The effect of selenium fertilizers on the selenium content of barley, spring wheat and potatoes

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Abstract When Se-enriched fertilizers were given to barley and spring wheat on fine sand soils in Southern Finland the Se content in the grain was raised as follows: 50 g Se/ha increased the Se content by around 50 μg/kg; 250 g Se/ha by appr. 400 μg/kg; and 500 g Se/ha by a little more than 900 μg/kg.

The selenium content of potatoes rose to Se/kg dry matter when the soil was enriched with 500 g Se in the form of Na₂SeO₄ per hectare. The selenium content of potatoes was found to be very low when no added selenium was given. The selenium content of potatoes did not fall when the potatoes were boiled.

Introduction

Selenium is not an indispensable nutrient for crops. Nevertheless, there have been experimental attempts at raising the selenium content of agricultural produce: in the USA (CARY and ALLAWAY 1973), in New Zealand (GRANT 1965, DAVIES and WATKINSON 1966), and in Denmark (GISSEL-NIELSEN 1971, 1975). The Se quantities used in the experiments have varied greatly, ranging from a few grammes when crops were sprayed (GISSEL-NIELSEN 1971) to several kilogrammes per hectare when transmitted through the soil (CARY and ALLAWAY 1973). When the selenium has been transmitted through the soil, selenium fertilizer quantities in the region of 100 g Se/ha have proved sufficient to give the desired Se level for fodder crops and hay, 50—100 μg Se/kg (GRANT 1965, GISSEL-NIELSEN 1977). It has been found that much smaller Se quantities give the same results when crops are sprayed if the spraying is done at the right time (GISSEL-NIELSEN 1977).

Pure selenium, selenate and selenite were used in the experiments to increase the selenium content of the fertilizers. GISSEL-NIELSEN (1977) has conducted many experiments and he holds that selenite is the best source, even though selenate may be more effective than selenite for raising the selenium content of crops. The same researcher has also demonstrated (GISSEL-NIELSEN 1977) that the sulphate content of the soil has a much greater influence on how selenate is transmitted than on how selenite is transmitted.

The present study made use of selenite only. The selenite was employed to raise the selenium content of the fertilizers and for crop spraying purposes. The study aims
at reaching a preliminary assessment of the manner in which the selenium content of barley, spring wheat and potatoes is raised when selenite fertilizers are sprayed and transmitted through the soil. The selenium-enriched barley obtained as a result of spraying has been used in feed tests on chickens, pigs and horses (KÄÄNTEE and KURKELA 1980a, and 1980b).

Materials and methods

The fertilizers used in the experiments were prepared at the small factory of Kemira Oy’s research plant. Ordinary commercial products were used as raw material; the fertilizers were granulated by being sprinkled with Na$_2$SeO$_3$·5H$_2$O solute. The Se content aims for the fertilizers were 0.01 % Se, 0.05 % Se and 0.10 % Se and these levels were realized. A tractor spray was used for carrying out the selenium spraying; a solution of sodium selenite in 400 litres of water was used over one hectare.

The field tests were carried out at the Kotkanemi experimental farm at Vihti. The fertilizers which were meant to be transmitted through the soil were placed with a combined drilling machine.

The Kemira Oy Oulu research plant conducted the selenium analyses. The hydridemethod was used (SAARI and PAASO 1980).

Results

1 Spraying

Suvi barley (sown 17. 5. 1978) growing on sandy loam was sprayed on 21. 6. 1978. The barley was being grown for experimental fodder and was just beginning to sprout when the spraying was carried out. Follow-up samples of the Suvi barley were taken the next year.

The spraying treatment was repeated on another plot of sandy loam in the summer of 1979. The Aapo barley had been sown on 17—18. 5. and the spraying was carried out on 21. 6. 1979 when the barley was sprouting. The initial selenium content of the plot sprayed in 1979 was slightly higher than the soil sprayed the year before.

2 Fertilizers transmitted through the soil

Grain

The selenium fertilizer experiments conducted in 1978—79 were carried out on coarse mineral soil. Barley and spring wheat were treated with experimental fertilizers which were enriched with Na$_2$SeO$_3$. Half of the experiment site was limed with 5 t/ha of agricultural lime before the experiment was instigated. The mean analysis results of the soil samples taken on 11. 5. 1978 before liming and fertilizing were as follows:
Table 1. The effect of Na$_2$SeO$_3$ spraying on the Se content of barley, 1978–79.

|                | barley grain Se content $\mu$g/kg dry matter |
|----------------|---------------------------------------------|
|                | spraying         | residual effect in 1979 |
| 1. untreated   | $< 10$           | $< 10$                   |
| 2. 0.1 kg/ha Se in the form of Na$_2$SeO$_3$ | 170              | $< 10$                   |
| 3. 0.5 $"$ " $"$ $"$ $"$ $"$ $"$ $"$ $"$ | 680              | 20                        |
| 4. 1.0 $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ | 1000             | 10                        |

Table 2. The effect of Na$_2$SeO$_3$ spraying on the Se content of barley, 1979.

|                | barley grain Se content $\mu$g/kg dry matter |
|----------------|---------------------------------------------|
|                | 1979                                        |
| 1. untreated   | 40                                          |
| 2. 0.1 kg/ha Se in the form of Na$_2$SeO$_3$ | 500                                          |
| 3. 0.5 $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ | 1100                                         |
| 4. 1.0 $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ $"$ | 2500                                         |

Four fertilizer types were prepared for the grain experiments. The main nutrient and boron content of each type was the same: N 15, P 8.7, K 12.4 and B 0.03%. Selenium content was regulated to four levels with Na$_2$SeO$_3$: 0.00, 0.01, 0.5, and 0.10% Se. The quantity of fertilizer with which the grain was treated was 500 kg/ha.

The spring wheat (Tähti variety) harvest was very low both years. The mean 1978 wheat harvest was 1790 kg grain/ha. The 1979 figure was as low as 1310 kg grain/ha. The barley harvest was satisfactory: an average of 4975 kg/ha was obtained in 1978, and an average of 3255 kg/ha in 1979. Neither year’s spring wheat crop was affected by the Se fertilizing. Halving with liming had no significant effect on the grain harvest either.

Soil samples were taken in the spring of 1979 after the first year of tests in order that selenium analyses might be made.

Following the first year of tests the experiment site was divided into two. One half of the site was re-treated with the same Se-enriched fertilizer, whereas the other half was treated with normal, seleniumless fertilizer. The type of fertilizer used was the same as that which had been employed the previous year. Liming was not repeated.
Table 3. The effect of the selenium content of fertilizers on the selenium content of grain, 1978. The same letter in the vertical column = no significant deviation of figures ($p = 0.05$).

| fertilizer | Se content | corn | middle | husk | limed | middle | husk | unlimed | middle | husk | mean |
|------------|------------|------|--------|------|-------|--------|------|---------|--------|------|------|
| 1          | 0.00% Se   | 170  | 175    | 117  | 100   | 105    | 137  | 40      | 50     |      |      |
| 2          | 0.01% Se   | 135  | 210    | 247  | 135   | 153    | 197  | 130     | 130    |      |      |
| 3          | 0.05% Se   | 467  | 600    | 765  | 290   | 433    | 575  | 450     | 480    |      |      |
| 4          | 0.10% Se   | 737  | 840    | 1032 | 970   | 1350   | 1325 | 1110    | 1200   |      |      |

Table 4. The quantities of water soluble selenium of soil samples after one test year.

| fertilizer | Se content | water soluble Se mg/l |
|------------|------------|-----------------------|
| 1          | 0.00% Se   | 0.0063                |
| 2          | 0.01% Se   | 0.0053                |
| 3          | 0.05% Se   | 0.0058                |
| 4          | 0.10% Se   | 0.0090                |

Table 5. The effect of selenium content of fertilizers on the selenium content of spring wheat grains, 1979. The same letter in the vertical column = no significant deviation of figures ($p = 0.05$).

| fertilizer | Se content | 1979 | 1978 | grain selenium content Se $\mu g/kg$ | 1979 | 1978 | grain selenium content Se $\mu g/kg$ |
|------------|------------|------|------|--------------------------------------|------|------|--------------------------------------|
| 1          | 0.00% Se   | 60   | 55   | 75                                   | 60   | 65   | 75                                   |
| 2          | 0.00% Se   | 40   | 50   | 50                                   | 90   | 95   | 60                                   |
| 3          | 0.00% Se   | 70   | 70   | 60                                   | 110  | 115  | 75                                   |
| 4          | 0.00% Se   | 170  | 200  | 160                                  | 120  | 120  | 150                                  |
| 2b         | 0.01% Se   | 135  | 195  | 195                                  | 190  | 235  | 210                                  |
| 3b         | 0.05% Se   | 415  | 470  | 560                                  | 410  | 495  | 625                                  |
| 4b         | 0.10% Se   | 1150 | 1400 | 1800                                 | 1100 | 1750 | 1800                                 |

*) limed/unlimed $F = 0.51$ i.e. liming has no significant effect

Table 6. The effect of the selenium content of fertilizers on the selenium content of barley grains, 1979. The same letter in the vertical column = no significant deviation of figures ($p = 0.05$).

| fertilizer | Se content | 1979 | 1978 | grain selenium content Se $\mu g/kg$ |
|------------|------------|------|------|--------------------------------------|
| 1          | 0.00% Se   | 0.00% Se | 40a  | 75a                                  |
| 2          | 0.00% Se   | 0.01% Se | 55a  | 60a                                  |
| 3          | 0.00% Se   | 0.05% Se | 70ab | 85ab                                 |
| 4          | 0.00% Se   | 0.10% Se | 105bc| 130b                                 |
| 2b         | 0.01% Se   | 0.01% Se | 110c | 95b                                  |
| 3b         | 0.05% Se   | 0.05% Se | 370d | 390c                                 |
| 4b         | 0.10% Se   | 0.10% Se | 1100c| 1300d                                |

*) limed/unlimed $F = 5.97^x$, i.e. the Se content on limed soil is significantly lower
Potatoes

The selenium fertilizer experiments conducted in 1978—79 were carried out on coarse mineral soil. Rekord potatoes were treated with experimental fertilizers which were enriched with Na₂SeO₃. Half of the experiment site was limed with 5 t/ha of agricultural lime before the experiment was instigated. The mean analysis results of the soil samples taken on 22. 5. 1978 before liming and fertilizing were as follows:

| Soil Type       | Fine Sand | pH H₂O | Ca NH₄Ac (mg/l soil) | K NH₄Ac | P NH₄Ac | Mg NH₄Ac | B Hot Water | Cu 2M HCl | Mn MgSO₄ |
|-----------------|-----------|--------|----------------------|---------|---------|----------|------------|-----------|----------|
|                 |           |        | 1400                 | 167     | 17      | 158      | 0.8        | 7.6       | 6.8      |

Four batches of fertilizer were prepared for the experiment. Apart from the selenium content, all the batches had identical nutrient contents: N 8.0, P 10.5, K 11.6, S 10.7, Mg 2.5, Cu 0.4, Mn 0.7, Zn 0.03, Mo 0.02 and B 0.15%. The quantity of fertilizer with which the potatoes were treated was 1000 kg/ha.

The Se fertilizer treatment was not repeated in 1979 on test plots which were treated with selenium-enriched fertilizer in 1978 (cp. the section on grain). Instead, a control experiment was set up on another spot on the same plot. The mean analysis results for this area prior to liming and fertilizing were as follows:

| Soil Type       | Coarse Fine Sand | pH H₂O | Ca NH₄Ac (mg/l soil) | K NH₄Ac | P NH₄Ac | Mg NH₄Ac | B Hot Water | Cu 2M HCl | Mn MgSO₄ |
|-----------------|------------------|--------|----------------------|---------|---------|----------|------------|-----------|----------|
|                 |                  |        | 1640                 | 164     | 16      | 102      | 0.3        | 8.1       | 12.6     |

The same fertilizer type was used in the 1979 potato fertilizing experiments as had been employed the year before.
Table 7. Potato crop, 1978 and 1979.

| fertilizer Se content | 1978 | 1979 | potato crop kg/ha | 1978 | 1979 |
|-----------------------|------|------|-------------------|------|------|
|                       | limed| unlimed|                  | limed| unlimed| |
| 1 0.00 % Se           | 0.00 % Se | 28 570 | 29 810 | 21 400 | 25 120 |
| 2 0.01 % Se           | 0.00 % Se | 37 170 | 35 400 | 24 830 | 26 100 |
| 3 0.05 % Se           | 0.00 % Se | 34 790 | 31 950 | 26 240 | 23 450 |
| 4 0.10 % Se           | 0.00 % Se | 35 100 | 26 640 | 23 980 | 21 260 |

Table 8. The effect of the selenium content of fertilizers on the selenium content of potatoes in 1978, and the residual effect in 1979. The same letter in the vertical column = no significant deviation of figures (p = 0.05).

| fertilizer Se content | 1978 | 1979 | potato Se content Se µg/kg dry matter | 1978 | 1979 |
|-----------------------|------|------|--------------------------------------|------|------|
|                       | limed| unlimed|                                  | limed| unlimed|
| 1 0.00 % Se           | 0.00 % Se | < 10a | < 10a | < 10a | < 10a |
| 2 0.01 % Se           | 0.00 % Se | 10a  | < 10a | < 10a | < 10a |
| 3 0.05 % Se           | 0.00 % Se | 103b | 87b  | 23a  | 13a  |
| 4 0.10 % Se           | 0.00 % Se | 160c | 203c | 33a  | 27a  |

Table 9. The potato crop and the selenium content of potatoes in the experiment instigated in 1979.

| fertilizer Se content | potato crop kg/ha | selenium content of potatoes (peeled) Se µg/kg dry matter1) |
|-----------------------|-------------------|------------------------------------------------------------|
|                       | limed | unlimed | limed | unlimed |
| 1 0.00 % Se           | 27 670| 24 380  | < 10a | 10a  |
| 2 0.01 % Se           | 28 290| 25 430  | 23a  | 27a  |
| 3 0.05 % Se           | 28 690| 27 300  | 110b | 100b |
| 4 0.10 % Se           | 27 980| 24 640  | 190c  | 213c |

1) The same letter in the vertical column = no significant deviation of figures (p = 0.05)

2) corresponding peels contained 297 µg Se/kg dry matter

Food preparation tests

A few barley samples were used to bake unleavened bread. The loaves were baked in an oven at a temperature of 200°C. The Se content of the baked loaves is given in Table 10.

A few potatoes which had formed part of the 1979 experiment were boiled. This was done as a type of random test and the results obtained are presented in Table 11.
Table 10. The Se content of barley flour and unleavened loaves baked from it.

| fertilizer Se content | selenium content Se μg/kg dry matter | flour¹ | unleavened loaf | flour² | unleavened loaf |
|-----------------------|-------------------------------------|--------|-----------------|--------|-----------------|
|                       | 1979                                | 1978   |                 |        |                 |
| 2b                    | 0.01 % Se                           | 0.01 % Se | 90             | 60    | 60              | 50 |
| 3b                    | 0.05 % Se                           | 0.05 % Se | 340            | 310   | 320             | 280 |
| 4b                    | 0.10 % Se                           | 0.10 % Se | 980            | 950   | 1010            | 960 |

1978

| 1 | 0.00 % Se | 50 | 60(40²) | 50 | 50 (40²) |
| 2 | 0.01 % Se | 120 | 130(90) | 110 | 120 (80) |
| 3 | 0.05 % Se | 390 | 300(450) | 430 | 490 (450) |
| 4 | 0.10 % Se | 1040 | 1210(1220) | 1110 | 1230 (1150) |

¹) repeat analyses were made of the flour used in the baking, and the figures in the column are not the same as those in Tables 4 and 8 for this reason.

²) the figures in parentheses were obtained by re-analyzing the unleavened loaves after they had been deep frozen for one year.

Table 11. The effect of boiling potatoes on their selenium content.

| fertilizer Se content | peeled potato Se μg/kg dry matter | corresponding boiled and peeled potato Se μg/kg dry matter |
|-----------------------|----------------------------------|----------------------------------------------------------|
|                       | limed                            | unlimed                                         | limed                            | unlimed |
| 1978                  | 1979                             |                                               |
| 0.10 % Se             | 0.00 % Se                        | 33                                            | 27                               | 40     | 37     |
|                       | 0.10 % Se                        | 190                                           | 213                              | 270    | 210    |

Discussion

The present study’s findings agree with the results of earlier experiments (SYVÄLAHTI and KORKMAN 1978). Selenium may be given to crops by spraying or by transmitting it through the soil. The natural selenium content of Finnish crops is very low (cp. e.g. KOIVISTOINEN 1979) and this means that selenium fertilizers have a marked effect on both grain and potatoes. When 50 g Se/ha (500 kg/ha of fertilizer containing 0.01 % sodium selenite) were transmitted to crops through the soil, the selenium content of the crops rose by a mean of 56 μg/kg during the first year. When 250 g Se/ha were given, the selenium content increased by 404 μg/kg on an average, and the content rose by a mean of 925 μg/kg when 500 g Se/ha was used.

GISSEL-NIELSEN (1977) found that a Se quantity corresponding to the smallest amount (60 g Se/ha) caused the Se content of barley to rise by 38 μg/kg, and the content of wheat by 64 μg/kg. The results of these experiments and the present study are thus of equivalent magnitude. On the other hand, the effect of the present study on the Se content of grain was less great than earlier studies might have led one to expect (cp. SYVÄLAHTI and KORKMAN 1978). Contrastingly, the natural content of spring wheat in particular was higher than normal (cp. YLÄRANTA 1980). The reason for this was not discovered. The very low harvest figures might
have a bearing, but it would also appear that the soil of the experiment site had a
greater than usual amount of selenium which could be used by plants.

The present study was unable to arrive at an unequivocal conclusion as to how
liming increases selenium uptake (cp. GEERING et al. 1968). Conflicting results
have been obtained in this field: in Sippola’s study (SIPPOLA 1979) a high pH
appeared to have some slight retarding effect on the Se uptake of plants in this ti-
mothy material.

The finding that selenium is comparatively evenly distributed over the various
parts of wheat grains and does not become concentrated in the husk to the same ex-
tents as other elements was noteworthy. Whilst the most selenium is found in the
husk and the least in the kernel, differences are not great.

The selenium content of the unleavened barley loaves did not fall during baking.
The content remained constant or rose a little. The Se content of the loaves was not
affected by being deep frozen for a year. Selenium was not lost when potatoes were
boiled.

There have been very few studies made with selenium fertilizers and potatoes.
The present study demonstrated that the amount of selenium transmitted to potatoes
is proportional to the quantity of selenium given during fertilizing. An estimate was
made of the total selenium content of the dry harvest and demonstrated that potato
is unlikely to be a more efficient user of selenium than spring wheat or barley.

The same problem is inherent in selenium fertilizers as mineral micronutrient fer-
tilizers: only a very small part of the fertilizing element is transmitted to the crop
and the rest of the element is bound to the soil or placed beyond the reach of the
crop in some other fashion. A rough estimate of the quantity of selenium transmitted
to the edible part of the plant in the first year (spring wheat and barley 1978, potato
1978—79) demonstrates that grain and potatoes are fairly alike in this regard:

| Se content of fertilizer | wheat | barley | potato |
|-------------------------|-------|--------|--------|
| Se uptake g/ha | Se increase % of quantity | Se uptake g/ha | Se increase % of quantity | Se uptake g/ha | Se increase % of quantity |
| 0.00 | 0.24 | — | 0.22 | — | 0.03 | — |
| 0.01 | 0.28 | 0.08 | 0.66 | 0.88 | 0.13 | 0.07 |
| 0.05 | 0.28 | 0.27 | 2.32 | 0.84 | 0.65 | 0.13 |
| 0.10 | 1.81 | 0.36 | 5.70 | 1.10 | 1.14 | 0.11 |

The above figures demonstrate that a maximum of slightly over one per cent of
the selenium given was transmitted to the edible part of the plant. There is a slight
indication that a greater proportion of selenium is transmitted to the crop when the
amount given is large than when it is small. The largest Se quantities increased the
Se intake of the harvest by a factor of 8—38 when compared to the zero level.

Both grain and potato showed a slight residual effect in the second year. This
finding agrees with the findings of earlier Finnish studies (SYVÄLAHTI and KORK-
MAN 1978). The study will be followed for a few more years in this respect.

A comparative study of the efficiency of selenite and selenate in practical fertili-
zing will be made in Finland in the near future (YLÄRANTA personal communication). It is hoped that this forthcoming study will enable the efficiency of
selenium fertilizers to be improved.
Summary

Selenium fertilizer experiments were made in 1978 and 1979 at the Kemira Oy experimental farm. Sodium selenite, Na₂SeO₃·5H₂O, was employed as the selenium source. Barley was subjected to spraying tests, and fertilizers were transmitted through the soil for barley, spring wheat and potatoes. Two types of selenium fertilizer were prepared at the Kemira research factory for the fertilizer trials. The fertilizers contained 0.00, 0.01, 0.05 and 0.10 % of selenium.

When 0.1, 0.5 and 1.0 kg Se/ha was sprayed, selenium content figures were obtained which were clearly excess of the content which is often used as an objective, 50–100 μg Se/kg of the absorbent parts of the plant. More field tests will have to be carried out to ascertain the right quantities to be used and the best spraying time before spraying may be used in order to boost the selenium content of crops.

The extents to which selenium fertilizers raised the selenium content of grain when the fertilizer was transmitted through the soil were as follows: 50 g Se/ha boosted the Se content by more than 50 μg/kg; 250 g Se/ha by approximately 400 μg/kg; and 500 g Se/ha by more than 900 μg/kg. Selenium was distributed in spring wheat in such a fashion that the content of the husk was the highest and the content of the kernel the lowest. However, the Se content of the husk was a mere mean 32 % higher than that of the kernel.

The selenium content of potatoes rose to 100 μg Se/kg dry matter when the soil was enriched with 500 g Se in the form of Na₂SeO₃ per hectare. The selenium content of potatoes was found to be very low when no added selenium was given. The selenium content of potatoes did not fall when the potatoes were boiled.

The present series of experiments was unable to increase selenium uptake of crops by liming. It should, however, be borne in mind that the pH value of the test plots was high for Finnish conditions — it stood at 6.0–6.2 whereas the mean pH value of Finnish arable soil is 5.6.

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SELOSTUS

Seleenipitoisten lannoitteiden vaikutus ohran, kevätvähnän ja perunan seleenipitoisuuteen

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Vuosina 1978 ja 1979 tehtiin Kemira Oy:n koetilalla seleenilannoituskokeita käyttäen seleenilähteenä natriumseleenitetä, NaSeO₄·5H₂O. Ruiskutuskokeita tehtiin ohralla, lannoituskokeita maan kautta ohralla, kevätvähnällä ja perunalla. Maahan annettava lannoitusta varten valmistettiin Kemiran koetehdaalla kahden lannoitelajin seleenipitoisia rinnakkaistuotteita, joissa oli 0,00, 0,01, 0,05 ja 0,10 % seleenii.

Ruiskutettaessa 0,1, 0,5 ja 1,0 kg Se/ha päiästiin seleenipitoisuuksiin, jotka ovat selvästi korkeampia kuin tavoitteena usein pidetty 50−100 µg Se/kg kasvin kuiva-ainetta. Mikäli ruiskuttamalla pyritään korottamaan sa- totuotteiden seleenipitoisuutta, tarvitaan vielä kentäkoekokemuksia lisää oikean käyttömäärän ja ruiskutusajan kohdan määrittämiseksi.

Maahan annettaessa seleenilannoitus korotti viljoihin pitoisuksia siten, että 50 g Se/ha korotti runsaalla 50 µg/kg, 230 g Se/ha noin 400 µg/kg ja 500 g Se runsaalla 900 µg/kg jyvä. Kevätvähnällä seleeni jakautui jyvä eri osiin siten, että kuoriosan pitoisuus oli korkein ja ydinason pitoisuus alhaisin. Kuoren Se-pitoisuus oli kuitenkin keskimäärin vain 32 % korkeampi kuin ydinason.

Perunan seleenipitoisuus nousi tasolle 100 µg Se/kg k.a. annettaessa maahan 500 g Se Na₂SeO₄:na hehtaa- ria kohti. Ilman lisäseleeniä perunan Se-pitoisuudet olivat varsin alhaisia. Perunan seleenipitoisuudet eivät laske- neet mukulointia hehtattäessä.

Kalkituksella ei tässä koesarjassa pystytty lisäämään kasvien seleeninsaantia. Tosin koemaiden pH :t olivat 6,0−6,2, mikä on melko korkea meikäläissä oloissa; onhan maamme peltomaiden keskimääräinen pH 5,6.