colourless (YUAN 1959). The calcium and magnesium contents were determined as for exchangeable cations. The effective cation exchange capacity was calculated as the sum of (Ca+Mg) and (Al+H) in me/100 g of soil (KAILA 1971).

— The readily soluble magnesium (activity of magnesium) was extracted into 0,01 M $CaCl_2$ by shaking the soil and solution (1 : 10 w/v) for 2 h (SCHACHTSCHABEL 1954). After filtration the magnesium content of the extract was determined as described above.

Because of the differences in the amounts of soil weighed per pot, the amounts of nutrients taken up by ryegrass as well as the soil analysis results, are calculated for 100 g of air-dry soil.

## RESULTS

### Magnesium content

The nutrient contents of the soil were determined only at the beginning and at the end of the experiment. The results do not permit accurate determination of the soil magnesium content which the symptoms of magnesium deficiency begin to appear in ryegrass.

At the end of the experiment the very finesand, silty clay (5), sandy clay (6) and heavy clay without magnesium fertilization contained significantly less at $N_2$ level than at $N_1$ level both in 0,01 M $CaCl_2$ extractable and 1 M neutral ammonium acetate extractable magnesium (Table 2). Likewise the difference between the amounts of magnesium taken up by ryegrass on these soils was significant. In sandy clay (7) and silty clay (8) the contents of magnesium did not differ significantly from each other at the two nitrogen levels, although the difference between the amounts of magnesium taken up by ryegrass was significant. In coarse mineral soils the differences in soil magnesium contents and in the magnesium uptake by ryegrass between the two nitrogen levels were not significant.

When magnesium fertilization was applied, there was significant differences in the soil magnesium contents ($CaCl_2$ or ammonium acetate extractable) between the two nitrogen levels in all soils. The high magnesium uptake by ryegrass produced at higher nitrogen level was reflected in the fact that the soil magnesium contents were lower than at the smaller nitrogen level.

Without magnesium fertilization more magnesium was removed along with yields on all soil types than indicated by the change in the $CaCl_2$ extractable magnesium content of the soil during the experimental period (Table 3). The plants may have taken up other than easily extractable

Table 2. The ammonium acetate (1 M, pH 7) extractable and $CaCl_2$ (0,01 M) extractable magnesium contents (mg/100 g soil) of the soils at the end of pot experiment.

| | 1 M ammonium acetate, pH 7 | | | | 0.01 M $CaCl_2$ | | | |
|---|---|---|---|---|---|---|---|---|
| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
| 1. Finesand | 0,44[a] | 6,33[c] | 0,53[a] | 4,33[b] | 0,46[a] | 4,96[c] | 0,49[a] | 3,16[b] |
| 2. Finesand | 1,72[a] | 9,20[c] | 0,55[a] | 6,90[b] | 1,31[b] | 6,67[d] | 0,54[a] | 4,58[c] |
| 3. Very finesand | 9,46[b] | 15,10[c] | 6 88[a] | 10,45[b] | 7,07[b] | 11,54[c] | 4,96[a] | 7,48[b] |
| 4. Muddy silt | 1,43[a] | 11,39[c] | 1,55[a] | 7,48[b] | 0,99[a] | 7,44[c] | 0,99[a] | 4,75[b] |
| 5. Silty clay | 6,46[b] | 14,10[d] | 4,83[a] | 8,09[c] | 4,58[b] | 9,89[d] | 3,41[a] | 5,80[c] |
| 6. Sandy clay | 13,25[b] | 25,50[d] | 8,28[a] | 19,92[c] | 8,83[b] | 16,39[d] | 5,60[a] | 12,96[c] |
| 7. Sandy clay | 38,75[a] | 47,33[c] | 37,08[a] | 44,75[b] | 25,60[a] | 31,42[c] | 24,25[a] | 29,25[b] |
| 8. Silty clay | 29,98[a] | 36,04[c] | 29,80[a] | 33,80[b] | 16,08[a] | 20,00[c] | 15,67[a] | 17,83[b] |
| 9. Heavy clay | 58,31[b] | 75,20[d] | 48,65[a] | 66,44[c] | 29,83[b] | 37,97[d] | 25,42[a] | 35,08[c] |

Table 3. The changes in ammonium acetate (1 M, pH 7), KCl (1 M) or $CaCl_2$ (0,01 M) extractable magnesium contenst of the soils during the pot experiment (start-end) and the magnesium uptake by ryegrass from soil sources (mg/100 g soil).

| | Mg mg/100 g soil | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mg uptake | Change in the soil (start-end) | | | — uptake of not extractable + fixed in not extractable | | |
| | | Amm. acet. | $CaCl_2$ | KCl | Amm. acet. | $CaCl_2$ | KCl |
| $N_1$ | | | | | | | |
| 1. Finesand | 1,42 | 0,92 | 0,64 | 0,71 | —0,50 | —0,78 | —0,71 |
| 2. Finesand | 4,08 | 5,22 | 3,22 | 3,99 | 1,14 | —0,86 | —0,09 |
| 3. Very finesand | 5,16 | 5,72 | 5,18 | 6,90 | 0,56 | 0,02 | 1,74 |
| 4. Muddy silt | 3,89 | 5,29 | 3,54 | 3,60 | 1.40 | —0,35 | —0,29 |
| 5. Silty clay | 4,58 | 5,68 | 4,05 | 5,60 | 1,10 | —0.53 | 1,02 |
| 6. Sandy clay | 7,17 | 10,43 | 5,17 | 7,30 | 3,26 | —2,00 | 0,13 |
| 7. Sandy clay | 6,32 | 13,57 | 6,15 | 13,02 | 7,25 | —0,17 | 6,70 |
| 8. Silty clay | 4,14 | 4,02 | 1,67 | 3,18 | —0,12 | —2,47 | —0,96 |
| 9. Heavy clay | 12,76 | 21,09 | 10,42 | 17,95 | 8,33 | —2,34 | 5,19 |
| $N_2$ | | | | | | | |
| 1. Finesand | 1,63 | 0,83 | 0,61 | 0,64 | —0,80 | —1,02 | —0,99 |
| 2. Finesand | 5,70 | 6,39 | 3,99 | 5,03 | 0,69 | —1,71 | —0,67 |
| 3. Very finesand | 7,14 | 8,30 | 7,29 | 9,35 | 1,16 | 0,15 | 2,21 |
| 4. Muddy silt | 4,50 | 5,17 | 3,54 | 3,73 | 0,67 | —0,96 | —0,77 |
| 5. Silty clay | 5,80 | 7,31 | 5,22 | 7,43 | 1,51 | —0,58 | 1,63 |
| 6. Sandy clay | 12,58 | 15,40 | 8,40 | 10,13 | 2,82 | —4,18 | —2,45 |
| 7. Sandy clay | 11,37 | 15,24 | 7,50 | 15,35 | 3,87 | —3,87 | 3,98 |
| 8. Silty clay | 4,95 | 4,20 | 2,08 | 4,73 | —0,75 | —2,87 | —0,22 |
| 9. Heavy clay | 24,54 | 30,75 | 14,83 | 26,63 | 6,21 | —9,71 | 2,09 |

magnesium reserves of the soil. On very finesand ryegrass took up only that magnesium extractable in $CaCl_2$, which accounted for more than 81 % of the ammonium acetate extarctable magnesium content at start of the experiment.

More magnesium was removed along with yields grown on finesand (1) and silty clay (8) than indicated by the change in the ammonium acetate extractable magnesium during the experiment. This suggests that ryegrass took up »non-exchangeable» magnesium, particularly at the higher nitrogen level.

On seven soils the magnesium uptake was less than the change in ammonium acetate extractable magnesium content during the experiment. This would seem to indicate that exchangeable magnesium may be fixed in a »non-exchangeable» form. In the case of unlimed soils (very finesand and silty clays) the amount of magnesium possibly converted in a »non-exchangeable« form constituted at most 9 % of the original exchangeable magnesium content of the soil. Relatively taking, the greatest conversion of exchangeable magnesium to »non-exchange-

Table 4. The fertilizer magnesium uptake by ryegrass, the changes in the ammonium acetate (1 M, pH 7) extractable magnesium contents of the soils during the pot experiment (start-end) and the fixation of fertilizer magnesium to »non-exchangeable» (mg/100 g soil, $Mg_1$—$Mg_0$).

| | Mg fertilization | $Mg_1$—$Mg_0$ | | | |
|---|---|---|---|---|---|
| | | Mg uptake | Change in soil (start-end) | Fixed in »non-exchangeable» | |
| | | | | mg | % |
| $N_1$ | | | | | |
| 1. Finesand ........ | 10,87 | 1,21 | 4,98 | 3,77 | 35 |
| 2. Finesand ........ | 12,45 | 1,00 | 4,97 | 3,97 | 32 |
| 3. Very finesand .... | 7,48 | 1,41 | 1,78 | 0,37 | 5 |
| 4. Muddy silt ...... | 15,79 | 2,65 | 5,83 | 3,18 | 20 |
| 5. Silty clay ....... | 9,93 | 1,16 | 2,29 | 1,13 | 11 |
| 6. Sandy clay ...... | 15,47 | 0,26 | 3,22 | 2,96 | 19 |
| 7. Sandy clay ...... | 11,81 | —0,19 | 3,23 | 3,42 | 29 |
| 8. Silty clay ........ | 8,51 | 0,04 | 2,45 | 2,41 | 28 |
| 9. Heavy clay ...... | 22,22 | 0,36 | 5,33 | 4,97 | 22 |
| $N_2$ | | | | | |
| 1. Finesand ........ | 10,87 | 4,26 | 7,07 | 2,81 | 26 |
| 2. Finesand ........ | 12,45 | 4,21 | 6,10 | 1,89 | 15 |
| 3. Very finesand .... | 7,48 | 2,78 | 3,85 | 1,07 | 14 |
| 4. Muddy silt ...... | 15,79 | 6,16 | 9,86 | 3,70 | 23 |
| 5. Silty clay ........ | 9,93 | 6,16 | 6,67 | 0,51 | 5 |
| 6. Sandy clay ...... | 15,47 | 2,10 | 3,83 | 1,73 | 11 |
| 7. Sandy clay ...... | 11,81 | 0,22 | 4,14 | 3,92 | 33 |
| 8. Silty clay ........ | 8,51 | 3,39 | 4,51 | 1,12 | 13 |
| 9. Heavy clay ...... | 22,22 | 1,20 | 4,43 | 3,23 | 15 |

able» seemed to take place in heavily limed muddy silt, accounting for almost 21 % of the initially exchangeable magnesium. A slight fall in the amount of exchangeable magnesium conversion into a »non-exchangeable» form was seen in six of the seven soils, when the amount of nitrogen fertilization was increased; the exception being very finesand. Leaching of magnesium from the soil during the experiment does not seem likely, since the water percolating through the soil was collected and returned to the plants.

There was a high correlation (r = 0,97**, n = 18) between the magnesium uptake by ryegrass and the ammonium acetate (1 M, pH 7) extractable magnesium content of the soil. The magnesium uptake was also close correlative with the 1 M KCl extractable magnesium in the soil (r = 0,95**), as well as with the 0,01 M $CaCl_2$ extractable magnesium.

In the case of soils to which magnesium fertilization was applied, the total magnesium uptake was less than the difference between (initially exchangeable magnesium+fertilizer magnesium) and the exchangeable magnesium at the end of the experiment (Table 4). Even the fertilizer magnesium appears to be converted into ammonium acetate not-extractable form, a conversion that seemed to be greater at the lower nitrogen level than at the higher. A greater proportion of

Table 5. The ammonium acetate (1 M, pH 7) extractable calcium and potassium contents of the soils (mg/100 g), the equivalent ratio Ca/Mg in the soils and the 1 M KCl extractable (Al+H) content (me/100 g) of the soils at the end of the pot experiment.

| | $N_1$ | $N_1Mg$ | $N_2$ | $N_2Mg$ |
|---|---|---|---|---|
| | Ca mg/100 g soil | | | |
| 1. Finesand .... | 123$^{a}$ | 103$^{a}$ | 115$^{a}$ | 94$^{a}$ |
| 2. Finesand .... | 205$^{a}$ | 210$^{a}$ | 192$^{a}$ | 215$^{a}$ |
| 3. Very finesand | 76$^{b}$ | 75$^{b}$ | 67$^{a}$ | 69$^{ab}$ |
| 4. Muddy silt ... | 316$^{b}$ | 320$^{b}$ | 262$^{a}$ | 276$^{a}$ |
| 5. Silty clay .... | 133$^{b}$ | 129$^{ab}$ | 119$^{a}$ | 121$^{a}$ |
| 6. Sandy clay ... | 343$^{a}$ | 346$^{a}$ | 327$^{a}$ | 325$^{a}$ |
| 7. Sandy clay ... | 343$^{a}$ | 354$^{a}$ | 353$^{a}$ | 348$^{a}$ |
| 8. Silty clay .... | 372$^{b}$ | 357$^{a}$ | 356$^{a}$ | 355$^{a}$ |
| 9. Heavy clay ... | 481$^{a}$ | 455$^{a}$ | 473$^{a}$ | 472$^{a}$ |
| | K mg/100 g soil | | | |
| 1. Finesand .... | 8,2$^{b}$ | 7,0$^{ab}$ | 5,4$^{ab}$ | 2,0$^{a}$ |
| 2. Finesand .... | 23,7$^{b}$ | 23,2$^{b}$ | 8,8$^{a}$ | 11,2$^{a}$ |
| 3. Very finesand | 3,2$^{a}$ | 3,0$^{a}$ | 2,7$^{a}$ | 2,8$^{a}$ |
| 4. Muddy silt ... | 9,3$^{ab}$ | 9,8$^{b}$ | 8,9$^{ab}$ | 6,5$^{a}$ |
| 5. Silty clay .... | 5,9$^{c}$ | 6,4$^{c}$ | 3,9$^{a}$ | 5,1$^{b}$ |
| 6. Sandy clay ... | 12,3$^{b}$ | 12,3$^{b}$ | 8,6$^{a}$ | 9,3$^{a}$ |
| 7. Sandy clay ... | 23,5$^{b}$ | 26,5$^{c}$ | 17,0$^{a}$ | 19,0$^{a}$ |
| 8. Silty clay .... | 16,3$^{b}$ | 16,1$^{b}$ | 15,7$^{ab}$ | 13,8$^{a}$ |
| 9. Heavy clay ... | 17,2$^{ab}$ | 17,8$^{b}$ | 16,5$^{a}$ | 17,3$^{ab}$ |
| | Equivalent ratio Ca/Mg | | | |
| 1. Finesand .... | 152,8$^{b}$ | 9,8$^{a}$ | 144,0$^{b}$ | 13,4$^{a}$ |
| 2. Finesand .... | 73,1$^{b}$ | 14,0$^{a}$ | 191,4$^{c}$ | 18,8$^{a}$ |
| 3. Very finesand | 4,9$^{c}$ | 3,0$^{a}$ | 5,8$^{d}$ | 4,0$^{b}$ |
| 4. Muddy silt ... | 131,4$^{c}$ | 17,1$^{a}$ | 100,4$^{b}$ | 22,5$^{a}$ |
| 5. Silty clay .... | 12,6$^{c}$ | 5,6$^{a}$ | 14,8$^{d}$ | 9,2$^{b}$ |
| 6. Sandy clay ... | 14,8$^{c}$ | 8,2$^{a}$ | 24,0$^{d}$ | 9,9$^{b}$ |
| 7. Sandy clay ... | 5,4$^{b}$ | 4,5$^{a}$ | 5,8$^{c}$ | 4,7$^{a}$ |
| 8. Silty clay .... | 7,5$^{c}$ | 6,0$^{a}$ | 7,3$^{c}$ | 6,4$^{b}$ |
| 9. Heavy clay ... | 5,0$^{c}$ | 3,7$^{a}$ | 6,0$^{d}$ | 4,3$^{b}$ |
| | (Al+H) me/100 g soil | | | |
| 1. Finesand .... | 0,40$^{a}$ | 0,40$^{a}$ | 0,66$^{a}$ | 0,59$^{a}$ |
| 2. Finesand .... | 0,41$^{a}$ | 0,40$^{a}$ | 0,53$^{b}$ | 0,50$^{b}$ |
| 3. Very finesand | 1,26$^{a}$ | 1,23$^{a}$ | 1,79$^{b}$ | 1,63$^{b}$ |
| 4. Muddy silt ... | 0,66$^{a}$ | 0,62$^{a}$ | 2,43$^{c}$ | 1,15$^{b}$ |
| 5. Silty clay .... | 2,29$^{a}$ | 2,19$^{a}$ | 3,28$^{b}$ | 2,89$^{b}$ |
| 6. Sandy clay ... | 0,39$^{a}$ | 0,37$^{a}$ | 0,62$^{b}$ | 0,57$^{b}$ |
| 7. Sandy clay ... | 0,48$^{a}$ | 0,43$^{a}$ | 0,61$^{b}$ | 0,62$^{b}$ |
| 8. Silty clay .... | 0,29$^{a}$ | 0,29$^{a}$ | 0,35$^{b}$ | 0,33$^{ab}$ |
| 9. Heavy clay ... | 0,29$^{a}$ | 0,41$^{ab}$ | 0,63$^{c}$ | 0,58$^{bc}$ |

fertilizer magnesium was fixed in the »non-exchangeable» form in limed soils than in unlimed soils.

## Other characteristics

At the end of the experiment the pH($CaCl_2$) of all soils was significantly lower at the $N_2$ level than at the $N_1$ level (results not presented). The pH values for muddy silt were 4,4 and 5,1 and for silty clay (8) 5,5 and 5,9 at the $N_2$ and $N_1$ levels respectively. These also represent the highest and lowest values obtained in the entire material. Magnesium fertilization had no significant effect on the soil acidity at either of the two nitrogen levels.

At the end of the experiment the ammonium acetate (1 M, pH 7) extractable calcium content of the limed soils were higher than at the start (Table 5), whereas there was little change for the unlimed soils. Monocalcium phosphate applied as phosphorus fertilizer supplied the soil with 4,5—6,2 mg/100 g calcium yearly. At lower nitrogen level, the calcium uptake by ryegrass was equal to the calcium supplied annually in the phosphorus fertilizer.

The neutral ammonium acetate extractable potassium content of the soils was at the end of the experiment significantly less at the higher nitrogen level than at the lower (Table 5). The differences between the exchangeable potassium contents of the soil are explained by the potassium uptake by ryegrass.

The Ca/Mg equivalent ratio was high at the start of the experiment in finesands and sandy clay (6). The first liming of the soil, and the total amounts of calcium given during the experiment caused the following changes in the Ca/Mg ratio when magnesium fertilization was not applied:

| | Ca me/100 g soil | | | Ca/Mg | |
|---|---|---|---|---|---|
| | In soil at start | 1st liming | 2nd liming | Soil + 1st liming | Soil + both limings |
| 1. Finesand .... | 1,1 | 2,2 | 4,3 | 30,0 | 69,0 |
| 2. Finesand .... | 6,9 | 2,5 | 5,0 | 16,5 | 25,3 |
| 4. Muddy silt .. | 3,0 | 9,5 | 6,3 | 22,7 | 34,2 |
| 6. Sandy clay .. | 14,1 | 2,3 | 2,3 | 8,4 | 9,6 |
| 7. Sandy clay .. | 11,4 | 2,4 | 4,7 | 3,2 | 4,3 |
| 9. Heavy clay .. | 18,7 | 2,7 | 2,7 | 3,3 | 3,7 |

The first liming caused the ratio Ca/Mg to become abnormally high in finesands and muddy silt. The amounts of calcium removed from these soils along with the ryegrass yields were at most 2 me/100 g soil throughout the experiment, i.e. an average of 0,7 me/100 g per year. The second liming applied two years later again changed the ratio of these two nutrients unfavorably.

When magnesium fertilizer was not applied, the soils contained over 100 times more calcium than magnesium at the end of the experiment (Table 5). The amount of magnesium fertilizer in the experiment was not sufficient, since the Ca/Mg equivalent ratio was higher at the end of the experiment than at the start.

As a result of liming, finesand soils, muddy silt and sandy clay (7) contained less 1 M KCl extractable (Al+H) at the end of the experiment than at the start. In the case of unlimed very finesand the (Al+H) content increased, though this was not found to be case with silty clays. With exception of finesands, all the soils contained significantly more (Al+H) at the end of the experiment at the $N_2$ level than at the $N_1$ level (Table 5). At the $N_2$ nitrogen level, application of magnesium fertilizer lowered the exchangeable (Al+H) content in muddy silt. Without magnesium fertilizer, the ryegrass yields on muddy silt was small in final year, and most of the fertilizer nitrogen remained in the soil, in which the $H^+$ ion level increased as a result of nitrification.

## DISCUSSION

This pot experiment suggests that ammonium acetate (1 M, pH 7) extractable magnesium in the soil may be the main source of magnesium for ryegrass, since the amount of magnesium taken up plants showed a close correlation with the change in soil magnesium content that took place during the experiment (start—end). A similar result was obtained by LOMBIN and FAYEMI (1976) with maize, and by SHADFAN (1976) in a pot experiment with ryegrass, when the indicator of magnesium availability was the amount of magnesium taken up by the plants. ALSTON (1972) found a low correlation between the exchangeable magnesium content of the soil and the ryegrass magnesium content, and that the exchangeable magnesium does not, therefore, depict the amount of soil magnesium available to the plants. According to SCHACHTSCHABEL (1956), the best indicator of the amount of magnesium available to the plants is the amount of magnesium extractable in 0,01 M $CaCl_2$, on the basis of the magnesium content of the plants. Even at the lower nitrogen level, the ryegrass in this pot experiment took up more magnesium than could be accounted for by the change in the $CaCl_2$ extractable magnesium content of the soil during the experiment. An exception were the results of very finesand, from which the ryegrass took up almost exclusively magnesium extractable in 0,01 M $CaCl_2$.

Without magnesium fertilization the change in the exchangeable magnesium content of the seven soils during the experiment was greater than the magnesium uptake by ryegrass. Some of the magnesium taken up by plants is, perhaps, unaccounted for, since the magnesium content of the roots not analysed. The soil samples, on the other hand, contained some of the roots. Leaching had no effect on the results, since the water percolating through the soils was collected and returned daily to the plants.

One reason for the pronounced decrease in ammonium acetate extractable magnesium content of sandy clays and heavy clay may be the fixation of exchangeable magnesium in a »nonexchangeable» form as a result of liming (KAILA 1974, EDMEADES and JUDD 1980). Some of the fertilizer magnesium also failed to extract in ammonium acetate in limed soils (McLEAN and CARBONELL 1972, JUO and UZU 1977). The results of the incubation experiment performed with the soils of this pot experiment confirm these assumptions to be valid (JOKINEN 1981 b). The amount of fixed magnesium appeared to be greater at the lower nitrogen level than at the higher level, which may indicate that at least some of the fixed magnesium was available to ryegrass. According to MOKWUNYE and MELSTED (1973), magnesium not extractable in ammonium acetate is on the exchange sites of the soil.

At the higher nitrogen level the ryegrass took up only slightly more magnesium from silty clays than at the lower nitrogen level, while the magnesium uptake from sandy clays and heavy clay almost doubled. The reason for the different amounts of magnesium taken up from the various clay soils appears to be the increase in exchangeable magnesium content with an increase in the amount of clay fraction ($<2\mu$, KAILA 1973, SIPPOLA 1974), and the fall in exchangeable magnesium content with an increase in the silt fraction (2—20 $\mu$, JOKINEN 1981 c). However, CHRISTENSON and DOLL (1973) found the magnesium uptake by oats harvested before they were ripe in a pot experiment to be almost the same from the clay fraction ($< 2\mu$) and from the silt fraction (2—20 $\mu$), which would seem to contradict the result obtained in the present pot experiment.

In addition to the differences in the clay and silt fraction contents of the clay soils the other properties of these soils may have an effect on the magnesium uptake by ryegrass. In the acid silty clay the high (Al+H) content might decrease the magnesium uptake (HUETT and MENARY 1980). In the near neutral silty clay the ammonium acetate extractable magnesium content was low because of high pH. The extremely high equivalent ratio Ca/Mg in finesands and muddy silt may decrease the magnesium uptake (MORGAN and JACKSON 1976).

Ryegrass was able to take up »non-exchangeable» magnesium fiom acid finesand and from near neutral silty clay (SALMON and ARNOLD 1963, HENRIKSEN 1971, CHRINTENSON and DOLL 1978), although the uptake was low (KAILA and KETTUNEN 1973, MOKWUNYE and MELSTED 1973). The finesand was limed twice during the experiment, and this may have caused the conversion of »non-exchangeable» magnesium to exchangeable (ALSTON 1966). An incubation experiment performed in the laboratory with the same soils indicated an increase in the ammonium acetate (1 M, pH 7) extractable magnesium content due to liming (JOKINEN 1981 b).

The favorable effect of the higher ammonium nitrate level on the magnesium uptake by ryegrass from clay soils may be in a small part due to cation exchange between ammonium and magnesium in the soil. In field experiments with ammonium nitrate LUTZ et al. (1977) found that the higher $NO_3$-N content of soil solution was invariably accompanied by higher calcium and magnesium concentrations in soils.

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## SELOSTUS

### Kahden typpilannoitemäärän vaikutus raiheinän kykyyn ottaa maan magnesiumia ja lannoitteen magnesiumia yhdeksästä kivennäismaasta II. Maiden magnesiumpitoisuus.

RAILI JOKINEN

Maatalouden tutkimuskeskus

Astiakokein tutkittiin kahdella typpilannoituksen tasolla ($N_1$ = 1500 mg/ast, $N_2$ = 3000 mg/ast N vuodessa, $NH_4NO_3$:na) raiheinän (*Lolium multiflorum*) maasta tai lannoitteesta (200 mg/ast Mg vuodessa, $MgSO_4 \cdot 7H_2O$:na) ottamaa magnesiummäärää ja sen vaikutusta yhdeksän kivennäismaan ravinnetilaan. Kuusi maata kalkittiin kalsiumkarbonaatilla raiheinän kasvun turvaamiseksi.

Raiheinän pääasiallisin magnesiumin lähde näytti olevan maan vaihtuva magnesium, sillä kasvustojen magnesiumin oton ja maasta 1 M ammoniumasetaattiin (pH 7) uuttuvan magnesiumpitoisuuden välinen korrelaatio oli korkea ($r = 0{,}97^{**}$, $n = 18$). Magnesiumin oton ja 1 M KCl uuttuvan magnesiumpitoisuuden välinen vuorosuhde oli myös kiinteä ($r = 0{,}95^{**}$), samoin kuin magnesiumin oton riippuvuus 0,01 M $CaCl_2$ uuttuvan magnesiumin määrästä ($r = 0{,}94^{**}$).

Kolmessa savimaassa typpilannoitemäärän lisäys tehosti raiheinän magnesiumin ottoa ja se näkyi merkitsevänä maan $CaCl_2$ (0,01 M) tai ammoniumasetaattiin (1 M, pH 7) uuttuvan magnesiumpitoisuuden alenemisena. Vastaavaa ei todettu kahdessa savimaassa todennäköisesti magnesiumin pidättymisen vuoksi eikä kolmessa karkeassa kivennäismaassa magnesiumvarojen niukkuuden vuoksi.

Kalkituissa maissa osa maan magnesiumvaroista samoin kuin lannoituksena annetusta magnesiumista ehkä pidättyi ammoniumasetaattiin uuttumattomaksi, sillä maan magnesiumpitoisuuden alenema koeaikana oli suurempi kuin raiheinän ottama magnesiummäärä. Suuremmalla typpilannoituksen tasolla raiheinä saattoi ottaa pidättynyttä magnesiumia.

Kalsiumkarbonaattina annettu kalkitus kohotti ekvivalenttisuhteen Ca/Mg muutamissa karkeissa kivennäismaissa erittäin korkeaksi, mikä saattoi osittain vaikeuttaa raiheinän magnesiumin ottoa.

ANNALES AGRICULTURAE FENNIAE, VOL. 20: 253—260 (1981)

Seria AGROGEOLOGIA ET -CHIMICA N. 107 — Sarja MAA JA LANNOITUS n:o 107

# THE EFFECT OF HEAT TREATMENT AND IONIZING IRRADIATION ON THE EXTRACTABILITY OF SOME MACRO- AND MICRONUTRIENTS IN SOILS

Väinö Mäntylahti and Toivo Yläranta

Mäntylahti, V. & Yläranta, T. 1981. **The effect of heat treatment and ionizing irradiation on the extractability of some macro- and micronutrients in soils.** Ann. Agric. Fenn. 20: 253—260. (Agric. Res. Centre, Inst. Soil Sci., SF-31600 JOKIOINEN, Finland).

The effect of heat treatment, germicidal and gamma irradiation on the contents of macro- and micronutrients extractable from five mineral soils were studied. Calcium, magnesium, potassium and phosphorus were extracted with acid ammonium acetate, and iron, manganese, zinc and copper with acid ammonium acetate containing ethylenediaminetetraacetic acid (EDTA). Boron was extracted with hot water.

In about 25 % of cases, heat treatment at 60°C for 2 h resulted in a decrease in the contents of extractable nutrients, in 45 % of cases there was no effect, and in 30 % it resulted in an increase in extractable nutrient contents. For the macronutrients, the largest changes were about ±25 % and for the micronutrients about ±20 %.

Germicidal irradiation, provided by an Airam LU 30 W disinfection lamp at a distance of 40 cm for 7 d, depressed the contents of extractable nutrients in about 25 % of cases, in 30 % there was no effect, and in 50 % of cases it increased contents. The effects of germicidal irradiation were greater than those of the heat treatment.

In about 35 % of cases, gamma irradiation at 4 Mrad resulted in a fall in contents of extractable nutrients, in 20 % of the samples there was no effect and in 50 % an increase in extractable nutrients resulted. In the extreme cases, the increase in contents of iron, magnesium and manganese amounted to 100—140 % of the control. In soils subjected to gamma irradiation, changes in nutrient contents were generally larger than in soils receiving heat treatment or germicidal irradiation.

Index words: Heat treatment, germicidal irradiation, gamma irradiation, extractable nutrients.

## INTRODUCTION

The soil micro-organisms and the enzymes they produce constitute a mechanism regulating the contents of soil nutrients available to plants. They break down the mineral constituents of the plough layer, and through their agency nutrients bound to soil organic matter are released in a form available to plants. As a result of microbial and enzymatic activities, nutrients are released catalytically, metabolically or, through the action of metabolic products, chemically (Schatz 1962, Duff et al. 1963, Silverman and Ehrlich 1964).

A condition for studying the interactions between micro-organisms, enzymes, soil and plants is the progressive and complete inactivation of e.g. enzymes and microbes in such a way that the chemical properties of the soil are minimally affected (NEWMAN et al. 1977). For example, nitrogen assimilation in plants, the dispersal adaptation and pathogenicity of microbes, as well as the effect of microbes or microbial enzymes on nutrient contents extractable from the soil, or upon the degree of oxidation of soil nutrients, can be investigated only after progressive inactivation of the micro-organisms and enzymes in the soil. To this end, workers have generally used heat, chemicals or ionizing radiation (McLAREN et al. 1957, BOWEN and CAWSE 1962, ENO and POPENOE 1964, SALAMA et al. 1973 a, b, NEWMAN et al. 1977, LAW 1979).

Many soil enzymes are inactivated by as little as 60—70 °C, although complete denaturation only occurs at 180 °C (GALSTYAN 1965). Heat treatment alters the contents of nutrients extractable from the soil (FUJIMOTO and SHERMAN 1945, 1948, BOWEN and CAWSE 1962, ENO and POPENOE 1964, NELSON 1977). As a result of the treatment, the soil may display toxic characters, some of which are caused by excessive contents of extractable nutrients (PETERSON 1962, SKYRING and THOMPSON 1966, SALONIUS et al. 1967).

The chemical inactivation of soil microbes and enzymes (for example with methyl bromide or chloropicrin) gives rise to similar changes in nutrient contents to those brought about by heat treatment (ENO and POPENOE 1964, NELSON 1977, NEWMAN et al. 1977).

As well as for atmospheric sterilization, germicidal irradiation is also used, for instance, for the purification of irrigation water (ROBINSON and ADAMS 1978) and to induce changes in the guanine and cytosine contents of strains of *Rhizobium* bacteria (SINGER and AMES 1970, LAW 1979). Germicidal irradiation has seemingly been used for the inactivation of soil microbes and enzymes to only a limited extent, owing to the low energy of this form of radiation.

Gamma radiation is used to a considerable extent for the partial or complete inactivation of soil enzymes and microbes. The method is well suited to the selective inactivation of microbes and to the investigation of enzymatic action in the absence of microbes (McLAREN et al. 1962, VOETS et al. 1965, SKUJINS 1967, p. 372, ROBERGE and KNOWLES 1968, SKUJINS and McLAREN 1969, CAWSE 1975, p. 228). Gamma irradiation gives rise to changes in contents of extractable nutrients in the soil (BOWEN and CAWSE 1962, 1964, ENO and POPENOE 1963, 1964, CAWSE 1967; CAWSE and CRAWFORD 1967).

The aim of the present study is to clarify how heat treatment, germicidal irradiation and gamma irradiation treatment influence contents of nutrients extractable from the soil. The extraction methods used were those generally employed for soil macro- and micronutrients in Finland.

## MATERIAL AND METHODS

The study material consisted of five mineral soil samples (0—20 cm) collected from southern Finnish fields used for cereal cultivation. The physical and chemical properties of the samples are shown in Table 1. Soil 1 and 3 were very similar in fractional composition, being sandy clays. Soils 4 and 5 were both finesandy silts. Soil 2 was distinctly coarser than the others, a finesand. Soils 1, 2, 4 and 5 held roughly similar contents of organic carbon (4,0—5,6 %).

Values for pH($CaCl_2$) were determined on 0,01 M $CaCl_2$ suspensions (v/v 1 : 2,5) of the samples after standing for 24 hours. The samples were stirred before measurement. Organic carbon was determined using an adapted version (GRAHAM 1948) of ALTEN's wet digestion method. The fractional composition was evaluated by the pipette method of ELONEN (1971).

The macronutrients Ca, Mg, K and P were extracted from the soils with acid ammonium

Table 1. The pH($CaCl_2$), organic carbon content and fractional composition of inorganic constituents of the soils.

| Soil sample | pH ($CaCl_2$) | Org. C % | Fractional composition, % | | | |
|---|---|---|---|---|---|---|
| | | | <0,002 mm | 0,002—0,02 mm | 0,02—0,2 mm | 0,2—2 mm |
| 1 ...... | 5,6 | 5,6 | 38 | 22 | 38 | 2 |
| 2 ...... | 5,8 | 4,6 | 8 | 5 | 78 | 9 |
| 3 ...... | 5,2 | 1,7 | 46 | 23 | 28 | 3 |
| 4 ...... | 4,7 | 4,0 | 15 | 40 | 30 | 15 |
| 5 ...... | 5,6 | 4,6 | 23 | 40 | 26 | 11 |

acetate (0,5 M $CH_3COONH_4$, 0,5 M $CH_3COOH$, pH 4,65). The extraction ratio was 1 : 10 (w/v) as specified in the soil testing method of VUORINEN and MÄKITIE (1955).

The micronutrients Fe, Mn, Zn and Cu were extracted in a 1 : 10 (w/v) soil/extractant ratio with acid ammonium acetate to which had been added EDTA (0,5 M $CH_3COONH_4$, 0,5 M $CH_3COOH$, pH 4,65, 0,02 M $Na_2EDTA$, LAKANEN and ERVIÖ 1971).

Boron was extracted from the soil with a modification (TARES and SIPPOLA 1978) of the hot water extraction method of BERGER and TRUOG and was determined spectrophotometrically by the azomethine H-method (SIPPOLA and ERVIÖ 1977).

On each soil sample, four paralled extractions of macro- and micronutrients were made.

Air-dry soil samples (ø ≤ 2 mm) were used for the study.

For the heat treatment the samples, held in one liter beakers and with a thermometer in the middle of each, were put in a drying oven. The temperature of the oven was raised to 60 °C and the samples were maintained at this temperature for two hours, starting from when the thermometer indicated 60 °C. The drying oven was then switched off, and the samples were allowed to cool to room temperature.

The germicidal irradiation of the experimental soils was performed with an Airam LU 30 W disinfection lamp, of whose radiation most, 90—95 % of the total, is emitted at a wavelength of 253,7 nm (Tables 2 and 3 UV). The soil samples were spread out in an approx. 1 cm layer on a watchglass (ø 35 cm). The radiation source, fitted with a reflective cylindrical parabolic aluminium shield, was set 40 cm above the soil samples. The samples were perturbed daily to expose as large a sample area as possible to the germicidal radiation during the 7 day treatment period.

Gamma irradiation of the soil samples was caused out with $^{60}Co$ (cobalt source of the Dept. Radiochemistry, Univ. of Helsinki). The radiation intensity was adjusted to a level whereby the samples absorbed 4 Mrad ($10^4$ J/kg) of energy during a 2,5 day period.

For the comparison of the means of the results obtained through the experiments, DUNCAN's (1955) test was applied at the 95 per cent confidence level. Significant differences between the quantities reported in the tables as means of the treatment replications are marked down as the upper index letters of each quantity. Those quantities that do not have the same letter in the upper index deviate from each other at a confidence level of 95 per cent.

## RESULTS

### Macronutrients

The differences in acid ammonium acetate-extractable nutrient contents were large both between soils and treatments. The highest calcium content, nearly 3000 mg/kg of soil, was extracted from soil no. 1 (Table 2) and the lowest, about 500 mg/kg, from soil no. 4. Soil 4 also released the least Mg, about 20 mg/kg, which amounted to only a tenth of the maximium Mg content extracted (from soil 3). Likewise, the variation in calcium content was 8-fold. The least potassium was extractable from soil 4, about 40 mg/kg and the most from soil 1, around

Table 2. The effects of heat treatment and of irradiation on acid ammonium acetate-extractable macronutrients. In each sample values with the same letter suffix do not differ significantly at P = 0,05. A separate test (four replicates) was made for each experimental soil and nutrient.

| Soil sample | Treatment | Extractable nutrients mg/kg of air-dry soil | | | |
|---|---|---|---|---|---|
| | | Ca | Mg | K | P |
| 1 | 0 | 2 850 b | 147 a | 360 a | 14,8 a |
| | 60 °C | 2 870 b | 148 a | 359 ab | 13,0 b |
| | UV | 2 960 a | 143 b | 295 c | 16,1 a |
| | $^{60}$Co | 2 780 c | 149 a | 351 b | 11,0 c |
| 2 | 0 | 2 090 a | 117 b | 51 c | 3,4 a |
| | 60 °C | 2 180 a | 123 ab | 53 c | 2,5 b |
| | UV | 2 230 a | 127 a | 58 b | 2,7 b |
| | $^{60}$Co | 2 150 a | 128 a | 67 a | 2,7 b |
| 3 | 0 | 1 060 d | 204 d | 177 d | 2,3 a |
| | 60 °C | 1 130 c | 234 c | 181 c | 1,7 b |
| | UV | 1 180 b | 282 b | 193 b | 1,5 b |
| | $^{60}$Co | 1 420 a | 456 a | 210 a | 1,8 b |
| 4 | 0 | 496 ab | 20,4 a | 44 a | 4,2 b |
| | 60 °C | 492 b | 20,9 a | 34 b | 4,5 a |
| | UV | 503 a | 20,5 a | 44 a | 4,2 b |
| | $^{60}$Co | 467 c | 19,5 a | 43 a | 3,5 c |
| 5 | 0 | 2 050 b | 91,4 ab | 209 b | 29,8 ab |
| | 60 °C | 1 990 c | 90,1 bc | 207 b | 28,0 b |
| | UV | 2 120 a | 92,5 a | 196 c | 30,1 ab |
| | $^{60}$Co | 2 110 a | 89,3 c | 217 a | 32,7 a |

350 mg/kg. The highest content of phosphorus, about 30 mg/kg was released from soil 5 and the lowest, 2 mg/kg from soil 3.

Heat treatment of the soils scarcely affected contents of extractable calcium. In one instance the magnesium content rose by 15 % (soil 3). The content of extractable potassium fell by 23 % in soil 4. The treatment affected the content of extractable phosphorus in four of the experimental soils. In soil 4 there was a 7 % increase, while the largest decrease, 26 %, was found in soils 2 and 3.

Contents of extractable calcium increased as a result of germicidal irradiation in three of the soils. The largest increment was 11 % (soil 3). The magnesium content rose by 38 % in soil 3 and by 9 % in soil 2. Contents of extractable potassium altered in four soils. The largest decrease was 18 % (soil 1) and the largest increase 14 % (soil 2). Contents of phosphorus diminished in two of the soils, by 21 % in soil 2 and 35 % in soil 3.

As a result of gamma irradiation, the content of extractable calcium increased by 34 % in soil 3. In this soil, the magnesium content rose by 124 %, which was the greatest relative alteration in the content of a macronutrient in the entire material. The largest increase in extractable potassium content, 31 %, was found in soil 2. Phosphorus contents fell in four of the soils (soils 1—4) by 17—26 %.

## Micronutrients

The highest iron content of 2320 mg/kg of soil was extracted from the gamma irradiated treatment of soil 2 (Table 3). This content was about eight times as high as the lowest content found in soil 4. Likewise, the variation in manganese contents was 8-fold, ranging from a value of 9,4 mg/kg (soil 2) to 91,1 mg/kg (soil 5). The highest zinc content, about 6 mg/kg, was extracted from soils 1 and 2 and the lowest, 1,1 mg/kg, from soil 4. Extractable copper contents displayed the widest variation. Whereas soil 4 released less than 1 mg/kg, a copper content of 17 mg/kg was extracted from soil 1. Differences in extractable boron contents between different soils were two-fold. The largest amount of extractable boron, about 1 mg/kg, was found in soil 5.

Compared with the control, heat treatment resulted in a 21 % increase in extractable iron for soil 4, and a 19 % increase for soil 1. In the case of soil 4, extractable manganese increased by 20 % and in soil 2 by 13 %. The content of extractable zinc in soil 1 fell by 19 %. The copper content was reduced by 9 % in sample 1, but increased by 8 % in sample 4. The content of water-soluble boron showed a 20 % increase in soil 4.

Germicidal radiation affected a 46 % increase in the content of extractable iron in soil 2. The largest increments in manganese content, 82 % and in copper content, 13 %, occurred in soil 2. In this same soil, the content of extractable zinc rose by 22 %. In soil 3, the boron content increased by 14 %.

Table 3. The effects of heat treatment and of irradiation on contents of EDTA-acid ammonium acetate-extractable Fe, Mn, Zn and Cu and water-soluble boron in the soils. In each sample values with the same letter suffix do not differ significantly at P = 0,05. A separate test (four replicates) was made for each experimental soil and nutrient.

| Soil sample | Treatment | Extractable nutrients mg/kg of air-dry soil | | | | |
|---|---|---|---|---|---|---|
| | | B | Fe | Mn | Zn | Cu |
| 1 | 0 | 0,81$^{b}$ | 413$^{c}$ | 16,5$^{a}$ | 6,4$^{a}$ | 16,2$^{a}$ |
| | 60 °C | 0,73$^{c}$ | 490$^{b}$ | 15,2$^{b}$ | 5,2$^{c}$ | 14,8$^{b}$ |
| | UV | 0,86$^{a}$ | 570$^{a}$ | 16,7$^{a}$ | 6,0$^{b}$ | 17,0$^{a}$ |
| | $^{60}$Co | 0,76$^{c}$ | 495$^{b}$ | 16,4$^{a}$ | 5,1$^{c}$ | 14,0$^{b}$ |
| 2 | 0 | 0,66$^{c}$ | 1 187$^{d}$ | 9,4$^{d}$ | 5,1$^{b}$ | 4,8$^{b}$ |
| | 60 °C | 0,71$^{b}$ | 1 270$^{c}$ | 10,6$^{c}$ | 5,3$^{b}$ | 4,9$^{b}$ |
| | UV | 0,72$^{b}$ | 1 734$^{b}$ | 17,1$^{b}$ | 6,2$^{a}$ | 5,4$^{a}$ |
| | $^{60}$Co | 0,78$^{a}$ | 2 320$^{a}$ | 22,2$^{a}$ | 6,1$^{a}$ | 5,8$^{a}$ |
| 3 | 0 | 0,49$^{b}$ | 431$^{a}$ | 23,5$^{a}$ | 3,6$^{a}$ | 8,5$^{a}$ |
| | 60 °C | 0,53$^{a}$ | 417$^{b}$ | 22,6$^{a}$ | 3,5$^{b}$ | 8,4$^{a}$ |
| | UV | 0,56$^{a}$ | 410$^{b}$ | 22,9$^{a}$ | 3,3$^{c}$ | 8,1$^{b}$ |
| | $^{60}$Co | 0,44$^{c}$ | 355$^{c}$ | 20,4$^{b}$ | 2,5$^{d}$ | 7,5$^{c}$ |
| 4 | 0 | 0,41$^{b}$ | 144$^{d}$ | 25,5$^{c}$ | 1,1$^{b}$ | 0,90$^{b}$ |
| | 60 °C | 0,49$^{a}$ | 174$^{a}$ | 30,6$^{a}$ | 1,1$^{b}$ | 0,97$^{a}$ |
| | UV | 0,43$^{b}$ | 147$^{c}$ | 26,9$^{b}$ | 1,2$^{a}$ | 0,95$^{a}$ |
| | $^{60}$Co | 0,48$^{a}$ | 152$^{b}$ | 30,4$^{a}$ | 1,2$^{a}$ | 0,96$^{a}$ |
| 5 | 0 | 0,90$^{b}$ | 195$^{c}$ | 76,5$^{c}$ | 3,5$^{a}$ | 2,5$^{c}$ |
| | 60 °C | 0,88$^{b}$ | 199$^{c}$ | 77,2$^{c}$ | 3,5$^{a}$ | 2,5$^{c}$ |
| | UV | 0,93$^{b}$ | 224$^{b}$ | 82,6$^{b}$ | 3,5$^{a}$ | 2,6$^{b}$ |
| | $^{60}$Co | 1,03$^{a}$ | 249$^{a}$ | 91,1$^{a}$ | 3,5$^{a}$ | 2,7$^{a}$ |

Gamma irradiation resulted in a change in extractable iron contents of all the soils. Compared with the control, the alteration varied from an 18 % fall (soil 3) to a 95 % rise (soil 2). The treatment influenced the content of extractable manganese in four of the soils. The only case of a decrease in manganese content, 13 %, occurred in soil 3. The largest increase, 136 %, was found in soil 2. Likewise, the zinc content was affected in four soils, the variation ranging from a 31% fall (soil 3) to a 20 % rise (soil 2). The content of extractable copper altered in all the soils. In soil 1 the copper content fell by 14 %, and in soil 3 by 12 %. The largest increase in copper content, 21 %, occurred in soil 2. In soil 5, the content of water-extractable boron rose by 14 %, in soil 4 by 17 % and in soil 2 by 18 %, but fell in the case of soil 3 by 10 %.

## DISCUSSION

Mild heat treatment caused changes in extractable nutrient contents of the soils. Depending on the soil sample and nutrient being considered, the change with respect to the control was either negative or positive. For the macronutrients, the largest changes amounted to $\pm 20$ %. The literature bears several examples of an entrancing effect of heat treatment on extractable fractions (e.g. FUJIMOTO and SHERMAN 1945, NELSON 1977). The influence of extractant temperature is similar (SILLANPÄÄ 1977). According to NELSON (1977), a mild heat treatment may also depress the content of an extractable nutrient. As a result of steaming, extractable nutrient contents can be influenced negatively or positively, depending on the nutrient and soil type under consideration (e.g. BOWEN and CAWSE 1962, NELSON 1977).

Ultraviolet radiation is used for the destruction of micro-organisms, either by irradiation of the atmosphere, or of the object to be protected from microbial attack, such as foodstuffs or drugs (JÄRVINEN 1973). Wavelengths corresponding to germicidal radiation are used for the inactivation of microbes e.g. in irrigation water, too. Good results are obtained when the object of irradiation receives 0,1 J/cm$^{2}$ of energy. With the exception of certain species of *Aspergillus*; this dosage is sufficient to destroy micro-organisms (MPELKAS 1971). In the present study, the amounts of energy used to irradiate the soils were not measured, but in view of the experimental conditions and characteristics of the radiation source, the amount of energy intercepted by the soil samples amounted to at least 300 J/cm$^{2}$ (ANON. 1970, Mpelkas 1971, Järvinen 1973). This treatment had a variable effect on the contents of extractable nutrients. No clear trend could be made out, but the effects were nevertheless larger than those of the heat treatment (60 °C).

Most of the commonly used methods of sterilization (autoclaving, steaming, chemical treatment) are known to have a considerable effect on the contents of nutrients extractable from a soil (e.g. McLaren et al. 1957, Bowen and Cawse 1962, Nelson 1977, Newman et al. 1977). Besides influencing soil microbes and enzymes, such treatments affect nutrient contents of the soil by direct chemical action. One way to overcome this drawback is to inactivate the enzymes and micro-organisms with gamma radiation. A dose of 4—5 Mrad will destroy micro-organisms (the amount of energy absorbed then corresponds to $10^4$ J/kg). On the other hand, this dosage is not sufficient to inactivate all enzymes (McLaren et al. 1957, 1962, Voets et al. 1965, Roberge and Knowles 1968, Skujins and McLaren 1969). In our study, a radiation dosage of 4 Mrad either enhanced or lowered contents of nutrients extractable from the soils. The direction and intensity of change depended both on nutrient and soil sample being considered. In sample 3 (sandy clay low in humus), the extractable contents of all micronutrients fell, as compared with the control. By way of contrast, in soils 2 and 4 (humus-rich finesand and humus-rich silt) the contents of all micronutrients rose. No other consistent trends could be found in the material. In this respect, the present results are in agreement with those in the studies of McLaren et al. (1957), Stotzky and Mortensen (1959), Stanovick et al. (1961), Bowen and Cawse (1962, 1964), Eno and Popenoe (1963, 1964), Cawse (1967) and of Cawse and Crawford (1967).

On average, changes in extractable nutrient contents of gamma-irradiated soils were larger than in the samples subjected to heat treatment or germicidal wavelengths.

Owing to the intricacy of soil composition, the modes of action of heat treatment, germicidal radiation and gamma radiation are difficult to clarify. For example, germicidal radiation, being a low energy form of electromagnetic radiation, impinges only on the exposed surfaces of the soil sample. The final result is largely determined by how much of the sample surface area is exposed to irradiation. Gamma radiation emitted by a $^{60}Co$ source (1,17 and 1,33 MeV) is many times higher in energy than the germicidal radiation used here (5 eV, 253,7 nm), and the effects of gamma irradiation are not confined to the surface of the samples. During gamma irradiation, as well as primary reactions, there also occur secondary reactions. In addition, atmospheric oxygen and water held by the soil take part in the reactions. It is thus obvious that contents of extractable nutrients can vary according to the treatment, soil type and nutrient under consideration.

The present study demostrates that heat, germicidal irradiation and gamma irradiation treatments alter the extractable nutrient contents of soils. On the basic of these findings, it is not possible to gauge the direction and magnitude of the change. This fact should be borne in mind during the planning of e.g. pot experiments involning soil sterilization.

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## SELOSTUS

### Lämpökäsittelyn ja ionisoivan säteilyn vaikutus maasta uuttuvien ravinteiden pitoisuuksiin

Väinö Mäntylahti ja Toivo Yläranta

Maatalouden tutkimuskeskus

Maan mikro-organismit ja entsyymit säätelevät kasveille käyttökelpoisia maan ravinnepitoisuuksia. Ne rapauttavat muokkauskerroksen mineraaliainesta ja toisaalta niiden vaikutuksesta orgaaniseen ainekseen sitoituneet ravinteet vapautuvat kasveille käyttökelpoiseen muotoon.

Mikro-organismien, entsyymien sekä maan ja kasvin vuorovaikutuksen tutkiminen edellyttää usein entsyymien ja mikrobien asteittaista inaktivoimista siten, että maan kemialliset ja fysikaaliset ominaisuudet muuttuvat mahdollisimman vähän. Tähän tarkoitukseen käytetään yleisesti joko lämpöä, kemikaaleja tai säteilytystä.

Tässä työssä tutkittiin lämpökäsittelyn (60 °C, 2 h), germisidaalikäsittelyn (Airamin desinfektiolamppu LU 30 W) ja 4 Mrad gammasäteilytyskäsittelyn vaikutusta maasta uuttuviin makro- ja mikroravinteisiin. Makroravinteet (Ca, Mg, K ja P) uutettiin maasta happamalla ammoniumasetaatilla ja mikroravinteista Fe, Mn, Zn ja Cu hapan ammoniumasetaatti + EDTA -liuoksella sekä B kuumalla vedellä.

Lämpökäsittely laski noin 25 %:ssa tapauksista uuttuvan ravinteen pitoisuutta, 45 %:ssa tapauksista sillä ei ollut vaikutusta ja 30 %:ssa tapauksista se kohotti uuttuvan ravinteen pitoisuutta. Suurimmat muutokset olivat makroravinteissa $\pm 25$ % ja mikroravinteissa $\pm 20$ %.

Germisidaalisäteilytys laski noin 25 %:ssa tapauksista uuttuvan ravinteen pitoisuutta, 30 %:ssa sillä ei ollut vaikutusta ja 50 %:ssa tapauksista se kohotti uuttuvan ravinteen pitoisuutta. Germisidaalikäsittelyn vaikutukset olivat lämpökäsittelyn vaikutuksia suurempia.

Gammasäteilytys aiheutti noin 35 %:ssa tapauksista uuttuvien ravinteiden pitoisuuksien laskun, 20 %:ssa tapauksista sillä ei ollut vaikutusta ja 50 %:ssa näytteistä se aiheutti uuttuvan ravinnepitoisuuden kohoamisen. Rauta-, magnesium- ja mangaanipitoisuuksien kohoaminen oli suurimmillaan 100—140 % käsittelemättömään verrattuna. Gammakäsitellyissä maissa uuttuvien ravinteiden pitoisuuksien muutokset olivat keskimäärin suuremmat kuin lämpö- ja germisidaalikäsitellyissä näytteissä.

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Serie HORTICULTURA N. 46 — Sarja PUUTARHAVILJELY n:o 46

# INCIDENCE OF COLLAR ROT IN APPLE TREES IN FINLAND 1975—79

JAAKKO SÄKÖ and EEVA LAURINEN

SÄKÖ, J. & LAURINEN, E. 1981. **Incidence of collar rot in apple trees in Finland 1975—79.** Ann. Agric. Fenn. 20: 261—267. (Agric. Res. Centre, Inst. Hortic., 21500 Piikkiö 4, Finland.)

In 1975 and 1978 cases were reported in Finnish apple orchards of injuries to and death of trees which differed from the usual pattern of winter injuries. The trouble was identified as collar rot (crown rot), the agent of which is most widely considered to be the fungus *Phytophthora cactorum* (Leb. & Cohn) Schroet. The Horticultural Research Institute sent out a questionnaire about the incidence of the disease to apple farmers in South-West Finland, and replies were received from 15 commercial orchards. The data obtained covered a total of 30 547 apple trees.

It emerged that collar rot was more likely to strike mature, yield-bearing trees than young trees under 6 years old. Collar rot occurred most frequently in the variety Red Atlas, in which 18 % of the trees were infected. The other commercially valuable varieties were also however liable to infection, e.g. Åkerö (10 %), Transparente Blanche (6 %), Melba (5 %) and Lobo (3 %). The extent of damage varied from one orchard to another from around one per cent to over thirty per cent. No definite connection could be established between the incidence of the disease or extent of damage and the type of soil, gradient of the surface, or the orchard soil management. The greatest destruction occurred in the very wet years, when the level of moisture was high both in the atmosphere and in the soil.

Index words: Apple tree, collar rot, crown rot, weather.

## INTRODUCTION

During the 1975 season, damage was observed to be occurring to trees in apple orchards in Finland which could not be attributed to poor wintering. The disease involved has been termed 'Collar rot' (TAHVONEN 1976), and it occurred on quite a large scale in Finnish orchards between 1977 and 1979, occasioning in some orchards extensive death of and damage to trees of particular varieties.

The disease mainly occurs on the stem of the tree from the surface of the soil upwards, but is also found in the lower parts of the main branches. The junction of the roots and stem may also suffer damage, but this does not extend down to the roots themselves (WELSH 1942). The incipience of the disease is rather difficult to notice. The first phase consists of wetness on the stem; moisture is exuded by the damaged cells and makes its way to the surface of the bark. The disease progresses rapidly; the entire stem may be encircled by dead cellular tissue before any other symptoms of the infection are visible. The fruit remain small, and ripen early. The foliage turns reddish brown, and falls early. By the following early spring, such trees are in most cases dead. Not all of the tree necessarily dies, however; if the infection affects the lower parts of the main branches, only a portion of the main branches die. The bark, including the phloem and cambium, become reddish brown, and watery, and begin to give off a sweet smell. The bark comes off in strips. Subsequently, the damaged bark dries up, peels off, and curls up. The progress of the disease may become arrested, whereupon a clear dividing line is found in the bark between the diseased and healthy cellular material.

The disease is considered in the literature to be caused by the fungus *Phytophthora cactorum* (Leb. & Cohn) Schroet., although other authorities suggest that it is physiogenic and simply due to the conditions. The fungus is soil-borne and thrives in moist environments. One point emphasized in the literature is the relation between the disease and the level of moisture in the soil. The disease prefers very moist soil. Under such conditions, and with optimum soil temperatures, the disease can develop into an epidemic. The extent of infection decreases with diminishing moisture levels in the soil. A high level of moisture in the subsoil is of more significance for the incidence of the disease than mere wetness of the surface. Excessive moisture weakens the vitality of the trees, and renders them more susceptible to infection. If precipitation is heavy and moisture is retained for a long time in the soil, the roots suffer from oxygen deficiency (WELSH 1942, COOLEY and GROVES 1950).

Inasmuch as the cause of the disease is a parasite, the pathogenicity of its varieties may differ. What they have in common, however, is that trees seven years old or more contract the disease more readily than younger ones (BAINES 1939, BRAUN & KRÖBER 1958, SCHWINN 1965). WELSH (1942) mentions that in the Okanaga Valley in Canada trees of all ages have been found to suffer, but the generally prevailing opinion is that trees become liable to infection after their first yield-bearing year. According to BRAUN and KRÖBER (1958), older trees contract the disease more easily than younger ones due to the greater number of cracks and cuts in their bark.

The susceptibility of different rootstocks and varieties of apple trees to collar rot varies, some sickening more easily than others. Certain ones are considered to be resistant (BAINES 1939, SEWELL 1956, BRAUN & NIENHAUS 1959, SEWELL & WILSON 1959, HILKENBÄUMER 1964, BIELENIN 1977, DRAHORAD 1977). There are considerable differences in the bark of different varieties, and also in its cracking, which are widely held to be responsible for susceptibility or resistance to the disease (SCHWINN 1965). It has been found possible to prevent collar rot by grafting or budding trees so as to raise the graft union higher than usual (30 cm) above the level of the soil (BAINES 1939).

This paper gives some information on the incidence of collar rot in Finland, in 1975—79.

## QUESTIONNAIRE MATERIAL

When reports of collar rot occurring in Finnish apple orchards began to come in, the Institute of Horticulture sent out a questionnaire to the major orchards. Information was requested on the incidence of collar rot in trees on different rootstocks in different varieties (especially commercial varieties). Additional information requested concerned the type of soil in the orchard, the gradiet of the ground, the maintenance of the soil, etc. Replies were received from fifteen commercial orchards, of which two were in central southern coast, one on the Åland Islands, and the others in southwestern Finland. The data obtained concerned a total of 30 547 trees.

## RESULTS AND DISCUSSION

Data on the incidence of collar rot in different varieties are given in Table 1. The disease occurs particularly frequently in trees of the Red Atlas variety, 18 % of which (833 trees) were infected. The disease also occurred frequently in trees of the varieties Åkerö, Lavia, Transparente Blanche, and was also sometimes found in the varieties Melba, Kanel, and Lobo. In the last-mentioned variety, as in Red Atlas, the disease was reported from every orchard. The initial impression on the basis of the questionnaire information was that the variety Raike was resistant to the disease, but information received subsequently indicated that this variety too is susceptible. The disease did not however occur in the variety Quinte.

It emerged from the questionnaire that the disease occurred less frequently in young trees than in yield-bearing trees of six years or more. This did not however apply in the case of Red Atlas and Transparente Blanche in which the disease occurred equally frequently in young and mature trees. In the total population of trees covered by the questionnaire, 3 % of young trees under 6 years old were infected, and 7 % of those older.

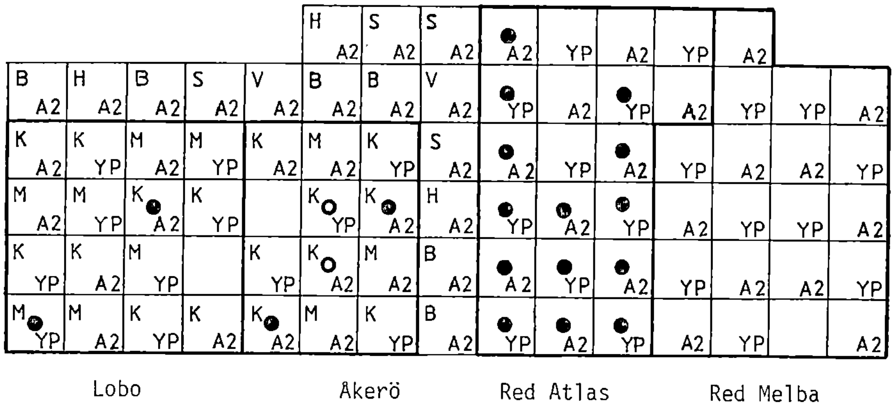
Table 1. Incidence of Collar Rot in Finnish Apple Orchards, 1975—79. Number of Orchards Replying to the Questionnaire: 15

| Variety and Number of Orchards | Total Trees | Total Infected Trees | | Infected Trees | |
|---|---|---|---|---|---|
| | | | | below 6 yrs | above 6 yrs |
| | N | N | % | % | % |
| Red Atlas (13) | 4 603 | 833 | 18 | 18 | 18 |
| Åkerö (8) | 914 | 90 | 10 | 0 | 10 |
| Lavia (4) | 308 | 26 | 8 | — | 8 |
| Transparente Blanche (10) | 1 587 | 97 | 6 | 7 | 6 |
| Melba (8) | 3 052 | 164 | 5 | 0 | 7 |
| Kanel (7) | 407 | 21 | 5 | — | 5 |
| Lobo (15) | 16 066 | 542 | 3 | 1 | 4 |
| Bergius (4) | 175 | 4 | 2 | — | 2 |
| Huvitus (4) | 222 | 2 | 1 | — | 1 |
| Raike (4) | 693 | 2 | 0 | 0 | 0 |
| Quinte (4) | 2 373 | 0 | 0 | 0 | 0 |
| Infection was also reported in the following varieties in individual orchards: | | | | | |
| Herbststreifling (1) | 64 | 8 | 13 | — | 13 |
| Ranger (1) | 23 | 0 | 0 | — | 0 |
| Linda (1) | 17 | 4 | 24 | — | 24 |
| Cox Pomona (1) | 13 | 1 | 8 | — | 8 |
| Antonovka (1) | 30 | 0 | 0 | — | 0 |

The questionnaire information did not provide any indication as to the significance of the rootstock for collar rot. Many of those replying did not know what rootstocks their trees had been grown on. There are however observations available on the susceptibility not only of clonal rootstocks but also of seedling rootstocks to the disease. In an experiment by the Institute of Horticulture using 20 trees of the Red Atlas variety, 14 trees (70 %) died of collar rot. The rootstocks here were A2 and YP. The rootstock did not in this case exert any effect (Fig. 1). Trees of the Red Melba variety growing alongside the experiment on the same rootstocks survived without becoming infected at all. Neither was high grafting on the same rootstock (30 cm above the ground level) of any assistance, since Lobo and Åkerö trees with this grafting also succumbed.

Nor did the questionnaire indicate the significance of the type of soil for the incidence of the disease, which occurred equally frequently on clay soil as on light soils. The same applied to sloping or level ground. The highest percentage loss (70 %) to be recorded was the roostock experiment in te Institute of Horticulture situated on a slightly sloping coarser sand. The soil here did not suffer from waterlogging. In a private apple orchard about three kilometres away, also situated on slightly sloping sandy clay, the losses were also considerable, with about 30 % of the Red Atlas trees dying. Consequently the heaviest losses occurred also under the same climatic conditions (Fig. 2). The disease occurred equally frequently on tilled soil and on grass. Nor did the questionnaire provide clear indications of the effect of using different composts on the incidence of the disease, although in two orchards which did use composts the losses were rather heavy. Composts become waterlogged, and keep the soil damper, than uncovered soil.

It was also suspected that the aluminium sheets set round the trees to protect them against moles might increase the likelihood of infection




K = High grafting (30 cm)

M = Low grafting (ground level)

O = Tree infected with collar rot

● = Tree dying of collar rot

A2, YP = rootstock varieties

B, H, S, V = collection varieties

Fig. 1. Apple trees infected with collar rot in the Horticultural Research Institute rootstock trials, 1978—79. Varieties: Red Atlas and Red Melba, plus Lobo and Åkerö. Planting distance: 4 x 4 m.

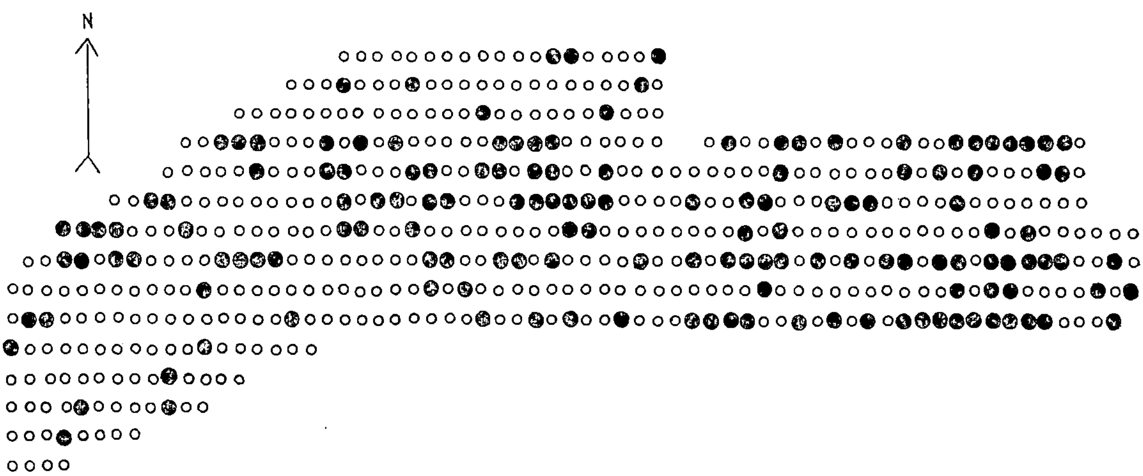



Fig. 2. Apple trees infected with collar rot, Luhta Orchard, 1978—79. Variety: Red Atlas. Planting distance: 3 x 5 m. Closed circles are dead trees.

through keeping the stem damper, but this could not be confirmed on the basis of the questionnaire material; the disease also occurred in cases where these guards were not used, or had been removed for the summer. No relation could be established between the methods of maintenance care of the trees, or the cultivation of strawberries, and the incidence of the disease. There are references in the literature to the likelihood of the proximity of strawberry plants increasing the danger of infection by collar rot, since the fungus *Phytophthora cactorum* is also a pathogen in the strawberry. In most of the places where collar rot was reported (11), strawberries neither were nor had been cultivated at or in the vicinity of the trees.

The intensity of collar rot infection varied from place to place. This is probably due to variations in the temperature during the growing season, especially the summer months, and to differences in relative humidity of the atmosphere and in waterlogging of the soil. The disease has been found to spread particularly when the relative air humidity and the temperature were relatively high, 16—21°C (GUPTA and SINGH 1979). High air humidity hampers the drying out of the soil, and probably also hampers the uptake of oxygen by the trees through their leaves. It was in the wet summers — 1974 and 1977—79 — that the disease established a foothold in Finland. Rainfall was higher than usual in 1974 and 1977,

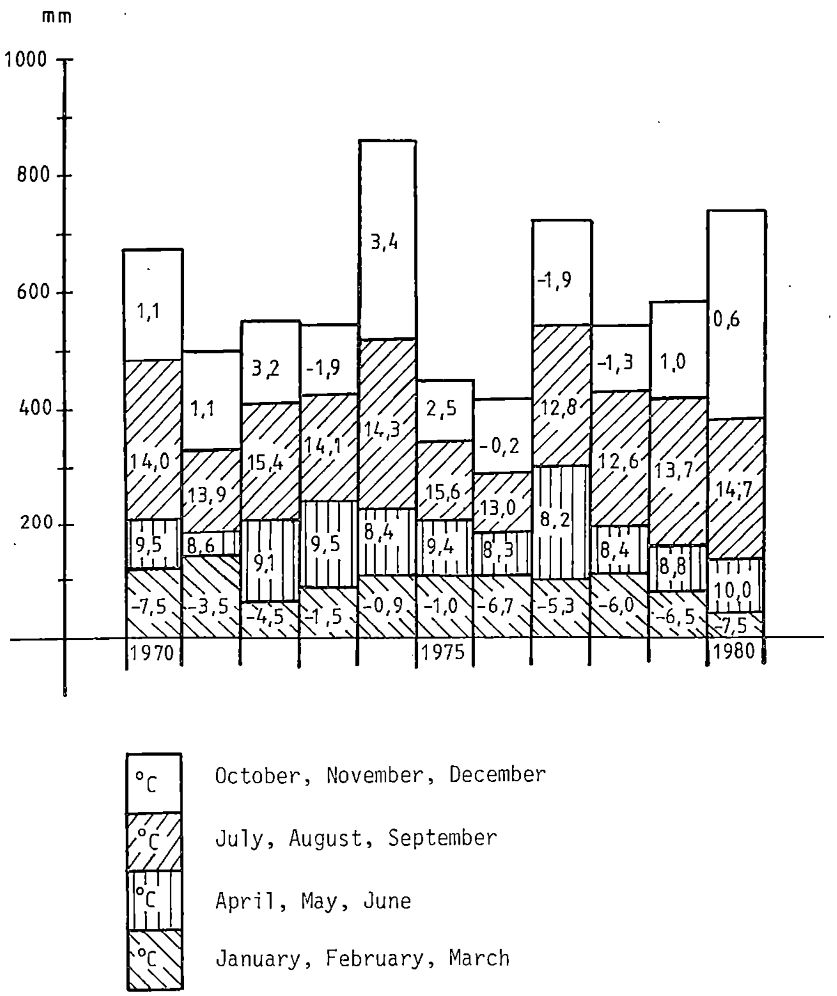



Fig. 3. Annual precipitation and mean temperatues, Piikkiö, 1970—1980.

the annual precipitation for those years being in Piikkiö 843 and 716 mm (Fig. 3). Rainfall occurred especially in the latter half of the year, from July onwards. Waterlogging of the soil, high air humidity, and delayed dormancy due to mild temperatures all increased the susceptibility of trees to infection. It is also clear that winter conditions affect the scale of incidence of the disease; trees normally winter less well after an unfavourable growing season than after a normal one.

Since the occurrence of the disease is dependent on climatic conditions during the growing season, it is extremely difficult to prevent. A further factor hampering prevention is that infection is usually only recognized the following spring. One way of avoiding infection is to avoid cultivating varieties susceptible to the disease, and the use of resistant rootstocks and interstocks is recommended. The literature also recommends the removal of rotting fallen apples, which are thought to be a major source of infection, as much as 80 % of infection being stated to be transmitted in this way (Braun and Nienhaus 1959). Damage to tree stems should be avoided, and they should be kept clear of weeds and compost. The spraying of the stems with a copper-content substance is also recommended in the early summer (Welsh 1942, Sewell and Wilson 1959). Copper spraying had in fact been used on two of the orchards which replied to the questionnaire, in autumn 1977 and in spring 1978, but no effect could be established of preventing the incidence of the disease.

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## SELOSTUS

# Omenapuiden kuorimätätaudin esiintyminen Suomessa 1975—79

Jaakko Säkö ja Eeva Laurinen

Maatalouden tutkimuskeskus

Vuosina 1975 ja 1978 havaittiin Suomen omenatarhoissa puiden vaurioitumista ja kuolemista, joka poikkesi tavallisista talvivaurioista. Ilmiö todettiin kuorimätätaudiksi, jonka aiheuttajana pidetään yleisimmin *Phytophthora cactorum*-sientä. Saastumisen edellytyksenä katsotaan olevan puiden kasvulle epäedulliset kasvuolot, erityisesti maaperän liika kosteus. Edellä mainittuja vuosia edelsivät epätavallisen runsassateiset kasvukaudet. Puutarhantutkimuslaitos lähetti taudin esiintymistä koskevan tiedustelun Lounais-Suomen omenaviljelijöille. Vastauksia saatiin 15:ltä kaupallista viljelyä harjoittavalta omenatarhalta. Tiedot koskivat yhteensä 30 547 omenapuuta.

Kuorimätätautia voitiin todeta esiintyneen enemmän vanhemmissa, satoikäisissä kuin nuoremmissa, alle 6-vuotiaissa puissa. Eniten kuorimätää tavattiin Punainen Atlas-lajikkeessa, jonka puista 18 % oli saastunut. Taudille alttiiksi osoittautuivat myös muut taloudellisesti merkittävät lajikkeet, kuten Åkerö (10 %), Valkea kuulas (6 %), Melba (5 %) ja Lobo (3 %). Vaurioiden laajuus eri omenatarhoissa vaihteli vajaasta prosentista yli kolmeenkymmeneen prosenttiin. Maaperän laadulla, maanpinnan kaltevuudella ja kasvualustan erilaisilla hoitomenetelmillä ei voitu todeta selviä yhtymäkohtia taudin esiintymiseen eikä vaurioiden laajuuteen omenatarhassa. Tuhoja esiintyi runsaimmin vuosina, jolloin maan ja ilman kosteus kasvukaudella olivat suuret.

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# 'HEISA' — A NEW NECTAR RASPBERRY VARIETY

HEIMO HIIRSALMI and JAAKKO SÄKÖ

HIIRSALMI, H. & SÄKÖ, J. 1981. **'Heisa' — a new nectar raspberry variety.** Ann. Agric. Fenn. 20: 268—272. (Agric. Res. Centre, Inst. of Hortic., SF-21500 Piikkiö, Finland.)

The nectar raspberry variety 'Heija', released for cultivation in 1975, unfortunately inherited some of the disadvantages of the raspberry, in particular its poor winterhardiness under Finnish conditions and the rather low level of yield.

A sister selection (the raspberry variety 'Malling Promise' × the nectar raspberry selection Merva) has however proved easier to cultivate, and this is therefore now to be released for cultivation, under the name 'Heisa'. In vegetative terms, it resembles the raspberry, and is better in its growth habit, winterhardiness, yield, and size of fruit than 'Heija'. The fruit of 'Heisa' are good in other respects too, and the aroma content is approximately the same as in the berries of 'Heija'.

The same techniques can be applied to the cultivation of 'Heisa' as with the raspberry.

Index words: Rubus idaeus × Rubus arcticus, nectar raspberry, winterhardiness, aroma.

## INTRODUCTION

Work had been initiated on crossing the raspberry (*Rubus idaeus* L.) with the nectarberry (*Rubus arcticus* L.) in 1939—1940, as a result of which the Institute of Horticulture released for cultivation the first nectar raspberry variety, under the name 'Heija', in 1975 (HIIRSALMI and SÄKÖ 1975, 1976). This variety successfully achieved the essential objectives set for the breeding of the nectar raspberry: the combination of the fine aroma of the nectarberry with the cultivability of the raspberry. Unfortunately this variety also inherited some of the disadvantageous characteristics of the raspberry, including its relatively poor winterhardiness under Finnish conditions and the associated rather low level of yield.

The results obtained in the cultivation of 'Heija' have been somewhat conflicting, for in some cases fruit have been obtained plentifully, while in others the yield has been virtually nonexistent. The very wet seasons of the past few years have been unfavourable for a variety such as 'Heija', which produces new canes in abundance; the rate of growth has relatively increased, with a consequent reduction in winterhardiness and yield. Tests and comparisons are therefore still being carried out on the most promising selections.

## MATERIAL AND METHODS

Two sister selections of 'Heija' have aroused particular attention: 62020018, and 62020037. These both originate from the same cross made in 1962 between the raspberry variety 'Malling Promise' and the nectar raspberry selection Merva, like the 'Heija' variety. A number of tests have been made in which these two have been compared both with 'Heija', and with the important raspberry variety 'Ottawa'. The first experimental results had in fact already been obtained at the Institute of Horticulture even before 'Heija' was released for cultivation. Subsequently, the tests have been extended at the South Savo Experimental Station in Mikkeli, and the North Pohjanmaa Experimental Station in Ruukki.

## RESULTS AND DISCUSSION

The investigations which preceded the release of 'Heija' for cultivation had already shown these two selections, 62020018 and 62020037, to be highly cultivable (Table 1) (Hiirsalmi and Säkö 1975, 1976). Organoleptic evaluation (Table 2), and the preliminary aroma analyses, showed that all of the selections contained compounds characteristic of the nectarberry, although in small quantities, while on the other hand they were found to contain only 1 % of the amount of negative taste compounds (e.g. alpha- and beta-ionones) found in the raspberry (Hiirsalmi et al. 1974). The most favourable aromatic composition appeared to be found in 'Heija', which was one of the reasons for its choice as the first variety to be released for cultivation.

In the ongoing comparisons, culminating in 1977, 62020018 has clearly emerged with the highest yield, higher even than the 'Ottawa' raspberry (Table 3) (Säkö and Hiirsalmi 1980, Säkö et al. 1980). It also ripened well before winter, which meant that winterhardiness is also good. Other advantages of this selection include

Table 1. Properties of three selections from the cross 'Malling Promise' × Merva: average yield, size of berries and ripening of shoots in 1970—1974; average hardiness, and start and duration of flowering in 1971—1974; length and spininess of canes in 1974. The raspberry variety 'Ottava' was used for comparison.

Experiment planted out in spring 1970.

Ratings: ripening of shoots: 0—100 = quite incomplete-quite complete; hardiness: 0—100 = all shoots dead-completely healthy: spininess: 0—100 = spineless-very spiny.

| Selection Variety | Total yield | Saleable yield | | Wt of 100 berries | Ripening of shoots | Hardiness |
|---|---|---|---|---|---|---|
| | kg/100 m² | | % | g | 0—100 | 0—100 |
| 62020018 (=Heisa) | 34 | 29 | 85 | 181 | 89 | 89 |
| 62020037 | 40 | 31 | 78 | 269 | 92 | 93 |
| 62020053 (=Heija) | 33 | 27 | 82 | 165 | 91 | 80 |
| Ottawa | 39 | 35 | 90 | 235 | 95 | 91 |

| | Start of flowering | Duration of flowering | Length of canes | Spininess of canes |
|---|---|---|---|---|
| | date | days | cm | 0—100 |
| 62020018 (=Heisa) | 19/6 | 15 | 189 | 40 |
| 62020037 | 19/6 | 17 | 174 | 53 |
| 62020053 (=Heija) | 19/6 | 15 | 212 | 33 |
| Ottawa | 18/6 | 17 | 158 | 58 |

Table 2. Properties of fruit of three selections from the cross 'Malling Promise' × Merva: average firmness, flavour, nectarberry aroma, shape and colour in the years 1970—1972. The raspberry variety 'Ottawa' was used for comparison.

Experiment planted out in spring 1970.

Ratings: firmness: 0—10 = very soft — very firm; flavour: 0—10 = very poor — very good; nectarberry aroma: 0—10 = absent — very strong; shape: 1 = conical, 2 = oval, 3 = round, 4 = flatly rounded; colour: 0—10 = white — purplish red.

| Selection Variety | Firmness | Flavour | Nectarberry aroma | Shape | Colour |
|---|---|---|---|---|---|
| | 0—10 | 0—10 | 0—10 | 1, 2, 3 and 4 | 0—10 |
| 62020018 (=Heisa) | 4,9 | 6,0 | 6,4 | 3 | 5,9 |
| 62020037 | 5,0 | 5,8 | 5,3 | 2 | 6,4 |
| 62020053 (=Heija) | 6,2 | 6,6 | 4,5 | 4 | 6,6 |
| Ottawa | 6,9 | 6,4 | 0,0 | 3 | 6,6 |

Table 3. Properties of three selections from the cross 'Malling Promise' × Merva: average yield, size of berries, ripening of shoots, and hardiness in 1972—1977. The raspberry variety 'Ottawa' was used for comparison.

Experiment planted out in spring 1970.
Ratings: See Table 1.

| Selection Variety | Total yield | Saleable yield | | Wt of 100 berries | Ripening of shoots | Hardiness |
|---|---|---|---|---|---|---|
| | kg/100 m² | | % | g | 0—100 | 0—100 |
| 62020018 (=Heisa) | 56 | 51 | 91 | 179 | 73 | 90 |
| 62020037 | 51 | 41 | 80 | 239 | 71 | 90 |
| 62020053 (=Heija) | 44 | 37 | 84 | 150 | 70 | 76 |
| Ottawa | 49 | 44 | 90 | 208 | 77 | 89 |

the earliness and brevity of the harvesting season. The selection 62020037, on the other hand, has distinctly larger fruit than the other selections.

A comparative test was set up in 1972 for the nectar raspberry selections, in an unheated plastic greenhouse. 62020018 and 62020037 have proved to be better suited than either 'Heija' or 'Ottawa' to plastic-greenhouse cultivation (Table 4) (Hiirsalmi 1980).

Good results have also been obtained with 62020018 at the South Savo and North Pohjanmaa Experimental Stations (Table 5). In Southern Savo, it gave the highest yields, and its winterhardiness was only exceeded by 'Ottawa'; in Northern Pohjanmaa, however, it did not quite come up to the same level as 'Ottawa'. The 'Heija' in the tests there suffered such serious damage the first winter after planting that it had to be removed.

In the tests carried out in the last few years, these selections, 62020018 and 62020037, have proved more cultivable than 'Heija', both in winterhardiness and in yield. The size of their berries has also been distinctly larger than that of 'Heija'. In aromatological tests carried out by a range of different methods in 1976 it also emerged that the fruit of all three selections contain approximately similar quantities of the desirable aromatic compounds found in the nectarberry (Pyysalo 1976), while the ionones that impair the flavour of the raspberry are present in very small quantities, though more so in 'Heija' than in the others. The beverages industry has stated that all three are viable raw materials for processing. The juice prepared from 62020037 rapidly changes in colour, however, due to oxidisation, and this probably also entails the loss of aroma.

On the basis of these comparative tests, it has been diceded to release 62020018 for cultivation in spring 1981, under the name 'Heisa', since it has proved superior to the 1975 variety, 'Heija', in a number of respects.

Table 4. Unheated plastic greenhouse experiment. Properties of three selections from the cross 'Malling Promise' × Merva: average yield, size of berries, ripening of shoots, hardiness and length of canes in 1973—1974. The raspberry variety 'Ottawa' was used for comparison.

Experiment planted out in spring 1972.
Ratings: See Table 1.

| Selection Variety | Total yield kg/100 m² | Wt of 100 berries g | Ripening of shoots 0—100 | Hardiness 0—100 | Length of canes cm |
|---|---|---|---|---|---|
| 62020018 (=Heisa) | 110 | 211 | 80 | 68 | 180 |
| 62020037 | 108 | 262 | 89 | 84 | 170 |
| 62020053 (=Heija) | 49 | 161 | 78 | 84 | 181 |
| Ottawa | 89 | 211 | 86 | 74 | 201 |

Table 5. Properties of three selections from the cross 'Malling Promise' × Merva: average yield, size of berries, ripening of shoots and hardiness at the South Savo Experimental Station in 1976—1979 (experiment planted out in spring 1974) and at the North Pohjanmaa Experimental Station in 1978—1980 (experiment planted out in spring 1976). The raspberry variety 'Ottawa' was used for comparison.

Ratings: See Table 1.

| Selection Variety | Total yield | Saleable yield | | Wt of 100 berries | Ripening of shoots | Hardiness |
|---|---|---|---|---|---|---|
| | kg/100 m² | | % | g | 0—100 | 0—100 |
| *South Savo* | | | | | | |
| 62020018 (=Heisa) | 62 | 58 | 93 | 185 | 68 | 68 |
| 62020037 | 52 | 45 | 87 | 211 | 84 | 61 |
| 62020053 (=Heija) | 35 | 32 | 93 | 140 | 70 | 57 |
| Ottawa | 56 | 53 | 94 | 228 | 84 | 86 |
| *North Pohjanmaa* | | | | | | |
| 62020018 (=Heisa) | 35 | 32 | 90 | 182 | 60 | 62 |
| Ottawa | 40 | 36 | 88 | 266 | 65 | 79 |

## The nectar raspberry variety 'Heisa'

The nectar raspberry variety 'Heisa' was selected from the offspring of a cross between the raspberry variety 'Malling Promise' and the nectar raspberry selection Merva, performed in 1962 at the Institute of Horticulture. In cross-breeding performed at the Institute in 1940, a raspberry (*Rubus idaeus* L.) variety of uncertain provenance had been pollinated by a nectarberry (*Rubus arcticus* L.) strain originating from Maaninka in Northern Savo. A single $F_1$ individual was obtained. A number of plants were selected from the offspring resulting from the free pollination of this individual and one of them yielded, by free pollination, Merva.

'Heisa' resembles the raspberry in its vegetative characteristics. In its growth habit, height, and in the shape and size of the canes, leaves, and flowers, it is identical with the raspberry. New canes are green in colour, but reddish-brown on the sunny side, especially higher up. They are upright and sturdy, and the branches growing on them are short. The plant grows to a height of almost 2 m. The thorns are hard, triangulate, about 1 mm long, projecting, and dark in colour. The leaves are bright green, though greyish underneath; trifoliate, though occasionally quinquefoliate. The middle leaflet is broadly cordate, 6—10 cm long, and 4—8 cm broad, and fairly evenly and sparsely dentate; there can also be some larger teeth on the middle leaflet. The diameter of the flowers is over 20 mm. The petals are white and narrow, approximately 7 mm long and 3 mm broad.

'Heisa' also resembles the raspberry in terms of cultivation. New canes are not formed as plentifully as in 'Heija', partly due to this, and partly to the early ripening of the canes, 'Heisa' possesses a satisfactory degree of winterhardiness — a characteristic of prime importance for small-fruit cultivars under northern conditions. 'Heisa' has also been found to provide a yield comparable with the best raspberry varieties, even surpassing that of 'Ottawa', which is the most widely cultivated variety in Finland. Like those of the raspberry, 'Heisa's' berries detach from the receptacle. They are round, and middle-sized at best, although always larger than those of 'Heija'. The weight of 100 berries is usually 150—200 g. The quality of the fruit is good in other respects too: the flavour is pleasantly fresh, and aromatic content approximately the same as in 'Heija'. The berries of 'Heisa' are evenly-shaped aggregate drupes, and maintain their shape; individual drupelets do not break off, as often happens in 'Heija'. The berries can be used either fresh or frozen. They can be used to make a fresh-tasting juice, and jam, while in the foodstuffs industry the main use will probably be in the preparation of liqueurs. An additional advantage of 'Heisa' is the earliness and concentration of the harvest.

Exactly the same techniques can be adopted in the cultivation of 'Heisa' as with the raspberry. In contrast to the nectarberry, it has been found to be highly self-fertile, and can therefore be planted out alone. Fertilization will however probably be more complete if the 'Heija' nectar raspberry, or some raspberry variety, e.g. 'Ottawa', can be planted adjacently as a pollinator. The resistance of 'Heisa' to spur blight is on the other hand no better than that of 'Heija' or 'Ottawa'.

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## SELOSTUS

### 'Heisa' — uusi mesivadelmalajike


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Maatalouden tutkimuskeskus



Puutarhantutkimuslaitoksessa vuodesta 1939 lähtien suoritetun vadelman (*Rubus idaeus* L.) ja mesimarjan (*Rubus arcticus* L.) välisen risteytysjalostuksen tuloksena laskettiin keväällä 1975 viljelyyn ensimmäinen mesivadelmalajike nimellä 'Heija'. Siinä mesimarjan hieno aromi yhtyy tyydyttävästi vadelman viljelyominaisuuksiin. Lajikkeeseen on kuitenkin periytynyt vadelman epäedullisia ominaisuuksia, etenkin heikko talvehtimiskyky.

'Heija'-lajiketta viljelyvarmemmaksi on sittemmin osoittautunut sen sisarjaloste risteytyksestä vadelmalajike 'Malling Promise' × mesivadelmajaloste Merva. Se on päätetty laskea yleiseen viljelyyn lajikenimellä 'Heisa'. Tämä kasvullisilta ominaisuuksiltaan vadelmaa muistuttava lajike on 'Heijaa' parempi kasvutavaltaan ja talvenkestävyydeltään sekä satoisuudeltaan ja marjakooltaan. Lisäksi 'Heisan' marjojen laatu on muutenkin hyvä ja aromipitoisuus suunnilleen sama kuin 'Heijan' marjoissa.

'Heisa'-lajikkeen viljelyssä voidaan noudattaa samaa tekniikkaa kuin vadelmallakin.

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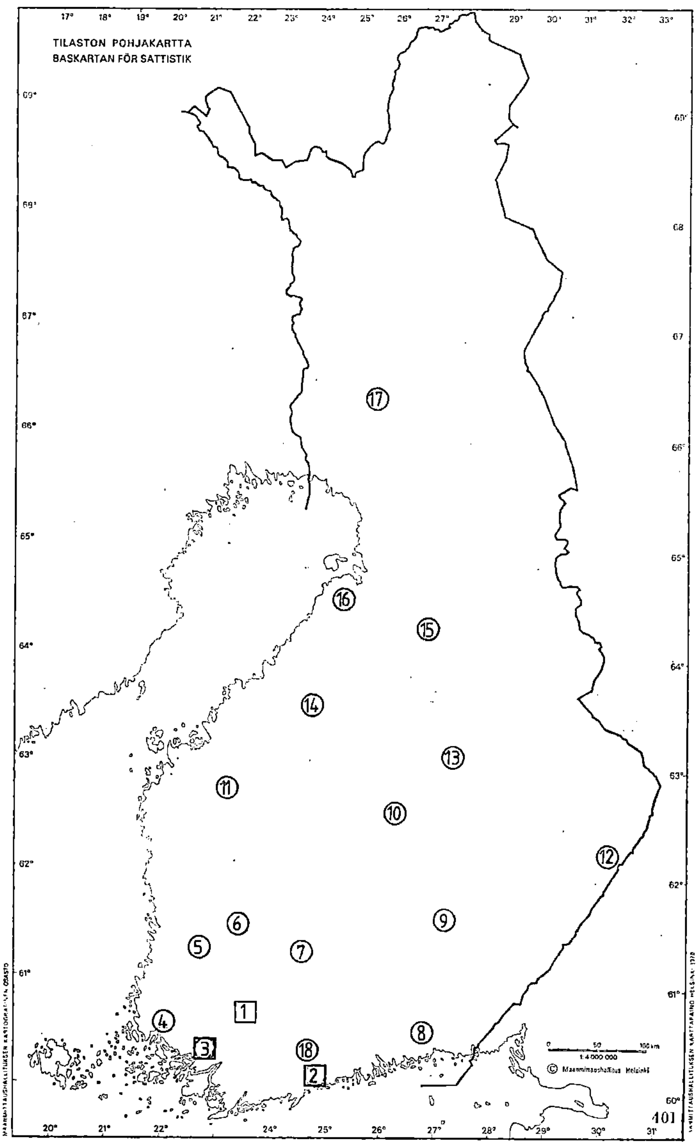




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