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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 100 μg Se/kg dry matter when the soil was enriched with 500 g Se in the form of Na_2SeO_3 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 μ g 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 $Na_2SeO_3 \cdot 5H_2O$ 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 Kotkaniemi 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_2SeO_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_2SeO_3 spraying on the Se content of barley, 1978–79.

	barley grain Se content μg/kg dry matter 1978 spraying	residual effect in 1979
1. untreated	< 10	< 10
2. 0.1 kg/ha Se in the form of Na_2SeO_3	170	< 10
3. 0.5 " " "	680	20
4. 1.0 " " "	1000	10

Table 2. The effect of Na_2SeO_3 spraying on the Se content of barley, 1979.

	barley grain Se content μg/kg dry matter
1. untreated	40
2. 0.1 kg/ha Se in the form of Na_2SeO_3	500
3. 0.5 " " " " " " " "	1100
4. 1.0 " " " " " " " "	2500

soil type	coarse sand	
pH H_2O	6,0	
Ca NH_4Ac	824	mg/l soil
K NH_4Ac	154	"
P NH_4Ac	6,5	"
Mg NH_4Ac	80	"
B hot water	0,5	"
Cu 2M HCl	5,1	"
Mn $MgSO_4$	4,4	"

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_2SeO_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 twŏ. 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	grain selenium content Se μ g/kg spring wheat limed kernel	middle	husk	unlimed kernel	middle	husk	barley limed	unlimed
1 0.00 % Se	170[a]	175[a]	117[a]	100[a]	105[a]	137[a]	40[a]	50[a]
2 0.01 % Se	135[a]	210[ab]	247[a]	135[a]	153[a]	197[a]	130[b]	130[a]
3 0.05 % Se	467[b]	600[bc]	765[b]	290[b]	435[b]	575[b]	450[c]	480[b]
4 0.10 % Se	737[b]	840[c]	1032[b]	970[c]	1050[c]	1325[c]	1110[d]	1200[c]

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

fertilizer Se content	water soluble Se mg/l limed	unlimed
1 0.00 % Se	0.0063	0.0068
2 0.01 % Se	0.0053	0.0060
3 0.05 % Se	0.0058	0.0065
4 0.10 % Se	0.0090	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*) μ g/kg limed kernel	middle	husk	unlimed kernel	middle	husk	mean
1 0.00 % Se	0.00 % Se	60	55	75	60	65	75	65[a]
2a 0.00 % Se	0.01 % Se	40	50	50	90	95	60	64[a]
3a 0.00 % Se	0.05 % Se	70	70	60	110	115	75	83[a]
4a 0.00 % Se	0.10 % Se	170	200	160	120	120	150	153[a]
2b 0.01 % Se	0.01 % Se	135	195	195	190	235	210	193[a]
3b 0.05 % Se	0.05 % Se	415	470	560	410	495	625	496[b]
4b 0.10 % Se	0.10 % Se	1150	1400	1800	1100	1750	1800	1500[c]

*) 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 μ g/kg limed*)	unlimed
1 0.00 % Se	0.00 % Se	40[a]	75[a]
2a 0.00 % Se	0.01 % Se	55[a]	60[a]
3a 0.00 % Se	0.05 % Se	70[ab]	85[ab]
4a 0.00 % Se	0.10 % Se	105[bc]	130[b]
2b 0.01 % Se	0.01 % Se	110[c]	95[b]
3b 0.05 % Se	0.05 % Se	370[d]	390[c]
4b 0.10 % Se	0.10 % Se	1100[c]	1300[d]

*) 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 Na_2SeO_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 22. 5. 1978 before liming and fertilizing were as follows:

soil type	fine sand	
pH H_2O	6.15	
Ca NH_4Ac	1400	mg/l soil
K NH_4Ac	167	"
P NH_4Ac	17	"
Mg NH_4Ac	158	"
B hot water	0.8	"
Cu 2M HCl	7.6	"
Mn $MgSO_4$	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 H_2O	6.0	
Ca NH_4Ac	1640	mg/l soil
K NH_4Ac	164	"
P NH_4Ac	16	"
Mg NH_4Ac	102	"
B hot water	0.5	"
Cu 2M HCl	8.1	"
Mn $MgSO_4$	12.6	"
Se water	0.0136	"

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		potato crop kg/ha			
		1978		1979	
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

		1978	1979
F	Se fertilizing	2.91	0.01
s_x	" "	5.6 %	4.4 %
F	liming	2.24	0.78
s_x	"	4.3 %	6.2 %

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

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 matter[1])	
	limed	unlimed	limed	unlimed
1 0.00 % Se	27 670	24 380	< 10[a]	10[a]
2 0.01 % Se	28 290	25 430	23[a]	27[a]
3 0.05 % Se	28 690	27 500	110[b]	100[b]
4 0.10 % Se	27 980	24 640	190[c] [2])	213[c]

[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 μ g/kg dry matter			
			limed		unlimed	
			flour[1])	unleavened loaf	flour[1])	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(40[2])	50	50 (40[2])
2	0.01 % Se	....	120	130(90)	110	120 (80)
3	0.05 % Se	....	390	500(450)	430	490 (430)
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 paretheses 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 μ g/kg dry matter		corresponding boiled and peeled potato Se μ g/kg dry matter	
1978	1979	limed	unlimed	limed	unlimed
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 μ g/kg during the first year. When 250 g Se/ha were given, the selenium content increased by 404 μ g/kg on an average, and the content rose by a mean of 925 μ g/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 μ g/kg, and the content of wheat by 64 μ g/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 timothy 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 extents 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 fertilizers: 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:

	wheat		barley		potato	
Se content of fertilizer	Se-uptake g/ha	Se increase % of quantity given	Se-uptake g/ha	Se increase % of quantity given	Se-uptake g/ha	Se increase % of quantity given
0.00	0.24	–	0.22	–	0.03	–
0.01	0.28	0.08	0.66	0.88	0.10	0.07
0.05	0.92	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 KORKMAN 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 fertilizing 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, $Na_2SeO_3 \cdot 5H_2O$, 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 μ g 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 μ g/kg; 250 g Se/ha by approximately 400 μ g/kg; and 500 g Se/ha by more than 900 μ g/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 μ g Se/kg dry matter when the soil was enriched with 500 g Se in the form of Na_2SeO_3 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, kevätvehnän ja perunan seleenipitoisuuteen

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Vuosina 1978 ja 1979 tehtiin Kemira Oy:n koetilalla seleenilannoituskokeita käyttäen seleenilähteenä natriumseleniittiä, $NaSeO_3 \cdot 5H_2O$. Ruiskutuskokeita tehtiin ohralla, lannoituskokeita maan kautta ohralla, kevätvehnällä ja perunalla. Maahan annettavaa lannoitusta varten valmistettiin Kemiran koetehtaalla kahden lannoitelajin seleenipitoisia rinnakkaistuotteita, joissa oli 0,00, 0,01, 0,05 ja 0,10 % seleeniä.

Ruiskutettaessa 0,1, 0,5 ja 1,0 kg Se/ha päästiin seleenipitoisuuksiin, jotka ovat selvästi korkeampia kuin tavoitteena usein pidetty 50–100 μg Se/kg kasvin kuiva-ainetta. Mikäli ruiskuttamalla pyritään korottamaan satotuotteiden seleenipitoisuutta, tarvitaan vielä kenttäkoekokemuksia lisää oikean käyttömäärän ja ruiskutusajankohdan määrittämiseksi.

Maahan annettaessa seleenilannoitus korotti viljojen pitoisuuksia siten, että 50 g Se/ha korotti runsaalla 50 μg/kg, 250 g Se/ha noin 400 μg/kg ja 500 g Se runsaalla 900 μg/kg jyviä. Kevätvehnällä seleeni jakautui jyvän eri osiin siten, että kuoriosan pitoisuus oli korkein ja ydinosan pitoisuus alhaisin. Kuoren Se-pitoisuus oli kuitenkin keskimäärin vain 32 % korkeampi kuin ydinosan.

Perunan seleenipitoisuus nousi tasolle 100 μg Se/kg k.a. annettaessa maahan 500 g Se Na_2SeO_3:na hehtaaria kohti. Ilman lisäseleeniä perunan Se-pitoisuudet olivat varsin alhaisia. Perunan seleenipitoisuudet eivät laskeneet mukuloita keitettäessä.

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