Annales Agriculturae Fenniae

Maatalouden tutkimuskeskuksen aikakauskirja

Vol. 4, 4

Journal of the Agricultural Research Centre

Helsinki 1965

ANNALES AGRICULTURAE FENNIAE

Maatalouden tutkimuskeskuksen aikakauskirja
Journal of the Agricultural Research Centre

Ilmestyy 4—6 numeroa vuodessa; ajoittain lisänidoksia
Issued as 4—6 numbers yearly and occasional supplements

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ANNALES AGRICULTURAE FENNIAE, VOL. 4: 223—237 (1965)

Seria ANIMALIA DOMESTICA N. 13 — Sarja KOTIELÄIMET n:o 13

SOME COEFFICIENTS OF HERITABILITY IN HORSES

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Received August 14, 1965

In horsebreeding, attention is paid to a great number of characteristics, only a few of which have been the subject of genetic investigations in our own stock. Investigations on the heritability of the most important characteristics have now become of great interest because, since the beginning of this year, the programme of Finnish horse breeding has been changed. Along with the studbook of draught horses, instead of the former studbook of general horses, the studbook for trotters has been instituted. Improvements in the breeding programme are expected to make both draught horse and trotter breeding better defined and more consistent, and to increase interest particularly in improving the draught horse. The material investigated consists of 5 996 mares of different ages, which have been entered in the studbook during the years 1952 to 1963. The estimation of the coefficients of heritability is based on the intraclass correlation of paternal half-sibs, calculated by variance analysis. The effect of variance between sires has been calculated separately in different age classes within both year classes and districts. The horses were divided into four-year classes according to whether their entry in the studbook took place in the period 1952—55, 1956—59 or 1960—63. The mares of each of these classes were divided into district groups according to the studbook districts where they had been registered.

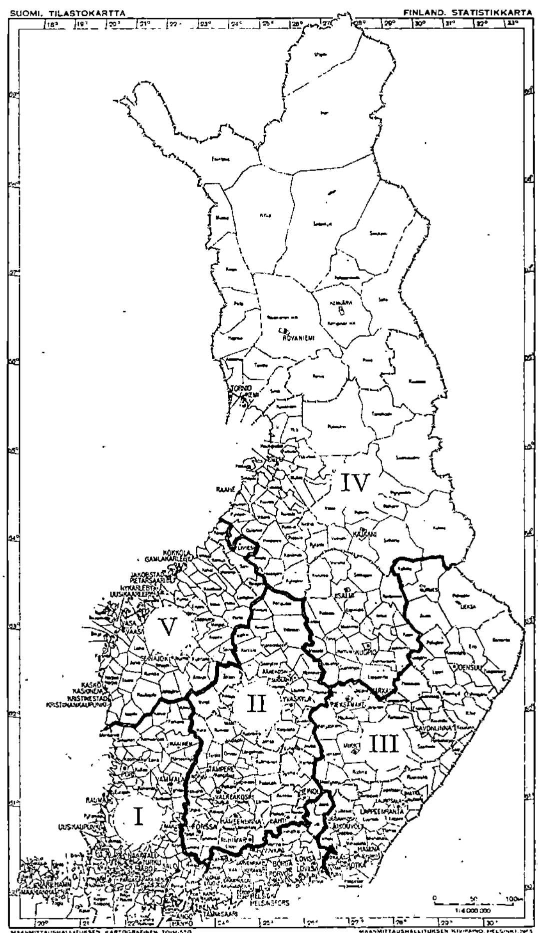

Fig. 1. The boundaries of the studbook districts.
Kuva 1. Kantakirjapiirien rajat.

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Table 1. The averages of the four-year-old mares by the 4-year classes and districts (d)

Taulukko 1. Nelivuotiaiden tammojen keskiarvot vuosiluokittain ja piireittäin

Characteristic *Ominaisuus*	Ageclass *Ikä-lk*	1952—5	I $^{d}_{p}$	II $^{d}_{p}$	III $^{d}_{p}$	IV $^{d}_{p}$	V $^{d}_{p}$
	1 799	759	150	184	65	223	137
1 Pulling power, in kilos [1]) — *Vetovoima kg*	437.4	425.8	421.0	425.0	436.0	429.9	421.0
2 Pulling power per cent [2]) — *Vetovoima %*	76.7	75.4	74.0	76.4	79.4	74.3	75.3
3 Steps — *Porrasluku*	7.8	7.6	7.3	7.7	8.2	7.5	7.5
4 Pace speed — *Käyntiaika*	8.17	8.22	8.28	8.34	8.05	8.24	8.03
5 Trotting speed — *Juoksuaika*	2.28	2.28	2.25	2.29	2.28	2.32	2.24
6 Draught points — *Vetopisteet*	7.4	7.3	7.2	7.3	7.7	7.1	7.3
7 Pace points — *Käyntipisteet*	3.9	3.8	3.6	3.4	4.2	3.7	4.3
8 Trotting points — *Juoksupisteet*	3.1	3.0	3.2	3.0	3.1	2.7	3.3
9 Style of gait — *Liikkeet*	2.4	2.3	2.2	2.2	2.4	2.4	2.3
10 Temperament — *Luonne*	4.5	4.4	4.4	4.4	4.4	4.2	4.5
11 Performance points [3]) — *Koepisteet*	21.3	20.7	20.7	20.3	21.8	20.1	21.6
12 Type judging points — *Tyypit*	4.8	4.7	4.6	4.5	4.5	4.7	4.9
13 Body shape — *Runko*	5.8	5.6	5.9	5.5	5.3	5.5	5.7
14 Feet — *Jalat*	3.5	3.5	3.5	3.4	3.5	3.4	3.9
15 Hoofs — *Kaviot*	2.9	2.8	2.7	3.0	2.7	2.6	3.0
16 Conformation judging points [4]) — *Rakennepisteet*	17.0	16.5	16.6	16.5	16.0	16.2	17.4
17 Points together [5]) — *Pisteet yhteensä*	38.3	37.2	37.3	36.7	37.8	36.3	39.0
18 Height of withers — *Säkäkorkeus*	157.7	157.6	157.0	155.8	157.7	159.5	157.8
19 Height of the rump — *Lautaskorkeus*	157.8	157.8	157.1	156.2	157.7	159.6	157.9
20 Body length — *Vartalon pituus*	168.4	167.9	167.7	166.8	167.9	169.0	167.5
21 Circumference of chest — *Rinnan ympärys*	188.7	188.1	189.2	187.5	185.8	188.9	187.7
22 Depth of chest — *Rinnan syvyys*	77.3	77.1	77.2	76.5	76.2	78.2	76.5
23 Width of shoulders — *Ryntään leveys*	45.8	45.6	45.9	45.6	45.2	45.3	46.1
24 Front width of hips — *Lautasen etuleveys*	58.5	58.3	58.4	57.6	58.4	58.3	58.8
25 Back width of hips — *Lautasen takaleveys*	55.2	54.8	55.1	54.6	54.7	54.8	54.9
26 Circumference of front knee — *Polven ympärys*	33.4	33.3	33.3	33.0	33.3	33.1	33.8
27 Circumference of front cannon — *Etusäären ympärys*	20.3	20.3	20.5	20.1	20.2	20.4	20.5
28 Bredth of front cannon — *Etusäären leveys*	7.5	7.5	7.6	7.5	7.3	7.5	7.5
29 Circumference of hind cannon — *Takasäären ympärys*	22.6	22.6	23.0	22.5	22.4	22.5	22.6
30 Bredth of hind cannon — *Takasäären leveys*	8.7	8.7	8.8	8.8	8.6	8.7	8.7
31 Weight estimation — *Painon arvio*	569.7	564.6	570.6	557.1	550.1	573.1	560.8
32 Fattness — *Lihavuusaste*	4.3	4.2	4.4	4.4	4.1	4.0	4.3

Characteristic *Ominaisuus*	1956—9	I $^{d}_{p}$	II $^{d}_{p}$	III $^{d}_{p}$	IV $^{d}_{p}$	V $^{d}_{p}$	1960—3	I $^{d}_{p}$	II $^{d}_{p}$	III $^{d}_{p}$	IV $^{d}_{p}$	V $^{d}_{p}$
	521	60	60	164	183	54	519	39	82	104	214	80
1	440.3	425.2	445.1	450.0	430.9	454.0	451.3	432.4	445.7	453.6	453.2	458.2
2	77.5	75.7	77.0	79.4	75.3	81.6	77.9	73.8	79.0	79.4	77.6	77.7
3	7.9	7.6	7.9	8.2	7.5	8.2	8.1	7.3	8.2	8.2	7.9	8.5
4	8.13	8.17	8.25	8.10	8.14	7.56	8.14	8.20	8.34	8.08	8.14	7.58
5	2.26	2.16	2.31	2.25	2.31	2.16	2.29	2.28	2.32	2.25	2.32	2.20
6	7.5	7.5	7.3	7.7	7.3	7.7	7.6	7.2	7.6	7.7	7.5	7.8
7	4.0	3.9	3.6	4.1	3.9	4.4	4.0	3.8	3.4	4.1	4.0	4.4
8	3.2	3.8	2.8	3.2	2.8	3.8	3.0	3.0	2.7	3.2	2.8	3.6
9	2.4	2.3	2.4	2.4	2.5	2.6	2.6	2.3	2.4	2.5	2.7	2.6
10	4.5	4.6	4.4	4.6	4.5	4.7	4.6	4.4	4.6	4.6	4.6	4.9
11	21.6	22.0	20.5	22.0	21.0	23.2	21.7	20.7	20.7	22.1	21.5	23.4
12	4.8	4.9	4.9	4.6	4.9	5.2	5.0	4.9	4.9	4.8	5.1	5.4
13	5.8	6.2	6.1	5.4	5.9	6.2	6.2	6.3	6.1	5.8	6.2	6.5
14	3.5	3.6	3.3	3.4	3.6	3.7	3.6	3.7	3.6	3.4	3.7	3.8
15	2.8	2.9	3.0	2.7	2.8	3.0	3.0	2.9	3.2	2.8	3.0	3.2
16	17.0	17.5	17.3	16.0	17.2	18.0	17.9	17.8	17.8	16.7	18.0	19.0
17	38.6	39.6	37.8	38.0	38.2	41.2	39.6	38.6	38.5	38.8	39.6	42.3
18	157.8	156.5	156.8	158.3	158.5	156.6	157.8	158.1	155.6	158.7	158.4	156.9
19	157.8	156.5	157.0	158.2	158.5	156.6	157.8	158.0	155.8	158.7	158.4	157.0
20	168.8	167.2	167.5	169.5	169.2	168.3	168.7	169.0	166.7	168.8	169.9	167.3
21	188.6	188.2	190.9	187.8	188.9	188.2	189.6	191.2	189.0	188.8	190.4	188.3
22	77.2	77.1	76.6	77.2	77.7	76.6	77.8	77.9	76.1	77.9	78.5	77.2
23	45.7	45.9	46.5	45.3	45.5	46.6	46.3	47.3	46.5	45.6	45.8	47.9
24	58.6	58.2	57.9	58.9	58.5	59.0	58.8	58.7	58.3	59.1	58.6	59.6
25	55.2	55.1	55.4	54.6	55.5	55.7	55.8	56.1	55.5	54.6	56.0	56.8
26	33.3	33.2	33.3	33.5	33.2	33.3	33.6	33.6	33.2	33.6	33.7	33.4
27	20.2	20.3	20.3	20.4	20.1	20.2	20.3	20.4	20.2	20.3	20.3	20.3
28	7.4	7.4	7.5	7.4	7.4	7.3	7.5	7.5	7.5	7.3	7.5	7.4
29	22.5	22.9	22.7	22.6	22.3	22.3	22.6	22.9	22.6	22.5	22.6	22.2
30	8.6	8.7	8.8	8.6	8.6	8.5	8.7	8.8	8.7	8.6	8.7	8.6
31	570.1	562.3	580.5	568.1	573.9	560.1	576.9	588.1	565.7	572.6	586.1	563.6
32	4.3	4.7	4.8	4.0	4.2	4.4	4.3	4.8	4.6	4.1	4.1	4.4

[1]) maximum draught
[2]) » » per cent of liveweight
[3]) 6 + 7 + 8 + 9 + 10
[4]) 12 + 13 + 14 + 15
[5]) 11 + 16

Step = A pulling stretch of 50 m. On the first step is the pulling resistance 25 % of the live weight, on the second 30 %, on the third 35 % a.s.o.

The material has been divided into 4-year-classes in order to eliminate from the heritability estimates the disturbing influence of any development which may possibly have taken place during the eight years concerned. The material has further been divided into districts in order to avoid errors due to the different conditions in different districts and possible differences in estimation by the studbook specialists.

Strictly speaking, the material is slightly selected, because only the mares that have been entered in the studbook have been included. Because the grounds for rejection in studbook tests may have been quite different, it has not been possible to direct culling very effectively to any particular characteristic. The number of rejected mares is quite small, only c. 15 per cent, so that culling cannot very much influence the heritability estimates. By including only studbook mares in the investigation the advantage has been gained that the heritability of each characteristic has been estimated within the same series of animals.

The averages of the age-classes and districts have been compiled in Tables 1—4. They show that age classes differ very slightly from each other, the older mares mostly being inferior to the young ones as regards their measurements and points. Only the results of pulling, walking and trotting tests form a clear exception in which the performance of the older horses has proved superior. Width of shoulders is the only measurement that increases as the horse grows older. The generally smaller measurements of the older age-classes can probably be explained by the fact that the best and most rapidly devel-

Table 2. The averages of the five-year-old mares by the 4-year classes and districts (d)
Taulukko 2. Viisivuotiaiden tammojen keskiarvot vuosiluokittain ja piireittäin

Characteristic *Ominaisuus*	Ageclass *Ikä-lk*	1952—5	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}
	1 989	1 010	225	272	59	194	260
1 Pulling power, in kilos [1]) — *Vetovoima kg*	455.4	447.3	444.2	450.9	461.8	440.4	447.7
2 Pulling power per cent [2]) — *Vetovoima %*	79.9	78.9	77.5	79.9	83.9	76.8	79.5
3 Steps — *Porrasluku*	7.4	7.2	6.9	7.4	8.0	7.0	7.4
4 Pace speed — *Käyntiaika*	8.14	8.18	8.18	8.32	8.11	8.27	8.00
5 Trotting speed — *Juoksuaika*	2.26	2.26	2.24	2.29	2.26	2.30	2.23
6 Draught points — *Vetopisteet*	7.1	7.0	6.8	7.1	7.6	6.8	7.2
7 Pace points — *Käyntipisteet*	4.0	3.9	3.8	3.5	4.1	3.6	4.4
8 Trotting points — *Juoksupisteet*	2.9	2.9	3.0	2.7	3.0	2.6	3.1
9 Style of gait — *Liikkeet*	2.3	2.2	2.1	2.1	2.4	2.3	2.3
10 Temperament — *Luonne*	4.5	4.4	4.5	4.3	4.4	4.3	4.5
11 Performance points [3]) — *Koepisteet*	20.8	20.4	20.2	19.7	21.5	19.7	21.5
12 Type judging points — *Tyypit*	4.7	4.6	4.6	4.5	4.3	4.7	4.8
13 Body shape — *Runko*	5.7	5.6	5.9	5.5	5.2	5.5	5.5
14 Feet — *Jalat*	3.5	3.4	3.4	3.2	3.4	3.4	3.7
15 Hoofs — *Kaviot*	2.8	2.8	2.7	2.9	2.8	2.5	2.9
16 Conformation judging points [4]) — *Rakennepisteet*	16.8	16.4	16.7	16.1	15.8	16.1	16.9
17 Points together [5]) — *Pisteet yhteensä*	37.6	36.8	36.9	35.9	37.3	35.8	38.4
18 Height of withers — *Säkäkorkeus*	157.4	157.1	156.8	155.9	158.8	158.8	156.9
19 Height of the rump — *Lautaskorkeus*	157.6	157.3	157.0	156.3	158.7	159.0	157.0
20 Body length — *Vartalon pituus*	168.0	167.4	167.9	167.0	168.2	167.7	167.1
21 Circumference of chest — *Rinnan ympärys*	188.7	188.4	189.7	188.3	185.8	188.6	187.6
22 Depth of chest — *Rinnan syvyys*	77.2	77.1	77.2	76.9	76.5	78.0	76.4
23 Width of shoulders — *Ryntään leveys*	46.1	45.9	46.3	45.5	46.1	45.3	46.3
24 Front width of hips — *Lautasen etuleveys*	58.4	58.1	58.4	57.5	58.6	57.9	58.7
25 Back width of hips — *Lautasen takaleveys*	55.1	54.9	55.3	54.6	55.1	54.5	54.9
26 Circumference of front knee — *Polven ympärys*	33.1	33.1	33.3	32.8	33.2	32.9	33.3
27 Circumference of front cannon — *Etusäären ympärys*	20.2	20.3	20.5	20.0	20.2	20.2	20.3
28 Bredth of front cannon — *Etusäären leveys*	7.4	7.5	7.6	7.5	7.3	7.5	7.4
29 Circumference of hind cannon — *Takasäären ympärys*	22.5	22.6	23.1	22.3	22.5	22.3	22.5
30 Bredth of hind cannon — *Takasäären leveys*	8.6	8.7	8.8	8.7	8.6	8.6	8.6
31 Weight estimation — *Painon arvio*	568.8	564.6	575.2	562.9	551.5	566.9	558.6
32 Fattness — *Lihavuusaste*	4.2	4.2	4.3	4.4	4.1	4.0	4.3

Characteristic *Ominaisuus*	1956—9	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}	1960—3	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}
	620	67	86	165	187	115	359	37	61	110	58	93
1	460.1	439.1	456.4	468.8	449.5	480.0	469.7	455.0	460.0	472.2	471.8	477.5
2	80.3	79.3	80.2	80.8	78.1	84.1	81.8	79.5	80.4	81.8	81.3	84.0
3	7.5	7.2	7.6	7.6	7.0	8.0	7.7	7.1	7.5	7.6	7.6	8.2
4	8.10	8.10	8.28	8.07	8.14	7.51	8.08	8.17	8.38	8.07	8.05	7.49
5	2.26	2.21	2.32	2.24	2.31	2.18	2.25	2.24	2.31	2.25	2.32	2.17
6	7.2	7.0	7.2	7.3	6.9	7.6	7.4	6.8	7.2	7.4	7.3	7.7
7	4.1	4.1	3.6	4.1	4.0	4.6	4.1	3.9	3.3	4.1	4.2	4.6
8	2.9	3.1	2.6	3.0	2.6	3.5	3.0	3.0	2.6	3.1	2.6	3.6
9	2.4	2.2	2.3	2.4	2.5	2.4	2.4	2.2	2.3	2.4	2.6	2.5
10	4.5	4.6	4.3	4.5	4.4	4.8	4.6	4.5	4.4	4.6	4.4	4.8
11	21.2	21.2	20.2	21.4	20.4	22.9	21.5	20.4	19.9	21.4	21.1	23.1
12	4.8	4.7	4.7	4.5	4.8	5.2	4.9	4.8	4.9	4.7	4.9	5.2
13	5.8	6.1	5.9	5.5	5.9	6.1	6.0	6.1	5.9	5.8	6.0	6.2
14	3.5	3.5	3.3	3.4	3.5	3.7	3.6	3.6	3.6	3.4	3.5	3.8
15	2.9	3.0	3.1	2.6	2.7	3.1	3.0	3.0	3.2	2.7	2.9	3.2
16	17.0	17.4	16.9	16.1	16.9	18.1	17.5	17.6	17.6	16.7	17.3	18.5
17	38.1	38.6	37.0	37.4	37.3	41.0	38.9	38.0	37.5	38.1	38.4	41.6
18	157.9	156.0	156.6	158.8	158.6	157.5	157.6	156.4	156.6	158.7	158.3	157.1
19	157.8	156.1	156.7	158.6	158.6	157.3	157.8	156.5	156.7	158.8	158.5	157.2
20	168.6	166.9	166.8	169.8	169.0	168.6	168.4	167.9	168.3	169.1	169.1	167.5
21	188.9	187.1	189.7	189.1	189.4	188.5	189.2	189.6	189.5	189.6	190.1	187.8
22	77.4	77.0	76.7	77.5	78.0	77.1	77.4	77.2	76.6	77.8	78.3	76.9
23	46.2	46.1	46.4	46.1	45.8	47.0	46.5	47.1	46.4	46.1	45.8	47.3
24	58.5	57.9	57.5	59.1	58.4	59.0	58.8	58.1	58.6	59.0	58.3	59.3
25	55.3	54.8	55.0	55.3	55.5	55.7	55.4	55.3	55.6	54.5	55.7	56.2
26	33.2	32.9	32.9	33.4	33.0	33.5	33.2	32.7	33.1	33.5	33.3	33.1
27	20.2	20.2	20.2	20.3	20.0	20.3	20.2	20.1	20.3	20.4	20.2	20.1
28	7.4	7.4	7.5	7.3	7.3	7.4	7.4	7.4	7.5	7.4	7.5	7.4
29	22.4	22.8	22.5	22.6	22.1	22.4	22.5	22.4	22.7	22.7	22.6	22.1
30	8.6	8.7	8.7	8.6	8.4	8.6	8.6	8.6	8.8	8.7	8.6	8.5
31	572.7	555.1	570.9	577.6	576.2	571.7	573.8	574.3	575.5	579.0	581.4	561.4
32	4.2	4.4	4.4	4.1	4.2	4.3	4.2	4.7	4.4	4.0	4.1	4.3

[1—5]) See Table 1 — *Katso taulukosta 1*

oped horses are offered to the studbook at the youngest age. The testing of slow-growing animals, which have probably been small-sized as well, has been postponed as long as possible to ensure their entry in the studbook, and in this way such animals have obviously been selected into the groups of older candidates.

The changes from one 4-yearclass to another have been very slight in all age-classes; relatively speaking, the measurements have changed little, whereas considerable progress can be seen in performance and in points of build. Table 5, however, shows that differences between year-classes have not generally been significant. They have been more significant in regard to the absolute pulling power in kilos, style of gait, temperament, body shape and type. Other significant differences have been noticed only in certain measurements of the oldest age-class.

How are we to interpret the fact that the improvement in certain measurements has been greatest in the oldest age-class. In chest circumference, knee circumference and estimated weight the differences between year-classes have been highly significant, and in body-length and width of hips significant. Can the explanation be that

the first year-class of the oldest age-class contains a relative abundance of horses whose development was disturbed by the defective feeding of the war years and the crisis that immediately followed the war. Thus the greater differences between year-classes (than within other age-classes) would be due not to greater variation in the animal material itself but to the greater variability of environmental factors.

Table 5 shows the proportion of the total variance of daughters due to year-classes and also that due to districts and sires. The differences between districts can be seen, even from Tables 1—4, to be considerable, and now it can be seen that they have generally been highly significant in all age classes. Different conditions in different districts are certainly one reason for the variance, but it is not impossible that the horses of different districts vary in their characterictics. Doubtless the part played by environmental factors in determining these variations is more significant than the differences in hereditary traits. It is certain, too that the breeders' attitude is one of the factors that produces territorial variation, its influence is most

Table 3. The averages of the six-year-old mares by the 4-year classes and districts (d)

Taulukko 3. Kuusivuotiaiden tammojen keskiarvot vuosiluokittain ja piireittäin

Characteristic *Ominaisuus*	Ageclass *Ikä-lk*	1952—5	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}
	937	589	122	140	54	55	218
1 Pulling power, in kilos 1) — *Vetovoima kg*	453.8	446.0	447.0	442.1	444.3	433.0	451.6
2 Pulling power per cent 2) — *Vetovoima %*	79.8	79.0	77.9	79.3	81.8	75.8	79.6
3 Steps — *Porrasluku*	7.4	7.2	7.0	7.3	7.6	6.6	7.3
4 Pace speed — *Käyntiaika*	8.12	8.15	8.22	8.32	8.12	8.25	7.59
5 Trotting speed — *Juoksuaika*	2.24	2.26	2.23	2.30	2.20	2.29	2.24
6 Draught points — *Vetopisteet*	7.1	7.0	6.9	7.0	7.3	6.5	7.1
7 Pace points — *Käyntipisteet*	4.0	3.9	3.7	3.5	4.0	3.7	4.4
8 Trotting points — *Juoksupisteet*	3.0	2.9	3.1	2.6	3.3	2.7	3.0
9 Style of gait — *Liikkeet*	2.3	2.2	2.1	2.1	2.3	2.3	2.3
10 Temperament — *Luonne*	4.5	4.4	4.5	4.4	4.5	4.2	4.5
11 Performance points 3) — *Koepisteet*	21.0	20.5	20.3	19.6	21.5	19.3	21.3
12 Type judging points — *Tyypit*	4.8	4.7	4.7	4.6	4.4	4.6	4.8
13 Body shape — *Runko*	5.7	5.6	5.9	5.6	5.2	5.4	5.6
14 Feet — *Jalat*	3.5	3.5	3.5	3.3	3.4	3.2	3.7
15 Hoofs — *Kaviot*	2.8	2.7	2.7	2.8	2.7	2.4	2.8
16 Conformation judging points 4) — *Rakennepisteet*	16.8	16.5	16.8	16.2	15.8	15.7	17.0
17 Points together 5) — *Pisteet yhteensä*	37.7	37.0	37.2	35.9	37.2	35.1	38.2
18 Height of withers — *Säkäkorkeus*	157.2	157.0	156.5	155.3	157.8	159.0	157.6
19 Height of the rump — *Lautaskorkeus*	157.2	157.1	156.5	155.7	158.0	159.3	157.5
20 Body length — *Vartalon pituus*	167.7	167.3	167.6	166.5	167.0	168.7	167.5
21 Circumference of chest — *Rinnan ympärys*	188.8	188.6	189.9	188.0	185.3	188.9	189.0
22 Depth of chest — *Rinnan syvyys*	77.1	76.9	77.1	76.6	76.0	78.3	76.9
23 Width of shoulders — *Ryntään leveys*	46.4	46.2	46.4	45.6	46.0	45.1	46.9
24 Front width of hips — *Lautasen etuleveys*	58.2	58.0	58.1	57.1	58.3	57.7	58.6
25 Back width of hips — *Lautasen takaleveys*	55.0	54.8	55.1	54.4	54.9	54.4	55.0
26 Circumference of front knee — *Polven ympärys*	33.1	33.0	33.0	32.6	32.9	32.9	33.2
27 Circumference of front cannon — *Etusäären ympärys*	20.2	20.3	20.4	20.0	20.2	20.2	20.4
28 Bredth of front cannon — *Etusäären leveys*	7.4	7.4	7.5	7.5	7.3	7.4	7.4
29 Circumference of hind cannon — *Takasäären ympärys*	22.5	22.5	22.9	22.3	22.3	22.3	22.6
30 Bredth of hind cannon — *Takasäären leveys*	8.6	8.7	8.7	8.7	8.5	8.7	8.7
31 Weight estimation — *Painon arvio*	568.1	565.7	575.5	558.4	544.3	572.3	568.5
32 Fattness — *Lihavuusaste*	4.2	4.3	4.4	4.4	4.0	3.8	4.2

Characteristic	1956—9	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}	1960—3	I^{d}_{p}	II^{d}_{p}	III^{d}_{p}	IV^{d}_{p}	V^{d}_{p}
	220	16	34	69	44	57	128	14	16	42	16	40
1	463.7	443.5	447.5	473.4	448.1	479.3	472.7	474.9	467.1	469.5	481.0	474.3
2	81.2	81.0	77.8	82.9	76.6	84.8	81.3	81.9	78.8	81.4	81.8	81.8
3	7.6	7.5	7.1	8.1	6.8	8.2	7.7	7.6	7.3	7.6	7.6	8.1
4	8.08	8.12	8.09	8.11	8.21	7.52	8.01	8.22	8.17	8.02	8.19	7.40
5	2.22	2.17	2.23	2.24	2.28	2.16	2.23	2.24	2.29	2.22	2.27	2.19
6	7.3	7.3	6.8	7.6	6.7	7.7	7.4	7.3	6.9	7.3	7.4	7.6
7	4.1	4.4	4.0	4.1	3.8	4.6	4.2	3.7	4.1	4.2	3.8	4.6
8	3.1	3.6	3.1	3.0	2.7	3.5	3.2	2.8	2.8	3.3	2.9	3.5
9	2.4	2.4	2.1	2.3	2.4	2.5	2.5	2.4	2.4	2.4	2.5	2.6
10	4.6	4.9	4.6	4.6	4.4	4.8	4.7	4.6	4.7	4.5	4.6	4.9
11	21.6	22.2	20.6	21.8	19.9	23.1	21.9	20.8	20.9	21.8	21.3	23.1
12	4.9	4.8	4.8	4.5	4.9	5.3	5.0	5.0	5.1	4.8	4.8	5.2
13	5.8	5.9	6.1	5.4	6.0	6.1	6.0	6.4	6.2	5.7	5.9	6.2
14	3.5	3.4	3.2	3.4	3.4	3.8	3.6	3.7	3.7	3.5	3.4	3.8
15	2.8	2.8	3.0	2.5	2.8	3.1	2.9	3.1	3.0	2.7	2.7	3.1
16	17.0	17.0	17.1	15.9	17.1	18.3	17.6	18.1	18.0	16.7	16.9	18.4
17	38.6	39.2	37.7	37.6	36.9	41.4	39.5	38.9	38.9	38.4	38.2	41.5
18	157.6	156.3	156.5	157.5	159.0	157.6	157.7	156.0	156.4	158.8	158.1	157.4
19	157.4	156.1	156.4	157.3	158.8	157.4	157.6	155.9	156.6	158.9	157.8	157.3
20	168.2	166.5	167.5	168.2	170.0	167.8	168.2	168.2	167.4	168.4	169.6	167.6
21	188.6	186.3	190.2	187.6	190.2	188.2	190.0	190.4	193.2	189.9	191.1	188.3
22	77.2	77.1	76.8	77.1	78.2	77.1	77.8	77.6	77.6	78.2	78.3	77.4
23	46.3	45.3	46.6	45.6	46.6	46.9	47.1	47.6	47.5	46.5	45.4	48.2
24	58.2	57.9	57.7	58.2	58.4	58.6	58.9	58.9	59.8	58.5	58.1	59.2
25	55.0	54.7	55.1	54.5	55.5	55.4	55.6	56.1	55.9	54.4	55.8	56.5
26	33.1	33.2	33.2	32.9	33.2	33.3	33.3	33.1	33.1	33.5	33.1	33.2
27	20.3	20.3	20.2	20.5	20.0	20.3	20.2	20.5	20.1	20.3	20.0	20.0
28	7.4	7.4	7.5	7.3	7.3	7.4	7.4	7.6	7.5	7.3	7.4	7.4
29	22.5	22.7	22.6	22.6	22.2	22.4	22.5	22.9	22.5	22.5	22.3	22.3
30	8.6	8.7	8.8	8.6	8.5	8.6	8.6	8.7	8.7	8.6	8.4	8.6
31	569.0	547.7	576.9	562.3	585.7	565.3	577.9	580.4	596.6	577.8	590.6	564.5
32	4.2	4.2	4.6	3.9	4.3	4.2	4.3	4.6	4.6	4.2	4.3	4.2

1—5) See Table 1 — *Katso taulukosta 1*

strongly felt when the breeding objective is being modified. Particularly the interest shown in sulky racing and the interest in improving the performance of the draught-horse as a puller vary from district to district. It is also quite natural the individual views of the local stud-book specialists when judging and appraising horses play a considerable role, especially as regards the differences of measurements that are the results of visual estimation.

As a whole, the differences between sires are also very significant. The most uncertain results are those in the class of six-year-old horses, where the total material as well as the progeny per father has been least. Obviously none of the 32 traits that have been investigated is independent of hereditary influences. Thus, there are good grounds for calculating the coefficients of heritability on the basis of the results obtained. The results also show that by selection it is possible to develop all the characteristics investigated, including performance capacity. Pulling power is one of the traits that are most difficult to estimate, but probably not all the possibilities for improved measuring methods have yet been explored.

Table 6 shows the coefficients of heritability. Besides the coefficients of each age-class, their weighed averages are also shown. The table also suggests the maximum values of the coefficients of heritability that could probably be reached if the differences between year-classes and districts could be eliminated.

As can be seen, the coefficients of heritability within different age-classes are generally quite analogous. In some cases the differences are clearly due to chance, but for some traits the values of the coefficients seem to change quite consistently with age. Among the consistently changing coefficients the greatest value most frequently seems to occur in the fifth year, after which there is a slight decrease. This is the trend, for instance, in pace speed, height of withers, height of rump, body length, chest circumference and estimated weight. The heritability of temperament, hoofs and depth of chest seem likewise to develop in a curvilinear way, but the highest value is reached in the six-year-olds. The heritabilities of trotting speed, width of shoulders and width of hips seem to increase rectilinearly with age. On the other hand, the heritabilities of draught points, circumference of

Table 4. The averages of the at least seven-year-old mares by the 4-year classes and districts (d)

Taulukko 4. Vähintään seitsemänvuotiaiden tammojen keskiarvot vuosiluokittain ja piireittäin

Characteristic *Ominaisuus*	Ageclass *Ikä-lk*	1952—5	I_p^d	II_p^d	III_p^d	IV_p^d	V_p^d
	1 271	420	54	81	31	41	213
1 Pulling power, in kilos [1]) — *Vetovoima kg*	464.5	449.3	445.8	452.2	463.3	443.6	448.1
2 Pulling power per cent [2]) — *Vetovoima %*	80.9	80.1	78.4	79.8	80.9	78.0	80.9
3 Steps — *Porrasluku*	7.6	7.4	7.1	7.3	7.5	7.0	7.5
4 Pace speed — *Käyntiaika*	8.07	8.10	8.22	8.26	8.09	8.23	8.00
5 Trotting speed — *Juoksuaika*	2.23	2.24	2.24	2.28	2.19	2.27	2.23
6 Draught points — *Vetopisteet*	7.3	7.1	6.9	7.0	7.2	6.9	7.2
7 Pace points — *Käyntipisteet*	4.1	4.0	3.7	3.6	4.1	3.8	4.3
8 Trotting points — *Juoksupisteet*	3.1	3.0	3.0	2.7	3.3	2.9	3.2
9 Style of gait — *Liikkeet*	2.2	2.1	2.0	2.1	2.1	2.1	2.2
10 Temperament — *Luonne*	4.5	4.4	4.4	4.4	4.5	4.2	4.5
11 Performance points [3]) — *Koepisteet*	21.3	20.8	20.0	19.8	21.3	20.0	21.4
12 Type judging points — *Tyypit*	4.9	4.7	4.6	4.7	4.6	4.7	4.7
13 Body shape — *Runko*	5.8	5.5	5.7	5.6	5.6	5.5	5.5
14 Feet — *Jalat*	3.5	3.4	3.4	3.3	3.2	3.3	3.6
15 Hoofs — *Kaviot*	2.8	2.7	2.7	2.8	2.7	2.5	2.8
16 Conformation judging points [4]) — *Rakennepisteet*	17.0	16.3	16.4	16.3	16.1	16.1	16.5
17 Points together [5]) — *Pisteet yhteensä*	38.3	37.1	36.4	36.0	37.4	36.1	37.8
18 Height of withers — *Säkäkorkeus*	157.3	157.1	157.1	156.1	159.4	158.3	156.8
19 Height of the rump — *Lautaskorkeus*	157.1	157.0	157.0	156.4	159.0	158.3	156.7
20 Body length — *Vartalon pituus*	168.2	167.3	167.5	167.6	170.0	167.8	166.5
21 Circumference of chest — *Rinnan ympärys*	189.1	188.1	189.0	188.8	188.4	189.0	187.4
22 Depth of chest — *Rinnan syvyys*	77.3	76.8	77.3	76.7	77.3	78.1	76.4
23 Width of shoulders — *Ryntään leveys*	46.7	46.3	46.3	46.0	47.5	45.5	46.4
24 Front width of hips — *Lautasen etuleveys*	58.1	57.9	57.9	57.0	59.3	58.0	58.0
25 Back width of hips — *Lautasen takaleveys*	55.0	54.6	54.9	54.7	55.7	54.5	54.3
26 Circumference of front knee — *Polven ympärys*	33.1	32.9	33.1	32.8	33.5	32.6	33.0
27 Circumference of front cannon — *Etusäären ympärys*	20.3	20.2	20.5	20.1	20.5	20.0	20.2
28 Bredth of front cannon — *Etusäären leveys*	7.4	7.4	7.5	7.5	7.4	7.4	7.3
29 Circumference of hind cannon — *Takasäären ympärys*	22.6	22.5	23.1	22.5	22.7	22.2	22.4
30 Bredth of hind cannon — *Takasäären leveys*	8.6	8.6	8.7	8.8	8.6	8.6	8.6
31 Weight estimation — *Painon arvio*	571.9	562.8	569.6	568.9	573.5	569.9	555.8
32 Fattness — *Lihavuusaste*	4.0	4.1	3.9	4.2	4.2	4.0	4.0

Characteristic *Ominaisuus*	1956—9	I_p^d	II_p^d	III_p^d	IV_p^d	V_p^d	1960—3	I_p^d	II_p^d	III_p^d	IV_p^d	V_p^d
	619	72	89	103	91	264	232	21	24	43	43	101
1	470.2	458.0	453.3	474.8	457.5	481.9	476.9	468.3	470.9	479.5	470.4	481.8
2	81.3	79.8	80.0	82.8	79.3	82.2	81.2	79.7	81.3	82.0	79.5	81.8
3	7.7	7.3	7.5	7.8	7.3	8.1	7.7	7.3	7.6	7.7	7.3	8.0
4	8.06	8.14	8.28	8.07	8.19	7.53	8.02	8.05	8.34	7.59	8.01	7.54
5	2.23	2.22	2.26	2.20	2.31	2.20	2.24	2.26	2.32	2.20	2.31	2.21
6	7.4	7.3	7.1	7.6	7.1	7.6	7.4	7.2	7.3	7.5	7.2	7.5
7	4.2	4.0	3.6	4.1	3.9	4.5	4.3	4.1	3.3	4.3	4.4	4.5
8	3.2	3.2	3.0	3.3	2.6	3.4	3.1	3.1	2.5	3.4	2.7	3.3
9	2.2	2.1	2.1	2.3	2.1	2.3	2.3	2.0	2.2	2.4	2.5	2.4
10	4.5	4.6	4.4	4.6	4.3	4.6	4.6	4.5	4.2	4.6	4.5	4.8
11	21.5	21.1	20.3	21.8	20.1	22.5	21.8	21.0	19.5	22.1	21.2	22.5
12	4.9	4.7	4.7	4.7	4.8	5.2	5.1	5.0	4.9	4.8	5.1	5.2
13	5.9	6.0	5.8	5.7	5.8	6.0	6.2	6.2	6.0	6.0	6.2	6.3
14	3.5	3.4	3.2	3.3	3.4	3.7	3.6	3.7	3.3	3.1	3.6	3.8
15	2.8	2.6	2.8	2.6	2.6	3.0	2.9	3.2	3.1	2.7	2.9	3.0
16	17.1	16.7	16.5	16.3	16.6	17.9	17.8	18.0	17.3	16.6	17.8	18.3
17	38.6	37.8	36.7	38.1	36.7	40.4	39.5	39.0	36.8	38.7	39.0	40.9
18	157.3	157.6	156.3	157.7	158.0	157.2	157.5	156.6	156.1	159.2	157.8	157.1
19	157.2	157.6	156.4	157.6	158.0	157.0	157.3	156.4	156.0	159.2	157.8	156.7
20	168.3	168.6	166.5	169.4	168.6	168.3	169.4	169.8	169.0	169.6	170.1	169.0
21	189.3	189.2	189.3	188.8	189.5	189.5	190.2	191.0	190.2	190.5	191.3	189.4
22	77.4	77.7	76.3	77.3	77.8	77.5	77.8	77.8	76.8	78.4	78.6	77.5
23	46.8	46.7	46.5	46.6	45.8	47.3	47.4	47.5	47.2	47.1	46.4	47.9
24	58.1	57.7	57.0	58.5	58.0	58.5	58.5	57.7	58.3	58.5	58.3	58.9
25	55.1	54.9	54.6	54.7	55.2	55.5	55.7	55.7	55.7	54.6	55.7	56.2
26	33.2	33.3	32.9	33.3	33.0	33.2	33.4	33.4	33.2	33.5	33.3	33.4
27	20.4	20.5	20.1	20.9	20.2	20.3	20.3	20.5	20.2	20.4	20.1	20.4
28	7.4	7.5	7.4	7.3	7.4	7.4	7.4	7.5	7.5	7.4	7.4	7.4
29	22.6	23.2	22.5	22.7	22.4	22.6	22.6	23.1	22.7	22.7	22.7	22.5
30	8.6	8.8	8.7	8.6	8.6	8.6	8.7	8.8	8.7	8.6	8.7	8.6
31	573.8	574.4	567.5	574.3	577.6	574.4	583.3	589.7	582.8	585.6	592.5	577.3
32	4.0	4.0	4.2	3.8	3.9	3.9	4.0	4.5	4.4	3.8	3.8	4.0

1—5) See Table 1 — *Katso taulukosta 1*

cannon and feet get weaker as the horse grows older. The change in the heritability of the feet points evidently has an influence on all the conformation judging points as well as on the sum total of the points. The increase in the heritability of draught points also has an effect on the total points.

In many cases the changes in heritability described above seem to be quite understandable. Thus the curvilinear changes can be understood, because the variable stages of development of the horses that are still growing lower the heritability, as compared with the full-grown ones. Eventually, however, the increasing influence of injuries and environmental conditions on older horses mask the hereditary characters and the coefficient of heritability consequently beings to fall again. The latter factors probably have such a strong effect on the foot points that the lowering of heritability has become continuous from the youngest age class. The ever-improving training probably explains the constant increase in the heritability of trotting speed as the horse grows older.

The above consideration shows that the heritability of a certain trait does not necessarily remain the same at different ages. On the other hand, it may even be natural that each characteristic should have an optimum stage at which its heritability is best estimated. The coefficients with their average errors presented here are not sufficient, however, to prove that the developmental trends perceived were real and could be generalized. Therefore, the scrutiny of the coefficients of heritability of different characteristics in the following is based on the weighed averages of all calculated estimates. In spite of this, it can be calculated that the averages of all coefficients in different age-classes from the youngest to the oldest were as follows: 0.29, 0.30, 0.25, and 0.25. The differences are not very great, but nevertheless, on the basis of the figures, it can be stated that horses should be brought for studbook tests at the age of four or five. This would render selection more effective for other reasons besides the generally higher coefficients of heritability within these age-classes.

Table 5. The share of different reasons in the total variance of mares in different age classes
Taulukko 5. Eri syiden osuus tammojen kokonaismuuntelussa eri ikäluokissa

Characteristic *Ominaisuus*	The share of yearclasses % *Vuosiluokkien osuus*				The share of districts % *Piirien osuus*				The share of sires % *Isien osuus*			
	4	5	6	7—	4	5	6	7—	4	5	6	7—
1 Pulling power, in kilos [1]) — *Vetovoima kg*	5.71**	3.16*	4.91**	4.90**	1.46**	2.35***	1.18	1.78**	5.30**	7.57***	5.94*	7.15**
2 Pulling power per cent [2]) — *Vetovoima %*	1.73	1.21	1.12	0.11	4.11***	4.29***	5.01***	0.88	4.42**	3.22*	5.71*	0.75
3 Steps — *Porrasluku*	2.58	0.98	3.12	1.47	4.93***	6.81***	8.33***	4.43***	6.80***	2.62**	2.75	5.58**
4 Pace speed — *Käyntiaika*	0.15	—0.63	—0.34	— 1.91	8.84***	14.18***	14.37***	13.84***	11.73***	12.71***	10.25***	5.90**
5 Trotting speed — *Juoksuaika*	— 1.20	—1.82	0.01	— 1.09	10.57***	9.51***	6.18***	5.77***	8.84***	9.95***	11.66***	13.14***
6 Draught points — *Vetopisteet*	2.42	0.72	1.35	2.12	3.51***	5.33***	6.50***	2.76***	4.43***	3.63***	3.63*	2.93**
7 Pace points — *Käyntipisteet*	— 0.59	—0.86	—1.28	— 1.44	8.91***	13.35***	13.82***	12.75***	11.02***	11.56***	12.67***	3.93*
8 Trotting points — *Juoksupisteet*	— 1.46	—1.44	0.23	— 0.97	10.17***	8.46***	6.64***	6.25***	8.41***	9.19***	9.74***	11.48***
9 Style of gait — *Liikkeet*	5.94**	3.38*	4.33**	1.63	3.23***	3.22***	1.01	2.02**	10.48***	10.21***	9.75***	10.45***
10 Temperament — *Luonne*	4.03**	0.81	3.12*	0.59	1.92***	4.01***	2.19*	3.90***	2.59	6.15***	8.43***	6.56**
11 Performance points [3]) — *Koepisteet*	3.61	1.42	4.37	0.59	9.62***	13.61***	12.92***	14.95***	9.56***	9.54***	8.43***	9.28***
12 Type judging points — *Tyypit*	7.98*	3.18	2.56	6.59*	9.84***	8.02***	9.07***	7.14***	5.89***	4.90**	2.40	4.93**
13 Body shape — *Runko*	10.59*	5.10*	2.98	11.48***	8.07***	4.99***	7.36***	1.54**	6.22***	6.07***	2.50	4.78*
14 Feet — *Jalat*	— 0.60	—0.25	—1.68	— 1.90	9.52***	7.45***	11.11***	13.59***	10.48***	6.64***	4.91*	1.81
15 Hoofs — *Kaviot*	2.36	—0.41	—0.10	0.55	10.66***	11.59***	7.51***	7.48***	9.87***	9.99***	11.32***	7.01**
16 Conformation judging points [4]) — *Rakennepisteet*	10.47*	5.02	2.60	8.18*	12.13***	9.32***	12.08***	10.23***	7.12***	6.39***	5.22*	2.74
17 Points together [5]) — *Pisteet yhteensä*	9.95*	5.35	6.81	6.70	10.94***	15.05***	15.11***	18.24***	8.01***	7.54***	6.75**	5.56**
18 Height of withers — *Säkäkorkeus*	— 2.56	—0.41	—0.98	— 0.60	12.13***	7.86***	8.06***	2.77***	6.27***	8.44***	6.63**	4.26*
19 Height of the rump — *Lautaskorkeus*	— 2.39	—0.97	—1.40	— 0.71	11.01***	7.31***	7.40***	2.86***	6.62***	8.59***	5.84*	5.05*
20 Body length — *Vartalon pituus*	0.22	1.55	0.69	2.68*	4.36***	2.11***	1.26	2.01**	5.34**	6.97***	5.34*	4.42*
21 Circumference of chest — *Rinnan ympärys*	0.88	—0.01	—0.16	1.94**	2.20***	1.79**	3.60**	— 0.31	8.11***	10.24***	9.62***	4.33*
22 Depth of chest — *Rinnan syvyys*	— 0.22	—0.55	1.29	2.07	9.41***	5.53***	3.41**	3.67***	6.82***	7.76***	8.91***	4.15*
23 Width of shoulders — *Ryntään leveys*	1.08	0.74	0.49	2.54	6.36***	4.74***	9.12***	4.11***	8.50***	7.44***	8.95***	9.95***
24 Front width of hips — *Lautasen etuleveys*	1.30*	1.05	1.43	0.19	4.47***	6.60***	6.56***	5.72***	7.68***	10.65***	0.00	11.19***
25 Back width of hips — *Lautasen takaleveys*	4.51	1.66	1.57	4.33*	6.01***	3.97***	5.20*	3.29***	7.14***	8.05***	2.30	8.54***
26 Circumference of front knee — *Polven ympärys*	0.80	—0.58	0.30	2.02**	3.21***	3.95***	1.83*	0.12	6.05***	5.93***	3.40	9.53***
27 Circumference of front cannon — *Etusäären ympärys*	— 0.21	—0.82	—0.86	— 0.05	2.92***	4.41***	3.50***	0.62	7.84***	6.06***	— 1.19	— 3.60
28 Bredth of front cannon — *Etusäären leveys*	2.06	1.24	0.68	— 0.57	4.94***	4.34***	3.27**	3.90***	6.59***	8.22***	5.34*	7.45***
29 Circumference of hind cannon — *Takasäären ympärys*	— 0.90	—1.61	—1.12	— 0.69	6.24***	10.92***	5.57***	5.16***	6.27***	5.83***	2.49	11.84***
30 Bredth of hind cannon — *Takasäären leveys*	1.04	0.65	0.08	— 0.94	3.76***	4.38***	2.05*	3.50***	6.74***	7.25***	5.42*	8.31***
31 Weight estimation — *Painon arvio*	0.98	0.62	0.06	2.56**	2.45***	1.46**	2.80**	— 0.09	7.58***	9.47***	7.02**	4.03*
32 Fattness — *Lihavuusaste*	— 1.98	—0.88	—1.06	— 0.36	9.64***	3.72***	5.32***	1.79*	6.41***	0.00	2.97	7.24***

Statistical significance (F) is denoted by stars as follows:
Tilastollinen merkitsevyys (F) ilmaistu tähdillä seuraavasti:

$P < 0.001$ ***; $P < 0.01$ **; $P < 0.05$ *

1—5) See Table 1 — *Katso taulukosta 1*

The highest heritabilities (0.40 <), according to the averages, have been gained for the speed of trotting and pacing and the style of gait, if the pace points are disregarded. It is only natural that classification by points, which is rougher than that by trotting and pace records, has lowered the heritabilities to some extent. The estimation of the style of gait is obviously the easiest of the visual estimations, because in all age-classes it has given quite a high and equal value to the heritability.

It is worth noting that the estimation of hoofs has led to quite a high value for heritability. Rather high coefficients have further been gained for width of shoulders, circumference of chest and front width of hips. The back width of the hips has proved to be a less reliable measurement than the front width of the hips. The weakest average heritability, in this investigation, has been found for the circumference of the front-cannon. The heritability of fatness is low, although it is surprising that heritability of this characteristic can be detected at all. Evidently the progeny of different sires have different abilities to maintain their condition. As was ascertained earlier, pulling power is also one of the characteristics that are most difficult to estimate, especially when measured as relative pulling power, expressed either as a percentage of the weight, in draught points or in steps.

Yet it must be taken into consideration that during the time in which this investigation has

Table 6. Coefficients of heritability with their average errors*)
*Taulukko 6. Periytymisasteet**)

	Characteristic *Ominaisuus*	Age in years *Ikä vuosia* 4	5	6	7—	Averages *Keskiarvot* Weighed *Punnittu*	Maximum *Maksimi*
1	Pulling power, in kilos 1) — *Vetovoima kg*	0.21±0.08	0.30±0.08	0.24±0.11	0.29±0.10	0.26	0.28
2	Pulling power per cent 2) — *Vetovoima %*	0.18±0.07	0.13±0.07	0.23±0.11	0.03±0.08	0.14	0.14
3	Steps — *Porrasluku*	0.27±0.08	0.10±0.07	0.11±0.10	0.22±0.10	0.18	0.20
4	Pace speed — *Käyntinopeus*	0.47±0.10	0.51±0.09	0.41±0.13	0.24±0.10	0.41	0.48
5	Trotting speed — *Juoksunopeus*	0.35±0.09	0.40±0.09	0.47±0.13	0.53±0.12	0.43	0.46
6	Draught points — *Vetopisteet*	0.18±0.07	0.15±0.07	0.15±0.10	0.12±0.09	0.15	0.16
7	Pace points — *Käyntipisteet*	0.44±0.09	0.46±0.09	0.51±0.14	0.16±0.09	0.40	0.45
8	Trotting points — *Juoksupisteet*	0.34±0.09	0.37±0.08	0.39±0.13	0.46±0.11	0.39	0.41
9	Style of gait — *Liikkeet*	0.42±0.09	0.41±0.09	0.39±0.13	0.42±0.11	0.41	0.44
10	Temperament — *Luonne*	0.10±0.07	0.25±0.08	0.34±0.12	0.26±0.10	0.23	0.23
11	Performance points 3) — *Koepisteet*	0.38±0.09	0.38±0.08	0.34±0.12	0.37±0.11	0.37	0.44
12	Type judging points — *Tyypit*	0.24±0.08	0.20±0.07	0.10±0.10	0.20±0.09	0.19	0.23
13	Body shape — *Runko*	0.25±0.08	0.24±0.08	0.10±0.10	0.19±0.09	0.20	0.25
14	Feet — *Jalat*	0.42±0.09	0.27±0.08	0.20±0.11	0.07±0.08	0.25	0.28
15	Hoofs — *Kaviot*	0.39±0.09	0.40±0.09	0.45±0.13	0.28±0.10	0.38	0.43
16	Conformation judging points 4) — *Rakennepist.*	0.28±0.08	0.26±0.08	0.21±0.11	0.11±0.09	0.22	0.28
17	Points together 5) — *Pisteet yhteensä*	0.32±0.08	0.30±0.08	0.27±0.12	0.22±0.10	0.28	0.36
18	Height of withers — *Säkäkorkeus*	0.25±0.08	0.34±0.08	0.27±0.12	0.17±0.09	0.26	0.29
19	Height of the rump — *Lautaskorkeus*	0.26±0.08	0.34±0.08	0.23±0.11	0.20±0.09	0.27	0.29
20	Body length — *Vartalon pituus*	0.21±0.08	0.28±0.08	0.21±0.11	0.18±0.09	0.23	0.24
21	Circumference of chest — *Rinnan ympärys*	0.32±0.08	0.41±0.09	0.38±0.13	0.17±0.09	0.32	0.34
22	Depth of chest — *Rinnan syvyys*	0.27±0.08	0.31±0.08	0.36±0.12	0.17±0.09	0.27	0.29
23	Width of shoulders — *Ryntään leveys*	0.34±0.09	0.30±0.08	0.36±0.12	0.40±0.11	0.34	0.37
24	Front width of hips — *Lautasen etuleveys*	0.31±0.08	0.43±0.09	0.00±0.09	0.45±0.11	0.33	0.35
25	Back width of hips — *Lautasen takaleveys*	0.29±0.08	0.32±0.08	0.09±0.10	0.34±0.11	0.28	0.30
26	Circumference of front knee — *Polven ympärys*	0.24±0.08	0.24±0.08	0.14±0.10	0.38±0.11	0.26	0.27
27	Circumference of front cannon — *Etus. ymp.*	0.31±0.08	0.24±0.08	—0.05±0.08	—0.14±0.07	0.13	0.14
28	Bredht of front cannon — *Etusäären leveys*	0.26±0.08	0.33±0.08	0.21±0.11	0.30±0.10	0.28	0.30
29	Circumference of hind cannon — *Takas. ymp.*	0.25±0.08	0.23±0.07	0.10±0.10	0.47±0.12	0.26	0.29
30	Bredht of hind cannon — *Takasäären leveys*	0.27±0.08	0.29±0.08	0.22±0.11	0.33±0.10	0.28	0.29
31	Weight estimation — *Painonarvio*	0.30±0.08	0.38±0.08	0.28±0.12	0.16±0.09	0.29	0.30
32	Fatness — *Lihavuusaste*	0.26±0.08	0.00±0.06	0.12±0.10	0.29±0.10	0.16	0.17

*) The average errors are calculated by the approximate method of Robertson (1959)
*) *Keskivirheet on laskettu Robertsonin (1959) likimääräisen menetelmän mukaan*
1—5) See Table 1 — *Katso taulukosta 1*

been made, the pulling points have risen to the eighth step only. Only eight points have been given for the pulling records of the eighth or a higher step, so that the variance of the pulling-record points has come to be abnormal. Simultaneously, it has made the distribution of pulling records generally biassed, because the owners have not been interested enough in getting the maximum pulling power out of the horses. It is clear that this has tended to depress the values for pulling power heritabilities found with different measuring methods. It is impossible to estimate how great this influence has been, but it is not impossible that it has made the coefficients somewhat smaller.

According to this, the pulling power as a percentage of weight seems to be, at least in mare estimates, the most uncertain method of measuring the pulling power. Draught points, in which attention has also been paid to the pulling style, have not been much better — their superiority has no statistical significance whatsoever. Measuring by steps, on the contrary, the variation of which has not been restricted, proves to be better than other relative measurements. The absolute pulling power, measured in kilos, however, proves to be the best measurement of the pulling power if superiority is estimated only according to the coefficient of heritability. It is clear, however, that the heritability of the absolute pulling power, measured in kilos, is the result of the combined effects of size and relative pulling power, the latter being independent of weight. The greater absolute pulling power and capacity for work of large and heavy horses, as compared with smaller ones, is self-evident and a fact recognized by most investigators.

Yet, at the same time, it has often been perceived that the relative pulling power varies widely independently of weight and size. Thus Ishizaki *et al.* (1961) have ascertained that in a performance test all the horses that weighed at least 498 kg succeeded and all those that weighed 478 kg at the most failed, but that of those between these limits many small horses passed the test whilst much larger ones failed. Terho (1942) pointed out that though there is a strong positive correlation between a horse's weight and its absolute pulling power in kilos: $r = 0.420 \pm 0.036$, there is a negative correlation: $r = -0.097 \pm 0.043$, between its weight and relative pulling power. The same negative correlation between weight and relative pulling power has also been ascertained by Vainikainen (1946): $r = -0.08 \pm 0.03$ in all and $r = -0.26 \pm 0.04$ in the horses that have been entered in the studbook, by Pravochenski and Piotraszewski (1954): $r = -0.2 \pm 0.03$, by Hesse (1957) and by Varo and Vainikainen (1958): $r = -0.161 \pm 0.029$. In the last-mentioned investigation the correlation between weight and pulling power in kilos was $r = 0.394 \pm 0.025$.

The above-mentioned correlation coefficients show that while the weight is growing, the pulling power, as measured in kilos, increases, but simultaneously the capacity for performance decreases with respect to the weight. Thus it depends on the object of breeding, what importance must be given in selection to the relative pulling power — which is best measured in steps — or the absolute pulling power in kilos. If efforts are made to increase the pulling power without enlarging the size by improving the pulling inclination, endurance and tenacity, the most suitable basis for selection is the relative estimation. But if the object is primarily only a great absolute pulling capacity, without reference to size, the estimate measured in kilos evidently give the quickest result. Engines, however, have started to replace the horse as a source of pulling power, particularly when great strength is needed. The importance of great pulling power measured in kilos, as represented by large horses, is apparently decreasing. On the other hand, in various functions which, in addition to enduring pulling capacity, also demand tenacious pulling inclination, alertness of disposition and agility, horses, at least for the present, are mainitaining their position as a living source of power because of their versatility, economy and eminent capacity to co-operate with man. Examined against this background, the relative pulling power, measured in steps, seems to be the best basis for estimating a horse's capasity for work.

When the coefficients of heritability, obtained now are compared with those estimated from the results of earlier investigations, considerable agreement can be seen. From the correlation coefficients that have been calculated in the investigations made in Finland, certain coefficients of heritability can be estimated. These have been compiled in Table 7. The greatest differences, compared with the estimates obtained in this investigation, seem to be in the coefficients of heritability of trotting speed, which are based on the correlations calculated by Vainikainen from the dam-son and by Lonka from the sire-son data. The reason for the differences is probably the small number of parents included and also the fact that the influence of common factors may be included in the correlation coefficients.

Table 7. Coefficients of heritability calculated earlier in Finland
Taulukko 7. Suomessa aikaisemmin arvioituja periytymisasteita

Characteristic *Ominaisuus*	Vainikainen (1946)		Lonka (1946)
	The basis of estimation *Arvion peruste*		
	$r_{\text{sire-son}}$ $r_{\textit{isä-poika}}$	$r_{\text{dam-son}}$ $r_{\textit{emä-poika}}$	$r_{\text{sire-son}}$ $r_{\textit{isä-poika}}$
Trotting speed — *Juoksunopeus*	0.40	0.60	0.62
Pace speed — *Käyntinopeus*	0.38	0.24	0.30
Conformation judging points — *Rakenne*	0.36	0.28	
Feet — *Jalat*	0.22	0.28	
Weight — *Paino*			0.20
Pulling power per cent — *Vetovoima, %*	0.14 [1]	0.20 [1]	0.14 [2]
Pulling power, in kilos — *Vetovoima, kg*			0.02

[1] Calculated by draught points — *Vetopisteistä arvioituna*
[2] Calculated by steps — *Porrasluvuista arvioituna*

Heritability seems to be clearer in dam- son correlations than in sire- son correlations, as is suggested by the results obtained by VAINIKAINEN. The high correlation found by LONKA between the weights of dams and sons: $r = 0.33 \pm 0.07$, also supports this view. The coefficient of heritability of the pulling power in kilos, based on the results of LONKA, is also unusually small and obviously due to the inadequate and random material. The investigation on data for stallions made by VARO and VAINIKAINEN (1959) gave a results of the same type, based on the variance between sires. Then the heritability found for the pulling power in kilos was 0.00 within the 4-year-olds and 0.18 within the 5-year-olds, or 0.07 on an average. The average heritability for the number of steps was 0.18.

In the literature available at the Department of Animal Breeding there is very little information about investigations made in other cantries on heritability. There are a couple of statements about trotting speed. ARTZ (1961) has calculated the heritability of the trotting speed of thoroughbred horses to be 0.243 by the dam-daughter regression and 0.1936 by the correlation of paternal half-sibs. The values are smaller than those obtained in Finland. But the values were especially small in OESAG and TOTH's (1959) estimations, according to which the heritability of speed in ridinghorses was only 0.06 and of trotters 0.04.

Summary

The coefficients of heritability of certain characteristics were estimated from material consisting of 5 996 four-, five-, six- and at least seven-year-old mares. The estimation was based on the paternal half-sib correlation, which was calculated within districts and 4-year classes separately in different age-classes. The results are shown in Table 6. It is possible that the most advantageous moment to estimate the heritabilities of different traits is at different ages, although the data utilized here were not sufficient to give significant results in this respect.

REFERENCES

ARTZ, W. 1961. Ein Beitrag zur Auswertung der Leistungsprüfungen in der Vollblutzucht unter besonderer Berücksichtigung der Rennleistungen einzelnen Hengstnachkommenschaften. Giessen. Schr.reihe Tierz. Haustiergenet. 2: 62 pp. Ref. ABA 31: 1782.

HESSE, H.-J. 1957. Körpergrösse, Körpergewicht und Arbeitsleistung bei Kleinpferden. Tierzüchter 9: 348—351. Ref. ABA 26: 41.

ISHIZAKI, S. & HONZAWA, S. & SHINOHARA, A. & KOYAMA, K. 1961. What size of working horse is necessary for deep ploughing? (Relationship between size and working ability in the horse. VI.) J. Kanto-Tosan agric. Exp.Sta., No. 18: 251—258. Ref. ABA 30: 1560.

LONKA, T. 1946. Hevosten vetokyvyn arvostelumahdollisuuksista. (The evaluation of the pulling ability of horses.) Valt. maatal.koetoim. julk. 126: 1—50.

ÓCSAG, I. & TOTH, I. 1959. A ló gyorsaságának öröklötéségéröl. (The heritability of speed in horses.) Agrártud. egy. MezögazdasTud. Karának Közl. (Gödöllö) 1959: 61—67. Ref. ABA 30: 1562.

PRAWOCHEŃSKI, R. & PIOTRASZEWSKI, W. 1954. Wyniki prób sily pociagowej koni robozych w 1951 i 1953 r. z zastosowaniem silomierza. (The results of tests of the loadpulling ability of draft horses in 1951 and 1953 using a dynamometer.) Roczn. Nauk. rol., B. 67: 283—306. Ref. ABA 22: 1306.

TERHO, T. & RØRDAM, H. 1942. Praestationsprøverne og deres betydning for hesteavlen. Nord. Jordbr. forskn. 1942, 1—2.

VAINIKAINEN, V. 1946. Suomalaisen hevosen jalostuksesta. (Breeding the Finnish horse). Suomen Maatal. tiet. seuran julk. 62: 1—117.

VARO, M. & VAINIKAINEN, V. 1958. Der für Pferde verschiedenen Gewichts und Alters anzusetzende Zugwiderstand. Maatal.tiet. aikak. 30: 105—113.

—»— Über die Zuverlässigkeit den Zugergebnisse von Hensgten. Acta agr.fenn. 94, 18: 1—9.

SELOSTUS

Hevosen eräiden ominaisuuksien periytyvyydestä

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Yhteensä 5 996 neli-, viisi-, kuusi- ja vähintään seitsemänvuotiasta tammaa käsittävällä aineistolla arvioitiin eräiden ominaisuuksien periytymisasteet. Arvio perustui isän puoleiseen puolisisarkorrelaatioon, joka laskettiin piirien ja vuosiluokkien sisällä erikseen eri ikäluokista. Tulokset on esitetty taulukossa 6. On mahdollista, että eri ominaisuuksien periytyvyyden arvioimiseen suotuisin ajankohta sattuu eri ikäkausille, joskaan nyt käytetty tutkimusaineisto ei riittänyt antamaan tässä suhteessa merkitseviä tuloksia. Taulukosta 5 voidaan havaita, että vuosiluokkien väliset erot eivät yleensä olleet tilastollisesti merkitseviä. Tarkastellun ajanjakson kuluessa tapahtunut kehitys oli näin ollen yksilöiden kokonaismuunteluun verrattuna vähäistä. Piirien väliset erot olivat sen sijaan suurempia ja yleensä erittäin merkitseviä. Kun ottaa huomioon, että sukupolvikierto on hevosella hidas, tarkasteltu ajanjakso suhteellisen lyhyt ja kehitys eri ikäluokkien aineistoissa ajallisesti ja alueellisesti osittain epäjohdonmukaista, on niin vuosiluokkien kuin piirienkin välisiä eroja pidettävä lähinnä olosuhteiden muutoksista johtuvina. Eroja aiheuttavina ympäristötekijöinä voidaan arvella olleen — luonnonolosuhteiden eroavuuksien ohella — mm. sellaiset inhimillisten tekijöiden aiheuttamat erot kuin arvostelua suorittavien henkilöiden eri piirteisiin kohdistama erilainen arvostus ja hevosten omistajien eri piirteiden kehittämiseen tuntema mielenkiinto.

Isienväliset erot ovat yleensä olleet erittäin merkitseviä, mikä osoittaa, kuten periytymisasteet taulukossa 6, että jalostusvalinnalle on olemassa hyvät edellytykset kaikkien tarkasteltujen ominaisuuksien kehittämiseksi.

ANNALES AGRICULTURAE FENNIAE, VOL. 4: 238—252 (1965)

Seria AGROGEOLOGIA, -CHIMICA et -PHYSICA N. 18
Sarja MAAPERÄ, LANNOITUS JA MUOKKAUS n:o 18

ON DETERMINATION OF LIME REQUIREMENT OF SOILS

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Received August 21, 1965

Estimation of lime requirement forms an important part of soil testing in Finland, where almost all the soils are rather acid. The current method of soil testing, which has been increasingly used over the last fifteen years in this country, is based on the acid ammonium acetate extraction of soil samples. The method is actually a modification of Morgan's method, but instead of sodium acetate, ammonium acetate is used at the concentration of 0.5 molarity, in respect of both ammonium acetate and acetic acid, which gives a pH value of 4.65 for the buffered extractant (Vuorinen and Mäkitie 1955).

In the estimation of lime requirement the amount of exchangeable calcium thus extractable at pH 4.65, the soil type and the pH of the soil are taken into account when liming recommendations for routine soil testing are carried out (Vuorinen 1953; Vuorinen and Kurki 1955).

A fair correlation has been found between the total exchangeable calcium extracted with *N* ammonium acetate at pH 7 or with the *N* ammonium chloride method formerly used (Tuorila *et al.* 1939), and the value obtained with acid ammonium acetate at pH 4.65 (Vuorinen and Mäkitie 1951, 1955). After a single shaking for one hour, such as is used for soil testing, not all the exchangeable calcium is extracted nor is all the calcium in the fraction extracted all exchangeable. Moreover, the fractions are not always comparable where soils of different origin and especially of varying organic matter content are concerned (Mäkitie 1956, 1957).

The amounts of exchangeable calcium in acid soils are naturally related to the lime requirement only in soils of similar exchange characteristics and exchange capacity within the range of neutralization. Appreciable amounts of calcium can be extracted from peat soils in »exchangeable» form with acid ammonium acetate. These amounts are not always correlated with the reaction of the soil or with the actual lime requirement (e.g. Puustjärvi 1957). Mineral soils, particularly clays with a high humus content, as well as soils of mixed composition of mineral and organic matter, often fail to give the expected increase in reaction and response on liming. The gyttja soils, rich in aluminium and sulphur, which are relatively common in Finland, also form a complicated group of soils in which the lime requirement tends to be underestimated (Aarnio 1935, Honkavaara 1951, Purokoski 1959).

In spite of the weaknesses inherent in the method of estimating the lime requirement by means of the amounts of soluble calcium extractable with acid ammonium acetate, the estimation has proved to be quite useful when the tests are interpreted correctly. The determination of the actual exchange acidity of the soil, or so-called net negative charge, would, however, undeniably give a clearer estimate of the neutralization required.

The so-called rapid buffer methods are another possible way of carrying out the determinations in routine soil testing laboratories. Some of these methods have therefore been studied and compared with the present method as well as with simple incubation tests of liming.

Salonen (1952) has previously studied the estimation of lime requirement by a modification of Brown's (1943) rapid buffer method and found it quite suitable as compared with the previous extraction method of Tuorila *et al.* (1939) and with the liming experiments.

Testing the lime requirement by buffer methods

The exchangeable hydrogen or total potential acidity in the pH range of neutralization of a soil indicates the amount of alkali or lime required to raise the reaction to the neutralized pH value wanted. In order to determine the amount of exchangeable hydrogen by a simple rapid method, a suitable buffer solution can be used for leaching and the exchanged acidity measured as the pH difference obtained between the equilibrated soil-buffer suspension and the untreated buffer solution itself. There are not many monobasic weak acids with an acid strength suitable for buffering in the region of 6—7 on the pH scale. p-Nitrophenol has therefore been popular. Schofield (1933) proposed the use of this weak acid for this purpose.

Woodruff's (1947, 1948) method, which has been widely used for lime requirement tests, is a modification in which p-nitrophenol and calcium acetate form a buffered solution. A new modification of the method of Shoemaker *et al.* (1961) with p-nitrophenol solution, in which triethanolamine, calcium acetate, calcium chloride and potassium chromate are also included in the buffer solution, has given a better correlation, especially in cases where Woodruff's method and Mehlich's triethanolamine titration method had failed (Shoemaker *et al.* 1961, Mehlich 1948). In the method of Shoemaker et al. the solution is weakly buffered and specially suitable for mineral soils rich in aluminium, but this method is reported to underestimate the liming needs of organic soils (Pratt and Bair 1962). The method of Adams and Ewans (1962), where p-nitrophenol and boric acid are used, is a modification that should also be mentioned.

Brown (1943) presented a simple method based on N ammonium acetate (neutralized to pH 7) as a buffer solution for the purpose of testing exchangeable hydrogen. Although this solution is actually not a buffer solution in the measuring range between pH 6—7, it gives reproducible values and since it gives the hydrogen exchanged by ammonium it would seem to be the most suitable standard method for all soils. Schachtschabel (1951) has analogously used a calcium acetate solution.

As stated, the exchange acidity is thus estimated by measuring the decrease of the pH of the buffer solution when shaken with the soil. The result is therefore observed at the equilibrium pH, which is different in each case and varies from pH values of nearly 7 down to 6 and even 5.5 in extremely acid peat soils. The neutralization curve and the shape of the curve depend greatly on the clay content and the amount of organic matter in the soil as well as on the character of the exchange complex generally. Therefore attention should be paid to the degree of neutralization at which the lime requirement is determined (e.g. Teräsvuori 1959, Tucker 1960). A correction to a standard pH should therefore be included.

In the case of Brown's method the equilibrium pH values are corrected in this study by extrapolation to the standard value of pH 6.5. This modification is actually possible only when the differences in the pH values are not too large, and assuming that the shape of the neutralization curve of all soils is constant. No practical error will be made, however, by generalization of the slopes of the neutralization curves,

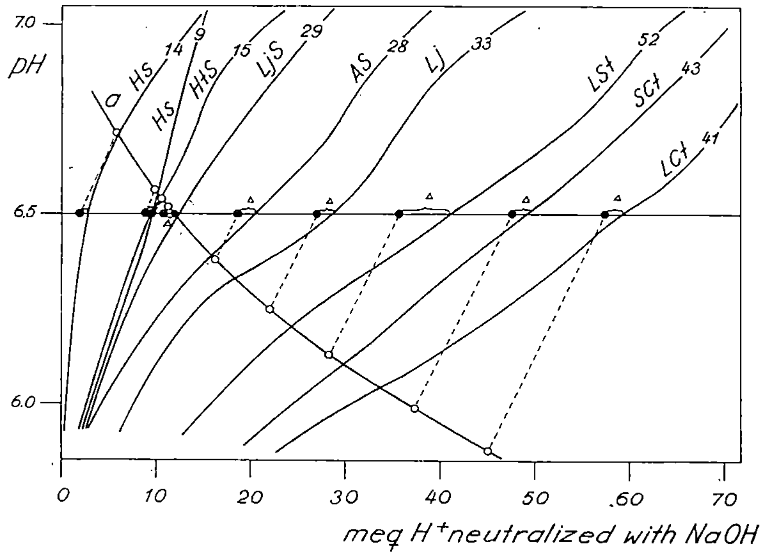

Fig. 1. Neutralization curves of some soils compared with the pH-values by the *N* ammonium acetate method (o) and with corrected (to pH 6.5) values of exchangeable hydrogen (●). Curve *a* represents the titration curve of *N* ammonium acetate.

Kuva 1. Muutamien maiden neutralointikäyrät verrattuina N ammoniumasetaatti menetelmän pH lukuihin (o) ja vaihtuvan vedyn pH 6.5:een korjattuihin arvoihin (●). Käyrä a esittää N ammoniumasetaatin titrauskäyrää.

although the estimate is less accurate if the equilibrium pH deviates greatly from the standard pH value of 6.5, as in the case of soils that are much too acid, especially raw peat soils.

Some neutralization curves, in the important pH range around pH 6—6.5, of the soils under study are presented in Fig. 1. These examples clearly show that the slope of the curves obtained for ordinary mineral soils (curves 9, 14, 15) is 0.1 pH unit per 1—2 meq H^+. For coarse mineral soils low in organic matter the slope is on the average 0.1 pH unit per 1 meq H^+, or even less. For soils rich in organic matter the slope decreases noticeably and, for instance, sample No. 28, a heavy clay with a high humus content, has the value 0.1 pH unit per 3.6 meq H^+. The organogenic soils (samples 33—52) give neutralization curves that are relatively slightly inclined. The slope of these curves is 0.1 pH unit per 4.2—5.4 meq H^+.

The examples in Fig. 1 show that in spite of the unknown shape of the neutralization curve, for practical purposes a standard correction slope (0.1 pH unit per 2 meq H^+) brings the figures very near the points where the neutralization curves cross the standard pH value of 6.5.

Taking into account that overliming is liable to occur with coarse mineral soils, no appreciable correction can be made with these soils, nor is it necessary, since they do not usually contain much exchangeable hydrogen. On the other hand, peat soils and likewise muddy soils as well as clays with a high organic matter content are very difficult to test for exact lime requirement. An average correction can be made and it works with all except raw peat soils, where the lime requirement will still tend to be underestimated with all rapid methods.

Material and methods

The experimental material consisted of 193 samples of acid soils. Of these, 32 samples represented coarse mineral soils, 40 silt soils, 71 clay soils (including 8 gyttja soils) and 50 samples were of organogenic origin. In the last-

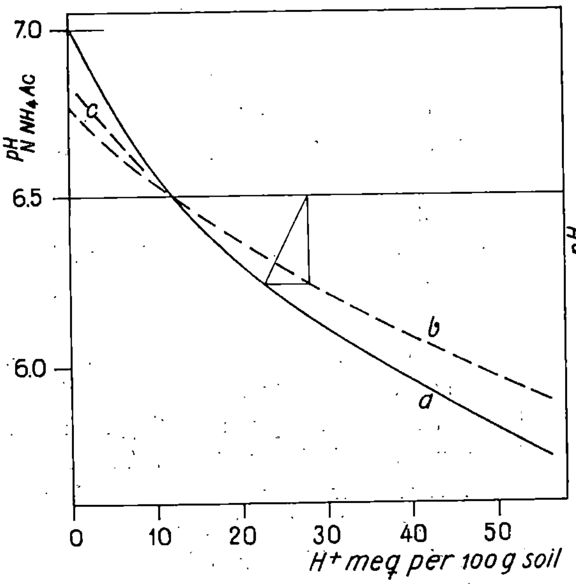

Fig. 2. Titration curve of *N* ammonium acetate (pH 7.0) titrated with acetic acid (curve *a*) and working curves (*b* and *c*) representing the correction to pH 6.5. Curve *b* is obtained with the slope 0.1 pH unit per 2 meq H^+ and curve *c* with the slope 0.1 pH unit per 1 meq H^+.

Kuva 2. N ammoniumasetaatin (pH 7.0) titrauskäyrä etikkahapolla titrattuna (käyrä a) ja pitoisuuskäyrät (b ja c) pH 6.5:een korjattuina. Käyrä b on saatu kulmakertoimella 0.1 pH yksikköä 2 mekv. H^+ kohti ja käyrä c kulmakertoimella 0.1 pH yksikköä 1 mekv. H^+ kohti.

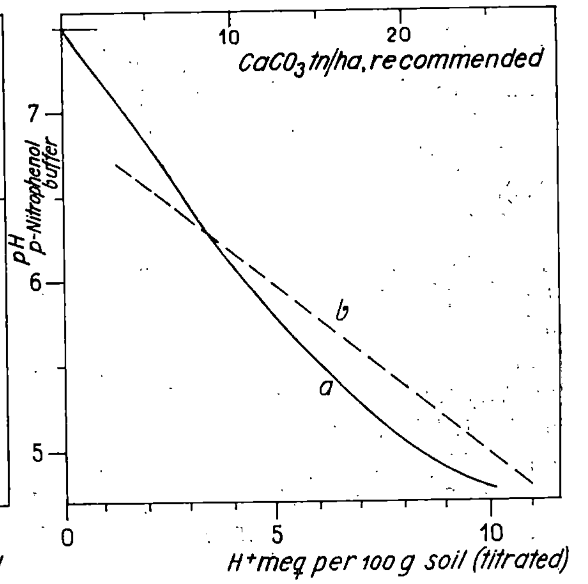

Fig. 3. Titration curve of p-nitrophenol buffer solution titrated with acetic acid (curve *a*) and working curve for lime recommendations (curve *b*) according to SHOEMAKER *et al.* (1961).

Kuva 3. p-Nitrofenolin puskuriliuoksen titrauskäyrä etikkahapolla titrattuna (käyrä a) ja pitoisuuskäyrä kalkitusohjeeksi (käyrä b) SHOEMAKER*in ym. (1961) mukaan.*

mentioned group 24 Carex and 12 Sphagnum peat soils were included. A few non-arable soils were also tested in order to have all soil types represented (samples of mor humus and some raw Sphagnum peat soils). The soil samples were air-dried, homogenized and sieved through a 2 mm round-holed sieve.

The acid ammonium acetate extractable calcium was extracted according to the soil-testing method and determined by flame photometry (VUORINEN and MÄKITIE 1951, 1955). The weight per volume was taken by the so-called tapping cylinder method used for correcting the values in the soil between the weight and volume bases. One hectare of 20-cm top-soil is thus considered to be equivalent to a soil volume of 2 million litres.

The lime requirement test by SHOEMAKER, MCLEAN & PRATT'S method was carried out with the buffer solution containing 1.8 g p-nitrophenol, 2.5 ml triethanolamine, 3.0 g K_2CrO_4, 2 g $(CH_3COO)_2Ca$ and 53.1 g $CaCl_2 \cdot 2\ H_2O$ per litre. Five g of soil was weighed and stirred with 5 ml of water (for pH determination 1 : 1) and 10 ml of buffer solution for 30 minutes, after which the pH of the suspension was measured. The equilibrium pH values were converted to liming recommendations for pH 6.5 according to the curve presented in Fig. 3 (SHOEMAKER *et al.*, 1961). It was necessary to extrapolate some very acid values, which thus apparently do not fit the experimentally found interpretation scale (down to pH 4.8 only), as reported by SHOEMAKER et al.

The titration curve of the buffer solution is presented in Fig. 2.

The exchangeable hydrogen as exchanged with *N* ammonium acetate solution (adjusted to pH 7.0) was determined in a soil suspension (1:10) according to BROWN's method. Five g of soil and 50 ml of solution were equilibrated by shaking and allowed to stand overnight. The pH of the suspension and of the supernatant solution are practically the same in ordinary soils (BROWN 1943).

Sufficient accuracy was obtained when the equilibrium stage of the suspension was reached and the pH can be expressed to two decimals.

The titration curve of N ammonium acetate (pH 7.0) titrated with a weak acid is presented in Fig. 1. The titration curve *(a)* is corrected to a working curve *(b)* which gives directly the amount of exchangeable hydrogen to be neutralized to the standard pH 6.5. The slope of the general neutralization titration curve with ordinary soils is taken as 0.1 pH unit per 2 meq H^+, which in practice deviates very little when soils of moderate clay and organic matter content are concerned. The hypotenuse of the correcting right-angled triangle gives the slope in question (Fig. 1.) For very poor mineral soils it is better to use the curve *(c)* with the slope of 0.1 pH unit per 1 meq H^+.

Incubation tests were carried out on 55 soils in small - sized polyethylene jars of 100 ml content. 40 g of soil (20 g of light peat soil) was weighed out and thoroughly mixed with calcium hydroxide, the amount of base being equivalent to the amount of exchangeable hydrogen found by the N ammonium acetate method, as corrected to the standard pH value of 6.5. The incubation period was 75 days. The pH measurements were carried out on air-dried soil, as in all other cases.

All the pH determinations were carried out by means of a Radiometer PHM 4c potentiometer with glass electrode and potassium chloride reference electrode at 25°C.

The organic matter content was determined in the mineral soil samples as organic carbon according to the known method by sulphuric acid-chromic acid oxidation with moderate external heating. The factor 1.73 was used for multiplying organic carbon to the approximate organic matter content.

Results and discussion

Some of the results are tabulated in Table 1, where values obtained with the four different methods of estimating lime requirement can be compared.

Ammonium acetate (pH 4.65) extractable calcium as listed in column *(d)* indicates calcium per litre of soil, which is the present way of expressing the results of soil testing. In column *(e)* the calcium figures are given in tons per hectare and corrected to exchangeable calcium, which is the former way of reporting the results (VUORINEN and MÄKITIE 1955). The figures represent, on an average, only 80 % of the total exchangeable calcium in soil when this is extracted by a simple shaking procedure according to the soil-testing method mentioned. The corresponding liming recommendation in $CaCO_3$ tons/ha is given in column *(f)*.

The results of the nitrophenol buffer method are listed in column *(g)*, where the equilibration pH values indicate the amount of exchangeable hydrogen. Column *(h)* shows the recommendation of liming (SHOEMAKER *et al.*, 1961). Some of the extreme figures are obtained by extrapolation of the recommended scale.

The results obtained with the N ammonium acetate buffer method (BROWN 1943) are correspondingly presented in columns *(i)* and *(j)* The values of exchangeable hydrogen are obtained by correcting the equilibrium pH value to pH 6.5, according to the modified method mentioned. The liming recommendations to obtain pH 6.5, calculated on a soil volume basis, are listed in column *(k)*.

The results of the incubation test are listed in column *(l)*, where the pH values found indicate the result of liming. The untreated soil is limed in order to neutralize the exchangeable hydrogen to pH 6.5 as estimated by the N ammonium acetate method (column *j*). Two samples (Nos. 1 and 20), which did not show any lime requirement to pH 6.5, were included and were limed to neutralize 2 meq H^+ per 100 g of soil in order to determine the liming effect for reference.

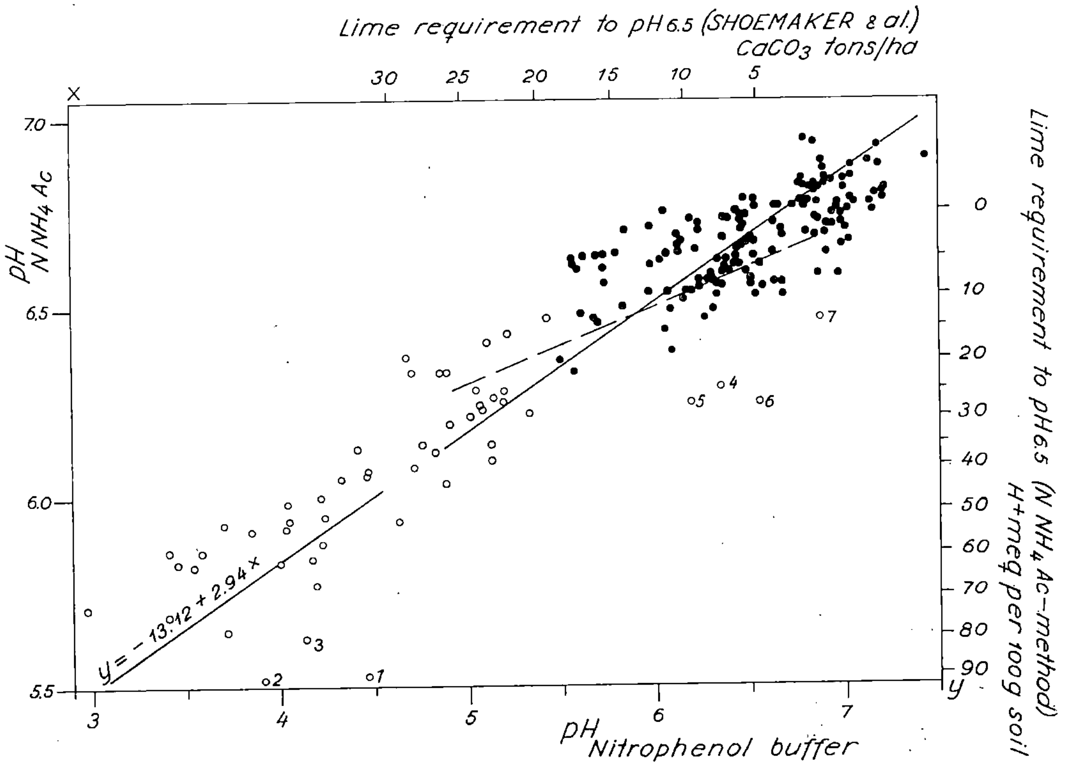

Fig. 4. Comparison of the two buffer methods. The dotted line represents the two lime requirement scales. The numbered plots are referred to in the text. ● = mineral soils, o = organic soils.

Kuva 4. Kahden puskurimenetelmän vertailu. Katkoviiva edustaa molempia kalkitustarveasteikkoja. Numeroidut pisteet on mainittu tekstissä, ● = kivennäismaat, o = eloperäiset maat.

Regressions found: *Saadut regressiot:*	Mineral soils; *Kivennäismaat:*	y = —11.67 + 2.72 x (r = 0.73, t = 12.81***; d.f. 142)
	Organic soils; *Eloperäiset maat:*	y = —11.02 + 2.58 x (r = 0.77, t = 8.40***; d.f. 49)
	All soils; *Kaikki maat:*	y = —13.12 + 2.94 x (r = 0.82, t = 19.97***; d.f. 192)

The four methods were compared with each other. The two buffer methods gave much the same results, as was to be expected. The regression, of the nitrophenol buffer method as a function of the *N* ammonium acetate method seems to be linear (Fig. 4):

$$pH_{\text{Nitrophenol buffer}} = -13.12 + 2.94\ pH_{N\,NH_4Ac.}$$

The regression $y = -11.67 + 2.72$ x was found for the mineral soils and the equation $y = -11.02 + 2.58\,x$ for the organic soils, respectively.

Some soils seem to deviate from the general grouping (Fig. 4). Some raw Sphagnum peat soils (Nos. 1—3, Fig. 4) as well as one Carex peat (No. 4), one gyttja (No. 5) and two gyttja clays (Nos. 6—7) appear to have a greater lime requirement with the *N* ammonium acetate method than with the method of SHOEMAKER *et al.* The last-mentioned method shows high lime requirement values with coarse mineral soils compared with leaching with *N* ammonium acetate, which can also be observed in Fig. 4, where coarse mineral soils deviate upwards from

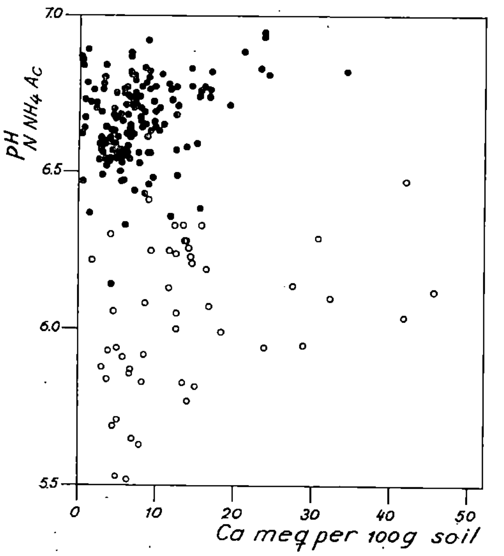

Fig. 5. The relationship between the pH values in N ammonium acetate and in calcium extractable in acid ammonium acetate in milliequivalents per 100 g of soil.

Kuva 5. N ammoniumasetaatilla saadut pH luvut happamaan ammoniumasetaattiin uuttuvan kalsiumin funktiona, mekv./100 g maata.

● = mineral soils — *kivennäismaat,*
○ = organic soils — *eloperäiset maat.*

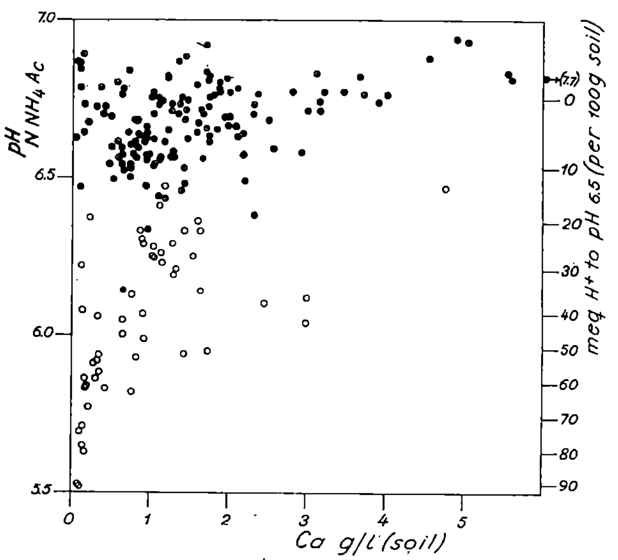

Fig. 6. Plot of pH values in N ammonium acetate as a function of calcium extractable in acid ammonium acetate in grams per litre of soil.

Kuva 6. N ammoniumasetaatilla saadut pH luvut happamaan ammoniumasetaattiin uuttuvan kalsiumin funktiona, g/litrassa maata.

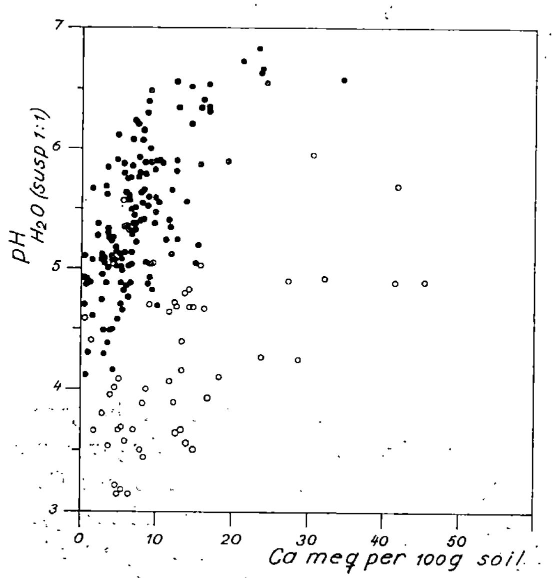

Fig. 7. Plot of soil pH (in water suspension 1 :1, volume: volume) as a function of calcium extractable in acid ammonium acetate in milliequivalents per 100 g of soil.

Kuva 7. Maan pH (vesisuspensiossa 1: 1 tilavuuden mukaan) happamaan ammoniumasetaattiin uuttuvan kalsiumin funktiona, mekv./100 g maata.

● = mineral soils — *kivennäismaat,*
○ = organic soils — *eloperäiset maat.*

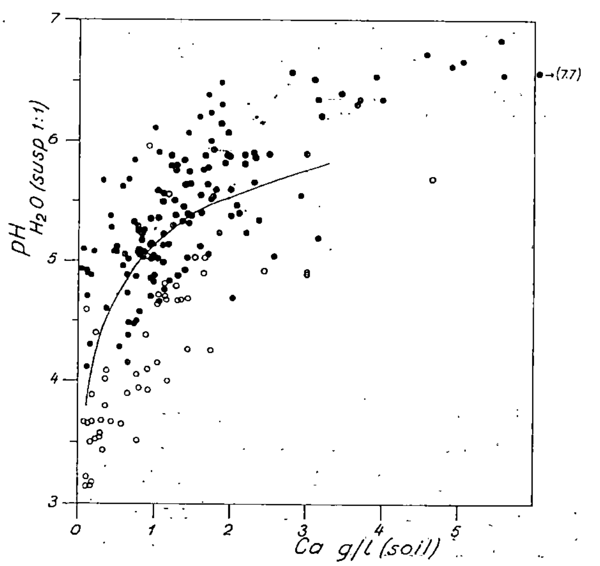

Fig. 8. Plot of soil pH as a function of calcium in grams per litre of soil.

Kuva 8. Maan pH kalsiumin funktiona, g/litrassa maata.

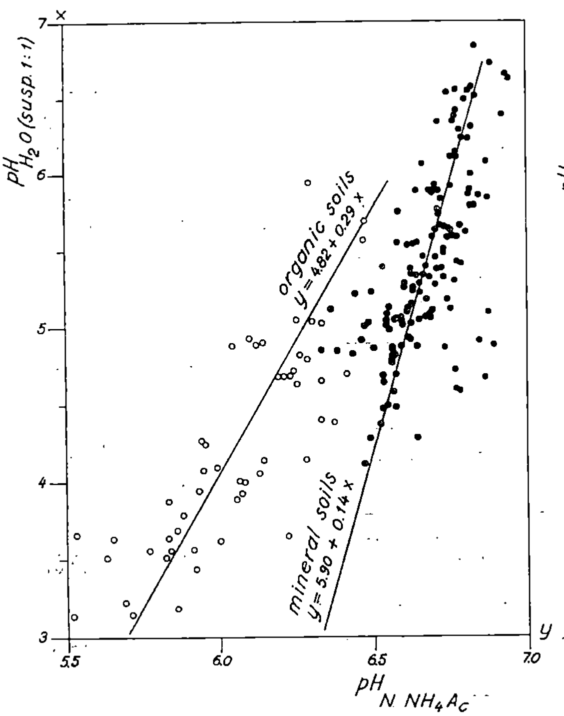

Fig. 9. Correlation between N NH_4Ac method and soil pH.

Kuva 9. N ammoniumasetaattimenetelmän ja maan pH:n välinen korrelaatio.

Regressions found:
Saadut regressiot:

Mineral soils; y = 5.90 + 0.14 x
Kivennäismaat:
(r = 0.66, t = 10.53***; d.f. 142)

Organic soils; y = 4.82 + 0.29 x
Eloperäiset maat;
(r = 0.81, t = 9.71***; d.f. 49)

All soils; y = 4.84 + 0.33 x
Kaikki maat;
(r = 0.83, t = 20.47***; d.f. 192)

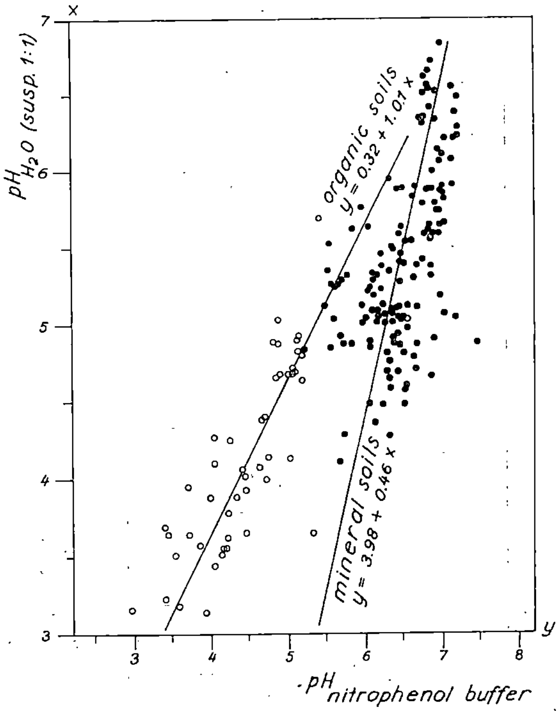

Fig 10. Correlation between the method of SHOEMAKER *et al.* and soil pH.

Kuva 10. SHOEMAKERin *ym. menetelmän ja maan pH:n välinen korrelaatio.*

Regressions found:
Saadut regressiot:

Mineral soils; y = 3.98 + 0.46 x
Kivennäismaat;
(r = 0.58 + 8.47***; d.f. 142)

Organic soils; y = 0.32 + 1.01 x
Eloperäiset maat;
(r = 0.85, t = 11.14***; d.f. 49)

All soils; y = 0.74 + 1.03 x
Kaikki maat;
(r = 0.82, t = 19.96***; d.f. 192)

the regression line. The dotted line is the interpretation line between the amount of hydrogen exchanged by N ammonium acetate at 4.65 and the lime requirement recommendation to obtain pH 6.5 given by the p-nitrophenol buffer method (SHOEMAKER *et al.* 1961). This line, observed pH values in N NH_4Ac as a function of the values in nitrophenol buffer (equation: $x = 5.30 + 0.20y$), is parallel with the corresponding regression line found for the mineral soils of the present material ($x = 5.39 + 0.20y$).

The difference between the two lines is on the average 4.5 meq H^+ per 100 g soil, which means that SHOEMAKER *et al.* (1961), as a result of their experiments, recommended about 4.5 tons of $CaCO_3$/ha more for soils relatively rich in extractable aluminium than the value found in the present study to be equivalent to exchanged hydrogen by the modified N ammonium acetate method in the mineral soils tested.

When the N ammonium acetate method is compared with the soil-testing method and the acid ammonium acetate (pH 4.65) extractable calcium is calculated by means of weight by volume as meq Ca per 100 g soil, the plot shows an indefinite distribution (Fig. 5). Treating the

Table 1. Data of part of the sample material

Taulukko 1. Tulokset osasta näyteaineistoa

No. of sample	Soil type *Maalaji*	Weight per volume of pretreated soil *Esikäsitellyn maan tilavuuspaino*	OM *Humus* %	pH_{H_2O} (susp. 1 : 1)	Calcium extractable in ammonium acetate (pH 4.65) *Ammoniumasetaattiin liukoinen kalsium*			Method of SHOEMAKER *et al.*		*N* NH_4Ac method			Incubation test *Muhituskoe*	
					Ca g per liter of soil *g/l maata*	$CaCO_3$ tons/ha**)	Liming recommendation $CaCO_3$ tons/ha *Kalkitusohje*	$pH_{buff.}$	Liming recommendation $CaCO_3$ tons/ha *Kalkitusohje****)	$pH_{buff.}$	H^+ meq/100 to pH 6.5	Liming recommendation to pH 6.5 *Kalkitusohje pH 6.5:een* $CaCO_3$ tons/ha	pH found when limed *pH kalkituksen jälkeen*	Apparent lime requirement at pH 6.5 $CaCO_3$ tons/ha *Todennäköinen kalkitustarve pH 6.5:ssä*
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)
1	HkMr Sand moraine	1.40	3.9	4.67	0.10	0.5	8	6.89	0	6.86	0	0	7.12*	1.3
2	HkMr »	0.80	9.1	4.14	0.65	3.5	7	4.75	28	6.14	35.2	28.2	5.86	38.6
3	KHt Finesand	1.06	5.9	5.24	0.87	4.8	4	5.61	17	6.63	5.2	5.5	6.25	6.8
4	KHt »	1.02	2.0	5.79	3.15	20.6	0	6.99	0	6.74	0.4	0.4	6.70	0.3
5	Hs Silt	1.00	3.8	4.88	0.63	3.4	6	6.39	7	6.59	7.0	7.0	7.22	4.8
6	Hs »	0.92	4.3	5.02	0.83	4.6	5	6.36	7.5	6.59	7.0	6.4	7.05	4.7
7	Hs »	0.94	6.3	5.09	0.83	4.6	5	6.11	10.5	6.68	3.2	3.0	6.51	3.0
8	Hs »	0.98	5.3	5.13	0.95	5.4	5	6.23	9	6.55	9.0	8.8	6.76	7.4
9	Hs »	0.82	1.0	5.01	1.04	6.0	5	5.97	12	6.54	9.5	7.8	6.47	7.9
10	Hs »	0.86	6.0	5.35	1.04	6.0	4	6.33	4	6.62	5.6	4.8	6.71	4.1
11	Hs »	0.88	8.8	5.13	1.18	6.8	5	5.97	12	6.61	6.0	5.3	6.17	7.1
12	Hs »	1.00	5.1	5.55	1.59	9.5	3	6.62	4	6.64	4.7	4.7	6.84	3.5
13	Hs »	0.86	6.1	5.54	1.73	10.5	3	6.53	5	6.63	5.2	4.5	6.81	3.4
14	Hs »	0.78	9.4	5.89	3.00	19.5	1	6.47	6	6.71	1.9	1.5	6.72	1.2
15	HHS Sandy clay	0.73	6.0	4.87	1.30	7.6	10	5.73	15	6.56	8.7	6.4	6.60	6.0
16	HtS »	0.84	7.1	5.23	1.84	11.0	7	6.22	9	6.65	4.2	3.5	6.10	5.1
17	HtS »	1.07	4.1	5.46	2.08	12.8	5	6.47	6	6.66	3.7	4.0	6.59	3.6
18	HtS »	1.17	3.6	5.88	1.95	13.2	4	6.80	2	6.69	2.6	3.0	6.91	1.9
19	HtS »	1.00	5.4	5.89	2.50	15.8	4	6.51	5.5	6.68	3.2	3.2	6.99	1.8
20	HtS »	1.08	4.0	6.31	3.65	24.3	0	6.76	2	6.82	0	0	7.10*	0.5
21	HsS Silty clay	0.80	9.9	4.85	0.96	5.5	12	5.56	17.5	6.33	22.0	17.6	6.63	16.4
22	HsS »	0.68	5.2	5.12	1.60	9.5	7	5.49	18.5	6.36	20.4	13.9	6.23	17.1
23	HsS »	1.10	4.0	5.89	2.18	13.5	4	6.91	1	6.64	4.7	5.2	7.39	2.2
24	AS Heavy clay	0.84	4.0	5.01	0.94	5.3	8	6.26	8.5	6.47	13.6	11.4	6.82	9.6
25	AS »	0.87	6.6	5.34	0.96	5.4	8	6.12	10.5	6.66	3.7	3.2	6.13	4.7

26	AS	»	0.77	5.4	5.22	1.10	6.4	8	6.05	11	6.44	15.7	12.1	6.90	9.3
27	AS	»	0.78	14.1	4.92	1.40	8.3	8	5.69	16	6.46	14.0	10.9	6.17	13.8
28	AS	»	0.79	11.5	4.85	2.32	14.5	8	6.08	11	6.38	19.1	15.1	6.93	12.0
29	LjS	Gyttja clay	0.90	4.7	4.37	0.65	3.5	12	6.15	10	6.52	10.5	9.5	6.39	10.0
30	LjS	»	0.91	4.5	4.49	0.75	4.1	12	6.07	11	6.54	9.5	8.6	6.25	9.8
31	LjS	»	0.88	4.6	4.82	0.98	5.6	12	6.51	5.5	6.57	8.1	7.1	5.90	11.1
32	LjS	»	0.91	4.7	4.76	1.13	6.5	10	6.33	8	6.56	8.7	7.9	6.81	6.8
33	Lj	Gyttja	0.83	15.1	5.05	1.54	9.1	6	6.19	(9.5)	6.25	27.2	22.6	7.28	14.8
34	Kh	Mor humus	0.36		3.65	0.12	0.6	12	5.33	(20.5)	6.22	29.6	10.7	5.48	16.3
35	Kh	»	0.24		3.57	0.28	1.4	12	3.85	(>30)	5.91	55	13.2	5.50	20.0
36	Ct	Carex peat	0.36		4.08	0.35	1.8	12	4.63	(29)	5.94	52	18.7	5.96	24.0
37	Ct	»	0.15		5.95	0.92	5.2	4	6.34	(7.5)	6.29	24.4	3.7	6.84	2.4
38	Ct	»	0.56		5.69	4.77	32.5	0	5.42	(19)	6.47	13.6	7.6	6.49	7.6
39	LCt	Ligno Carex peat	0.10		3.64	0.14	0.7	12	3.72	(>30)	5.65	80	8.0	6.61	7.7
40	LCt	»	0.30		3.56	0.20	1.0	12	4.17	(>30)	5.84	61	18.3	5.51	27.8
41	LCt	»	0.60		3.79	0.35	1.8	12	4.22	(>30)	5.88	57	34.2	5.76	47.0
42	LCt	»	0.58		4.66	1.43	8.5	8	4.85	(26)	6.33	22.0	12.8	6.31	14.2
43	SCt	Sphagnum Carex peat	0.25		4.10	0.92	5.2	10	4.04	(>30)	5.99	47	11.8	6.14	13.9
44	SCt	»	0.44		4.64	1.03	5.9	8	5.18	(22)	6.25	27.2	12.0	6.18	14.5
45	SCt	»	0.40		4.83	1.13	6.5	6	5.13	(23)	6.26	26.8	10.7	6.14	13.6
46	SCt	»	0.40		4.69	1.15	6.6	7	5.07	(24)	6.23	29.0	11.6	6.15	14.4
47	SCt	»	0.52		5.03	1.65	9.8	3	4.88	(26)	6.33	22.0	11.4	6.18	14.4
48	ErSt	Eriophorum Sph. peat	0.16		3.18	0.18	0.9	12	3.58	(>30)	5.86	59	9.4	5.29	14.8
49	LCSt	Ligno Carex Sph. peat	0.25		3.95	0.82	4.5	10	3.70	(>30)	5.93	53	13.3	5.65	19.9
50	LSt	Ligno Sph. peat	0.14		3.15	0.14	0.7	12	2.97	(>30)	5.71	74	10.4	6.22	11.2
51	LSt	»	0.10		3.56	0.22	1.2	12	4.19	(>30)	5.77	66	6.6	5.71	9.0
52	LSt	»	0.33		4.06	0.77	4.2	10	4.41	(>30)	6.13	36.0	11.9	6.36	12.6
53	LSt	»	0.30		4.27	1.43	8.5	9	4.05	(>30)	5.94	52	15.6	6.10	19.0
54	St	Sphagnum peat	0.08		3.67	0.08	0.4	12	4.46	(>30)	5.53	90	7.2	6.19	8.1
55	St	»	0.08		3.14	0.10	0.5	12	3.91	(>30)	5.52	91	7.3	6.25	7.9

*) limed for reference — *kalkittu vertailun vuoksi*
**) corrected values as referred in the text — *korjatut arvot kuten tekstissä on mainittu*
***) to pH 6.5 by SHOEMAKER *et al.* (1961); extrapolated figures in parentheses — *sulkeissa ekstrapoloidut arvot*

Table 2. Correlation of the different methods as compared with the incubation test
Taulukko 2. Menetelmien korrelaatiot muhituskokeeseen verrattuina

Methods *Menetelmät*		Standard deviation ($CaCO_3$ tons/ha) *Standardipoikkeama* S.D. = $\sqrt{\Sigma\triangle^2/2n}$	Parameters of the regression equation ($y = a + bx$): *Regressioyhtälön parametrit* a	b	Correlation coefficient *Korrelaatiokerroin* r
SOIL TESTING method — *Viljavuusanalyysimenetelmä*					
coarse soils — *karkeat maat*	(n = 14)	6.22	3.70	0.099	0.438
clay soils — *savimaat*	(n = 18)	2.58	4.21	0.447	0.667**
org. soils — *eloperäiset maat*	(n = 23)	10.32	7.28	0.129	0.330
all soils — *kaikki maat*	(n = 55)	5.85	5.26	0.210	0.506***
Method of SHOEMAKER *et al.* — *menetelmä*					
coarse soils — *karkeat maat*	(n = 14)	3.66	4.59	0.656	0.871***
clay soils — *savimaat*	(n = 18)	2.36	2.71	0.841	0.817***
all soils — *kaikki maat*	(n = 32)	3.00	4.00	0.704	0.844***
N NH_4Ac method — *menetelmä*					
coarse soils — *karkeat maat*	(n = 14)	2.14	1.54	0.706	0.980***
clay soils — *savimaat*	(n = 18)	1.46	1.03	0.874	0.907***
org. soils — *eloperäiset maat*	(n = 23)	4.91	2.53	0.650	0.913***
all soils — *kaikki maat*	(n = 55)	2.68	1.99	0.694	0.935***

organic soils on a weight basis does not reveal any relation between the extractable calcium and exchangeable hydrogen. A far better relation is obtained when calcium is calculated on a volume basis (Fig. 6). Calcium alone gives a poor indication of the neutralization required if no other soil characteristics are known.

The correlation between the amounts of calcium and the soil pH of 1:1 (soil: water, by volume) suspension is shown in Figs. 7 and 8. A better relation can obviously be found in the latter figure where calcium is again calculated on a soil volume basis.

The fact that soil testing should be based on soil volume when soils of different and considerable organic matter content are concerned is here again clearly brought out. The soil volume thus offers a practical unit for all soils; even the peat soils do not need to be handled as a separate group for soil-testing purposes.

The plots of the *N* ammonium acetate method against soil pH in a 1:1 water suspension are shown in Fig. 9. The organic soils are taken separately from the mineral soils, showing lower pH values with the buffer solution and giving the left regression: $y = 4.82 + 0.29\,x$. The regression $y = 5.90 + 0.14\,x$ was calculated for mineral soils. It should be noted that the soils on the right-hand side of the line, which have pH values around 5 or even less, are coarse soils with a very low buffer capacity. A straight regression line, $y = 4.85 + 0.33\,x$, would represent all soils of the present material together.

The pH values in the buffer solutions used by SHOEMAKER *et al.* are compared with the pH values of soil-water suspensions in Fig. 10. The mineral soils differ clearly from the organic soils, as the regressions ($y = 3.98—0.46\,x$ and $y = 0.32—1.01\,x$) show.

The incubation test with a soil sample can be considered the most thorough laboratory determination, comparable with a practical liming trial. The results of simple incubation tests with 55 soil samples are shown in Table 1. The *N* ammonium acetate method was taken as a basis and the lime additions were equivalent to the amounts of exchangeable hydrogen found (column *j*). The deviation of the pH values of the limed samples (column *l*) from the pH 6.5 wanted thus indicates the unrealiability of the modified N ammonium acetate method. The apparent lime requirement to obtain pH 6.5 was estimated by means of the linear relation between the untreated and limed pH values (column *m*).

Correlations between the different methods and the incubation test are shown in Table 2. It has to be mentioned that one is not justified in comparing the soil-testing method as such with the buffer methods. The soil-testing method based on the soil type, soil pH and amount of calcium extractable with acid ammonium acetate generally recommends only careful liming and its objective is to raise the soil pH to just over 6 in an acid soil (Vuorinen and Kurki 1955). Thus placing the methods side by side, as in Table 2, does not do justice to the soil-testing method. It has been done here, however, in order to emphasize the weaknesses.

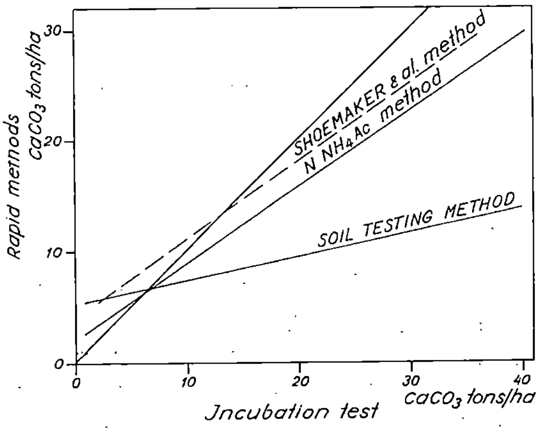

Fig 11. Regression lines of the different methods (all soils, except just mineral soils with the method of Shoemaker *et al.*)

Kuva 11. Eri menetelmien regressiosuorat (kaikki maat paitsi vain kivennäismaat Shoemaker*in ym. menetelmällä)*

Conclusions

The estimation of the lime requirement by the soil-testing method is, on the whole, reliable. The accordance with the apparent actual lime requirement found by the incubation test is relatively good in mineral soils and especially good with the clay soils of the material. In a few cases, however, the recommendations are unsuitable and these few cases spoil the statistical figures. This kind of unreliability is more or less unknown with the buffer methods, although in some cases the weakly buffered method of Shoemaker *et al.* shows a similar uncertainty for some reason.

The weakness of the soil-testing method depends on the poor correlation between the reaction of the soil and amount of extractable calcium, as well as between the amounts of exchangeable hydrogen and extractable calcium. The correlations are noticeably better when calcium is calculated on a soil volume basis, as recognized and used in the soil-testing method.

The two buffer methods are similar in character. A pronounced correlation exists between the modified N ammonium acetate method and the incubation test. The correlation between the method of Shoemaker *et al.* and the incubation test is clearly less significant regarding the soils of the material.

The lime requirement of the gyttja soils of the material was estimated unexpectedly well by all the methods tried. Organic matter seems to be the most disturbing factor in all the methods and the trouble is intensified in the estimation of the lime requirement of many organic soils of the material.

All the methods underestimate the real lime requirement in most cases. The best accordance is found with the mineral soils low in organic matter. The mineral soils of the material generally represent a low lime requirement, too. In the light of the comparison made in the present study, an increase in the rate of liming recommended in connection with soil testing is justified (Kurki *et al.* 1965).

There is no reason to reject the present soil-testing method when rapid lime requirement estimations have to be carried out. The N ammonium acetate »buffer» method, however, offers a simple, more accurate way to estimate the real need of liming.

Summary

The present method for estimating lime requirement in connection with soil testing and two so-called rapid buffer methods, the weakly buffered p-nitrophenol method of SHOEMAKER *et al.* (1961) and the modified *N* ammonium acetate method of BROWN (1943) have been compared with simple incubation tests of liming, at the standard pH 6.5.

The soil-testing method shows relatively good accordance with the real lime requirement in spite of the fact that the method is based in the interpretation of soil type, soil pH and the acid ammonium acetate extractable calcium content of the soil, as indications of the liming required. The rapid buffer methods are greatly superior. Particularly the *N* ammonium acetate method (modified to pH 6.5) shows highly significant correlations with the incubation test. The results of 55 soils gave the standard deviations 5.85 and 2.68 tons of $CaCO_3$/ha and correlation coefficients 0.506*** and 0.935*** for the soil-testing method and *N* ammonium acetate method, respectively.

The fact that lime requirement can be rapidly estimated by determination of calcium, extractable with the »universal» acid ammonium acetate extractant (pH 4.65) strongly supports the use of the present method. The superiority of the ammonium acetate »buffer» method deserves note and would be of use, especially in critical cases when the lime requirement has to be more accurately estimated. In the case of the organic soils the weakly buffered method of SHOEMAKER *et al.* is apparently out of the question.

The modified *N* ammonium acetate method, in which the exchanged acidity to be neutralized is corrected to the standard pH 6.5 and to soil volume, is presented.

Acknowledgements. — The statistical calculations were carried out by Mr. Seppo Hyvärinen, whose work is gratefully acknowledged.

REFERENCES

AARNIO, B. 1935. Über den Einfluss von Kalk auf die Reaktion des Bodens und über Reaktionsschwankungen während der Vegetationsperiode. Selostus: Kalkin vaikutuksesta maan reaktioon ja reaktiovaihteluista kasvukautena. Agrogeol. publ. 41: 1—20.

ADAMS, F. & EWANS, C. E. 1962. A rapid method for measuring lime requirement of red-yellow podzolic soils. Soil Sci. Soc. Amer. Proc. 26: 355—357.

BROWN, I. C. 1943. A rapid method of determining exchangeable hydrogen and total exchangeable bases of soils. Soil Sci. 56: 353—357.

HONKAVAARA, T. 1951. Tuloksia huomattavimmasta kalkituskokeestamme. Koetoim. ja käyt. 8:1.

KURKI, M. & LAKANEN, E. & MÄKITIE, O. & SILLANPÄÄ, M. & VUORINEN, J. 1965. Viljavuusanalyysien tulosten ilmoitustapa ja tulkinta. Summary: Interpretation of soil testing results. Ann. Agric. Fenn. 4: 145—153.

MEHLICH, A. 1948. Determination of cation- and anion-exchange properties of soils. Soil Sci. 53: 1—14.

MÄKITIE, O. 1956. Uuttamisesta viljavuusanalyysissa. Summary: Studies on the acid ammonium acetate extraction method in soil testing. Agrogeol. publ. 66: 1—25.

—»— 1957. Pääravinteiden uuttumisesta viljavuusanalyysissa. Koetoim. ja käyt. 14:2.

PRATT, P. F. & BAIR, F. L. 1962. Buffer methods for estimating lime and sulfur applications for pH control of soils. Soil Sci. 93: 329—332.

PUROKOSKI, P. 1959. Kalkituksen vaikutuksesta rannikkoseudun rikkipitoisissa maissa. Referat: Über Kalkungswirkung in schwefelhaltigen Böden an der Meeresküste Finnlands. Agrogeol. publ. 72: 1—22.

PUUSTJÄRVI, V. 1957. On the base status of peat soils. Acta Agric. Scand. 7: 190—223.

SALONEN, M. 1952. Vaihtuvien emästen ja vaihtuvan vedyn kokonaismäärien käytöstä maan kalkintarpeen arvioimisessa. Summary: On the use of exchangeable hydrogen and the sum of exchangeable bases at determining the lime requirement of soil. Maatal.tiet. aikak. 24: 135—144.

SCHACHTSCHABEL, P. 1951. Die Methoden zur Bestimmung des Kalkbedarfs im Boden. Z. Pfl. Ernähr. Düng. 54: 134—145.

SCHOFIELD, R. K. 1933. Rapid methods of examining soils. II. The use of p-nitrophenol for assessing lime status. J. Agr. Sci. 23: 252—254.

SHOEMAKER, H. E. & MCLEAN, E. O. & PRATT, P. F. 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminum. Soil Sci. Soc. Amer. Proc. 25: 274—277.

TERÄSVUORI, A. 1959. Über das Bestimmen der Kationensorptionskapazität und des Basensättigungsgrades des Bodens. Selostus: Maan kationinpidätyskyvyn ja emäskyllästysasteen määrittämisestä. Valt. maatal.koetoim. julk. 175: 1—80.

TUCKER, B. M. 1960. The measurement of the ion-exchange properties of soils. Soil Publ. 15. Comm. Sci. Ind. Res. Organ. (Melbourne), pp. 40. 1960.

TUORILA, P. & TAINIO, A & TERÄSVUORI, A. 1939. Suomen viljelysmaiden kalkitustarpeesta. Referat: Über den Kalkungsbedarfs der finnischen Böden. Valt. maatal.koetoim. julk. 104: 1—529.

WOODRUFF, C. M. 1947. Determination of the exchangeable hydrogen and lime requirement of the soil by means of the glass electrode and a buffered solution. Soil Sci. Soc. Amer. Proc. 12: 141—142.

—»— 1948. Testing soils for lime requirement by means of a buffered solution and the glass electrode. Soil Sci. 66: 53—63.

VUORINEN, J. 1953. Viljavuustutkimuksen tarkennettua tulkintaa. Koetoim. ja käyt. 10: 6.

VUORINEN, J. & KURKI, M. 1955. Viljavuustutkimustulosten tarkennettu tulkintaohje. Maantutkimuslaitos, Helsinki. 1955.

—»— & MÄKITIE, O. 1951. On determination of calcium direct from soil extract by means of spectrophotometer with flame attachment. S. Kemistilehti B 3: 7—14.

—»— & MÄKITIE, O. 1955. The method of soil testing in use in Finland. Selostus: Viljavuustutkimuksen analyysimenetelmästä. Agrogeol. publ. 63: 1—44.

SELOSTUS

Maan kalkitustarpeen määrittämisestä

OSMO MÄKITIE

Maatalouden tutkimuskeskus, Maantutkimuslaitos, Tikkurila

Tutkimuksessa on käsitelty maan kalkintarpeen määrittämistä viljavuustutkimuksen ja ns. puskurimenetelmien avulla sekä suoritettu niiden vertailu yksinkertaisiin muhituskokeisiin nähden.

Viljavuustutkimuksen osana käytössä oleva kalkintarpeen määritystapa perustuu maalajin, maan pH:n ja 0.5 *N* happameen ammoniumasetaattiliuokseen uuttuvan kalsiumin mukaan suoritettavaan maan kalkintarpeen arvioimiseen. Likimääräinen arvioiminen on täten mahdollista ravinteiden, kaliumin ja fosforin uuton yhteydessä viljavuusanalyysissa. Kalkituksella neutraloitavan maan kokonaishappamuuden erillinen määrittäminen tekisi taas viljavuusanalyysin nykyisestään melkoisesti monimutkaisemmaksi.

Maan vaihtuvan kalsiumin määrä ei tunnetusti ole kalkintarpeen mitta, elleivät muut, maan kationien vaihtokapasiteettiin ja sen emäskyllästysasteeseen vaikuttavat tekijät ole samoja. Kalsiumin ja maan pH:n välinen korrelaatio on sen vuoksi heikko milloin maat ovat erilaisia (kuvat 7—8), samoin kalsiumin ja vaihtuvan vedyn välinen (kuvat 5—6).

Ns. nopeita puskurimenetelmiä käytetään yleisesti varsinaiseen kalkintarpeen määritykseen. Neutraloinnin tarve on tietyllä puskuriliuoksella arvioitavissa maasta vaihdetun vedyn määrän suhteen, ja korrelaatio myös maan hydrolyyttiseen happamuuteen eli maan näennäiseen pH:hon on ilmeisen selvä (kuvat 9—10).

Kaksi tällaista pikamenetelmää oli tutkimuksessa mukana, nimittäin heikosti puskuroitu p-nitrofenolimenetelmä (SHOEMAKER ym. 1961) ja tätä tutkimusta varten mukailtu *N* ammoniumasetaattimenetelmä (alkuper. BROWN 1943). Molemmat menetelmät osoittautuivat pääpiirtein samanlaisiksi luonteeltaan (kuva 4).

Muhituskokeen (kalkitseminen pH 6.5:een) perusteella osoittautuivat puskurimenetelmät 55 maanäytettä käsittäneen aineiston mukaan selvästi paremmiksi. Varsinkin *N* ammoniumasetaattimenetelmän korrelaattiokertoimet osoittivat erittäin suurta merkitsevyyttä kaikissa maalajiryhmissä (taulukot 1—2).

Viljavuusanalyysi osoittautui täten epävarmemmaksi, osittain tosin virheellisesti, sillä kalkintarpeen tulkinta on ollut varovaista ja vain pyrkinyt meikäläisten suhteellisen happamien maiden pH:n yleiseen kohottamiseen pH 6:een (VUORINEN ja KURKI 1955). On ilmeistä, että käsillä olevan aineiston perusteella kalkitusohjeissa voitaisiin kuitenkin multaville kivennäismaille ja eloperäisille maille suositella yleisesti suurempia kalkkimääriä (kuva 11). Niin ikään on perusteltua kiinnittää entistä enemmän huomiota maan multavuusasteeseen. Viljavuusanalyysien uudessa tulkintaohjeessa onkin jo tehty muutoksia tähän suuntaan (KURKI ym. 1965).

Viljavuusanalyysin tulkintaa kalkintarpeesta on pidettävä varsin onnistuneena, etenkin kun viljavuustutkimuksessa on oivallettu käyttää maan tilavuusyksikköä perustana. Tämä ilmenee erityisesti turvemaista tämänkin tutkimuksen aineistossa. Aineiston savimaiden kohdalla menetelmä osoittautui varmaksi, ja aineiston liejusavissakin kalkintarve on tullut hyvin arvioiduksi. Kalkintarpeen arvioimiselle nykyisen viljavuusanalyysin avulla on luonteenomaista kuitenkin tietty epävarmuus eräissä aineiston maalajeissa, joiden tulokset näin ollen ovat pilanneet tilastolliset arvot (taulukko 1, esim. näytteet 1, 2, 41).

Mitään syytä ei ole kuitenkaan luopua nykyisestä menetelmästä yleisessä viljavuustutkimuksessa. Tutkimuksessa esitetty mukailtu *N* ammoniumasetaattimenetelmä on huomionarvoinen pikainen määritystapa varsinkin erikoistapauksia varten, joissa kalkitustarve on tarpeellista määrittää tarkemmin. Tämän ns. *N* NH_4Ac-puskurimenetelmän perusteita on tarkasteltu lähemmin tutkimuksen yhteydessä (kuvat 1—2) ja se menetelmä osoittautui olosuhteissamme sopivammaksi kuin p-nitrofenolin käyttöön perustuvaksi mukailtu toinen vertailtu puskurimenetelmä (SHOEMAKER ym. 1961). Periaatteeltaan samantapainen puskurimenetelmä on kalkituskokeitten maanäyteaineistossa jo aikaisemmin osoittautunut käyttökelpoiseksi kalkintarpeen arvioimisessa (SALONEN 1952).

ANNALES AGRICULTURAE FENNIAE, VOL. 4: 253—255 (1965)

Seria AGROGEOLOGIA, -CHIMICA ET -PHYSICA N. 19
Sarja MAAPERÄ, LANNOITUS JA MUOKKAUS n:o 19

DER EINFLUSS VON SCHWEFELDÜNGUNG AUF DEN SCHWEFELGEHALT VON KLEE UND TIMOTHEE

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Eingegangen am 7. 9. 1965.

Bei den im Auftrage der Zentrale für Landwirtschaftliche Forschung in den Jahren 1959—63 durchgeführten Feldversuchen bei Anwendung von Volldüngemitteln, mit und ohne Schwefel, ergaben sich im allgemeinen keine nennenswerte Einflüsse von Schwefel auf die Ertragshöhe. Möglicherweise beruhte dies auf dem Schwefelgehalt der Düngung, die in früheren Jahren verwendet wurde. Dagegen ergab sich in der Qualität des Ertrages bei Verabreichung von Gips ein signifikanter Einfluss, denn der Schwefel- und Kalkgehalt stieg an, während dieser an Magnesium abnahm. Im Gehalt der anderen Pflanzennährstoffe äusserten sich die eingetretenen Veränderungen jedoch nicht in statischtisch gesicherten Unterschieden (SALONEN *et al.* 1965).

Die Versuche wurden mit dem Mischdünger Yn, bestehend aus Montansalpeter, Superphosphat und Kalisalz durchgeführt und mit dem Mischdünger Yd aus schwefelfreiem Diammonphosphat und Kalisalz verglichen. Ausserdem war ein Versuchsglied Ydk vorhanden, welches zur Yd-Düngung als Ergänzung Gips erhielt, so dass die gegebene Schwefeldüngung bei den Yn- und Ydk-Versuchsgliedern die gleiche war. Zuzüglich war ein ungedüngtes Versuchsglied im Versuch vorhanden.

Die Düngung wurde in zwei verschieden hohen Gaben verabreicht, wobei die kleinste Düngermenge (1) aus 25 kg N, 65 kg P_2O_5 und 50 kg K_2O pro ha bestand. Die gegebene Schwefelmenge betrug im Versuch mit Yn 37—41 kg und mit Ydk 40—43 kg pro ha. Die höchste Düngungsstufe (2) bestand in der doppelt verabreichten Menge. Eine genauere Beschreibung der im Versuch angewandten Düngung ist in der obenerwähnten Veröffentlichung enthalten (S. 156—158).

Im Folgenden seien die dich im Gesamtschwefelgehalt ergebenden Unterschiede des Klee- und Timotheegrases im gleichen Versuchsmaterial näher untersucht. Als Versuchsmaterial dienten 15 Versuchserträge, jeder 7 Versuchsgliedern enthaltend, deren sortierte Klee- und Timotheeproben zur Bestimmung des Schwefelgehaltes zur Verfügung standen.

Die Ernte erfolgte im allgemeinen zur Blüte des Timothees und im Anfangsstadium der Blüte des Klees. Die durchschnittlichen Schwefelgehaltszahlen der Proben sind in Tabelle 1 angeführt.

Der Schwefelgehalt des Klees war deutlich höher als der des Timothees (vgl. JOHANSSON 1959). Er nahm sowohl beim Klee als auch beim Timothee mit verabreichter schwefelhaltiger Düngung bemerkenswert zu. Auf den unterschiedlichen Schwefelgehalt der Pflanzenarten war durch die Schwefeldüngung auch ein sehr signifikanter Einfluss festzustellen, der

Tabell 1. Der Einfluss der Düngung auf den Schwefelgehalt von Klee und Timothee (15 Versuche)

Taulukko 1. Lannoituksen vaikutus apilan ja timotein rikkipitoisuuteen (15 koetta)

	Schwefel in mg/g Trockensubstanz *Rikkiä S mg/g kuiva-ainetta*		
	Düngerart *Lannoitelaji*		
	Yn (mit S)	Yd (ohne S)	Ydk (mit S)
Düngungsstufe 1 *Lannoitemäärä 1*			
Klee — *Apila*	1.95	1.75	1.93
Timothee — *Timotei*	1.26	1.15	1.20
Unterschied — *Erotus*	0.69	0.60	0.73
Düngungsstufe 2 *Lannoitemäärä 2*			
Klee — *Apila*	1.93	1.66	1.96
Timothee — *Timotei*	1.24	1.13	1.26
Unterschied — *Erotus*	0.69	0.53	0.70

Schwefelgehalt des Klees stieg mit der in dem Dünger enthaltenen Schwefelmenge mehr als der des Timothees an. Demgegenüber war durch die Höhe der Düngermenge kein Einfluss auf den Schwefelgehalt festzustellen. Der durchschnittliche Schwefelgehalt der ungedüngten Versuchsglieder (bei Klee 1.76, bei Timothee 1.21) wich nicht bemerkenswert von denen der schwefelfreien Düngung Yd ab.

Als besonders stark erwies sich auch der durch die unterschiedlichen Versuchsverhältnisse hervorgerufene Einfluss. Dennoch konnte bei diesem geringen Material nicht festgestellt werden, welche Bedeutung die Bodenart oder der im Boden enthaltene Schwefel auf dem Einfluss der Schwefeldüngung hat.

Ausserdem wurde das Verhältnis zwischen dem Gesamtstickstoff und Gesamtschwefel der Pflanzenproben bestimmt, welches in Unter-

Tabell 2. Gesamtstickstoff und Gesamtschwefelgehalt sowie das $\frac{N}{S}$-Verhältnis von Klee und Timothee (13 Versuche)

Taulukko 2. Apilan ja timotein kokonaistyppi- ja kokonaisrikkipitoisuus sekä $\frac{N}{S}$-suhde (13 koetta)

	Düngs-stufe *Lannoite-määrä*	Düngerart *Lannoitelaji*			
		—	Yn (mit S)	Yd (ohne S)	Ydk (mit S)
Klee — *Apila:*					
N mg/g Trockensubstanz — *kuiva-ainetta*	0	24.6			
	1		25.1	24.3	25.0
	2		25.6	25.1	24.3
S mg/g Trockensubstanz — *kuiva-ainetta*	0	1.80			
	1		2.00	1.76	1.97
	2		1.98	1.68	1.98
$\frac{N}{S}$-Verhältnis — *suhde*	0	13.9			
	1		12.8	14.1	12.9
	2		13.2	15.3	12.5
Timothee — *Timotei:*					
N mg/g Trockensubstanz — *kuiva-ainetta*	0	10.7			
	1		11.0	11.6	11.0
	2		11.3	11.2	10.9
S mg/g Trockensubstanz — *kuiva-ainetta*	0	1.22			
	1		1.27	1.06	1.23
	2		1.26	1.15	1.28
$\frac{N}{S}$-Verhältnis — *suhde*	0	9.0			
	1		8.6	9.9	8.9
	2		8.9	9.8	8.5

suchungen als einfaches Mass gebraucht werden ist, um festzustellen, ob die Pflanzen im Vergleich zur Höhe der Stickstoffdüngung genügend Schwefel erhalten (ØDELIEN 1963). Die vollständigen Zahlenreihen konnten aus 13 Versuchserträgen ermittelt werden, deren Durchschnittswerte in Tabelle 2 angeführt sind.

In der varianzanalytischen Verrechnung der Ergebnisse ergab sich zwischen Klee und Timothee im N:S -Verhältnis ein besonders deutlicher Unterschied. Es wurde aber auch durch die Beschaffenheit der Düngung und deren Schwefelgehalt stark beeinflusst, ohne von der Pflanzenart abhängig zu sein. Die Verhältniszahlen zwischen den verschiedenen Versuchsgliedern waren jedoch normal, und kein Schwefelmangel konnte im Versuchsboden festgestellt werden.

LITERATUR

JOHANSSON, O. 1959. On sulfur problems in Swedish Agriculture. K. Lantbr.högsk. ann. 25: 57—169.

ODELIEN, M. 1963. Svovelforsyningens virkning på planteproduktenes kvalitet. Tidsskr. norske landbr. 70: 35—49.

SALONEN, M. & TÄHTINEN, H. *et al.* 1965. Rikkipitoisten ja rikittömien moniravinteisten lannoitteiden käyttöarvoa selvitteleviä tutkimuksia. Summary: Comparative studies on the effect of sulfur-containing and sulfur-free multi-nutrient fertilizers. Ann. Agric. Fenn. 4: 155—177.

SELOSTUS

Rikkilannoituksen vaikutuksesta apilan ja timotein rikkipitoisuuteen

HILKKA TÄHTINEN

Maatalouden tutkimuskeskus, Maanviljelyskemian ja -fysiikan laitos, Tikkurila

Kenttäkokeista (15 koesatoa) saatujen lajiteltujen timotei- ja apilanäytteiden perusteella voitiin todeta apilan rikkipitoisuuden olevan korkeamman kuin timotein. Lannoitteen sisältämä rikki lisäsi kasvien rikkipitoisuutta, apilalla enemmän kuin timoteilla, vaikka maassa ilmeisesti ei ollut rikin puutetta. Kokonaistypen ja kokonaisrikin suhde oli apilalla korkeampi kuin timoteilla. Kasvilajista riippumatta rikkiä saaneilla koejäsenillä ko. suhdeluku oli alempi kuin rikittömillä.

ANNALES AGRICULTURAE FENNIAE, VOL. 4: 256—276 (1965)
Seria AGRICULTURA N. 23 — Sarja KASVINVILJELY n:o 23

COMPARATIVE STUDIES WITH THREE HERBICIDES, MCPA, MCPA PLUS 2,3,6-TBA, AND MECOPROP FOR WEED CONTROL IN SPRING CEREALS

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Received October 30, 1965

In Finland herbicides began to be used on field crops in the years 1948—50. At first, the method developed slowly, and at the end of the 1950's only about 80 000—100 000 hectares were annually treated. In the 1960's, however, the use of herbicides began to increase rapidly. In 1965 the area of fields treated exceeded 450 000 hectares, of which spring cereals comprised 425 000. This amount represents about 40 % of the total area under spring cereals in Finland.

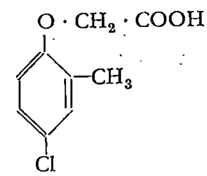
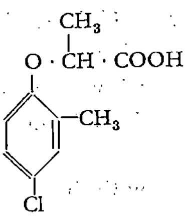
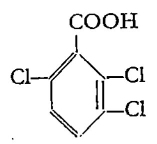
MCPA has been virtually the only compound used in spring cereals. It is effective against most of the broad-leaf weeds occurring in this country. The chemical is easy to use, cheap, relatively safe to cereal crops, and rapidly dissipates in the soil as well as in plant tissues. During the 1950's the average yield increases as a result of MCPA were roughly 300 kg/ha or 15 % for oats, 200 kg/ha or 10 % for barley and 230 kg/ha or 12 % for wheat (Marjanen 1962).

At present (1965), the most important MCPA products available in Finland are the following: *Agro-Hormo* (Koge/Kasvinsuojelu), *Hedonal* (Bayer/Berner), *Herbotal* (Agro-Kemi/Farmos), *Hormonal* (Schering/Fincos), *Hormotex* (Gullviks), *Hormox* (Österr. Stickst./Nieminen), *Hormotuho* (Rikkihappo), *P-46 Plus* (Finsons/Nieminen) and *W-30* (Äänekoski/Rikkihappo). Most of these contain MCPA as the sodium salt; *Hormotuho* however has the potassium salt and *P-46 Plus* a mixture of potassium and sodium salts. *Agro-Hormo*, in addition, also offers two products containing mixtures of potassium, sodium and amine salts.

Broad-leaf weeds resistant to MCPA make up about 20 % of the total weeds in spring cereals in Finland (Mukula *et al.* 1963). Even as early as the 1950's the proportion of resistant species was seen to be increasing on fields where MCPA had been used for several successive years. Moreover, in certain areas the original weed population was composed chiefly of broad-leaf species resistant to MCPA. Under such conditions, it is obvious that MCPA does not offer a satisfactory solution. Instead, there is an evident need for new herbicides, which either singly or together with MCPA would control those species resistant to MCPA. The first such herbicides introduced in Finland were 2,3,6-TBA and mecoprop. Their properties, as well as those of MCPA, are given in Table 1.

The compound 2,3,6-TBA will be referred to in this paper as simply TBA. It is a translocatable foliar herbicide, but more active and less

Table 1. Herbicides used in the trials

Common or abbreviated name	Chemical name	Formula	Acute oral LD_{50} mg/kg
MCPA	4-chloro-2-methylphenoxyacetic acid		700
mecoprop	2-(4-chloro-2-methyl-phenoxy)propionic acid		650
2,3,6-TBA	2,3,6-trichlorobenzoic acid		700—1 500

selective than MCPA. In soil and in plant tissues it is more persistent than MCPA (Dewey 1960, Grower 1963, Andersson 1964). In 1957—58 preliminary trials with TBA were carried out by the Department of Plant Husbandry at Tikkurila using the commercial product *Pesco* 18-15, developed by Fisons Pest Control Ltd. in England (Pfeiffer 1958). This product contains the sodium salts of MCPA and TBA in the weight ratio 4:1. In these trials *Pesco* was found to be more effective against many MCPA-resistant species than MCPA alone. On the basis of these results the product was officially approved by the Finnish Plant Protection Institute in 1959. The use of this herbicide has, however, been limited to winter wheat.

In Sweden *Pesco* was put on the market at the same time as in Finland (Walther 1959). In Norway the product was approved in 1961 (Vidme 1961c) and in Denmark in 1963 for the control of *Polygonum* species (Tidsskr. Planteavl 1963, Thorup 1964).

Mecoprop resembles MCPA in its mode of action, being a translocatable foliar herbicide. It consists of two groups of isomers, of which the *d*-isomers are active and the *l*-isomers inactive. Since equal amounts of both isomers are formed during the manufacture of the compound, mecoprop must consequently be used in amounts twice as large as those of MCPA. The herbicidal properties of mecoprop were discovered in 1956—58 in England by Boots & Co. (Lush and Leafe 1956, Lush 1957, Lush *et al.* 1958). In Finland, preliminary trials carried out by the Department of Plant Husbandry showed that mecoprop had the same effect on most broad-leaf weeds as MCPA, while on some it provided better control. In 1960/61 the Plant Protection Institute gave official approval to certain commercial products containing the potassium salt of mecoprop. At present (1965), the following products are available in Finland: *Erikois-Hedonal* (Bayer/Berner), *Herbotal PP* (Boots/Farmos), *Hormo Cornox* (Gullviks), *Hormonit MP*-58 (Schering/Fincos) and *Mepro* (Rikkihappo). The area of spring cereals treated with mecoprop has been only a few thousand hectares annually. In Sweden, Denmark and Norway mecoprop was introduced at about the same time as in Finland (WALTHER 1959, VIDME 1961a, 1961b, Tidsskr. Planteavl 1960).

Methods

In order that a more complete picture could be obtained on the utility of MCPA, TBA and mecoprop in controlling weeds in spring cereals, the senior author prepared a 3-year program to be conducted at various locations throughout the country. The program comprised three trial series which are listed below with their respective treatments:

Series A. Experiment stations:

Untreated	
MCPA, sodium	1.0 kg/ha
MCPA/TBA (4 : 1), sodium	1.0 »
mecoprop, potassium	2.0 »

Series B. Local trials (private farms):

Untreated	
MCPA, sodium	1.0 kg/ha
MCPA, potassium	1.0 »
mecoprop, »	2.0 »
» »	3.0 »

Series C. Department of Plant Husbandry:

Untreated	
MCPA, sodium	0, 1/2, 1, 1 1/2 and 2 kg/ha
MCPA/TBA (4 : 1), sodium	0, 1/2, 1, 1 1/2 and 2 »
mecoprop, potassium	0, 1, 2, 3 and 4 »

A total of 91 trials were carried out, of which 39 were located at experiment stations (series A), 43 on private farms (series B) and 9 at the Department of Plant Husbandry (series C). The geographical distribution of the trials is seen in Fig. 1. Since the trial methods were similar at the stations and at the Department of Plant Husbandry, the treatments of the 9 trials in series C were partly included also in series A. Hence, the total number of the trials in the latter series became 48.

The varieties grown at the Department of Plant Husbandry were Pendek oats, Pirkka barley and Diamant spring wheat. At the stations and on the farms various varieties were used. The total of the trials on oats was 33 (32 harvested), on barley 19 and on spring wheat 39.

The fields on the private farms (series B) were not selectively chosen and can thus be regarded as random samples. However, the yield level of oats and barley was higher in series B than the average for the entire country. At the stations (series A) and especially at the Department of Plant Husbandry (series C) the yield level of each

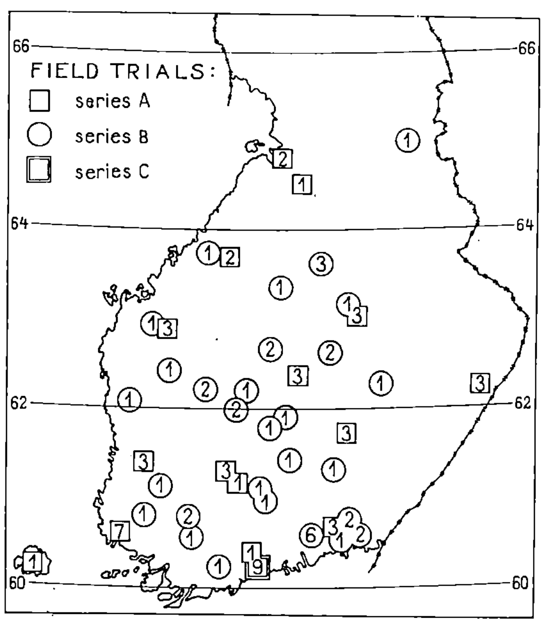


Fig. 1. Location of field trials. Series A = experiment stations, B = private farms, C = Department of Plant Husbandry. The figure within the symbols denotes the number of trials.

cereal was considerably higher than the average for the country, as can be seen from the following figures:

	Mean grain yields 1961—63, kg/ha oats	barley	spring wheat
Average for the country	1 730	1 670	1 670
» » series A	2 410	2 660	1 625
» » series B	3 445	2 810	2 435
» » series C	4 330	4 510	2 900

The degree of weed infestation was not determined at private farms (series B). On the fields of the experiment stations and of the Department of Plant Husbandry the amount of weeds is usually lower than the average for the entire country. In order to minimize this difference, the most weedy fields were selected for the trials in series A and C. As a result, an average of 609 weed plants per square meter was obtained. This is a somewhat higher number than the average for the country (484) in 1961—63 (cf. MUKULA *et al.* 1963).

As could be expected, the composition of the weed population varied in the different trials. The most important dicotyledonous species were well represented, although their proportions were not similar to the average for the country, as can be seen from the following figures:

Species	Number of plants per sq.m in 1961—63 average for the country	averages for series A and C
Galeopsis spp.	76	85
Spergula arvensis	66	48
Stellaria media	60	150
Viola arvensis	48	35
Chenopodium album	42	45
Cruciferae	28	14
Polygonum spp.	19	79
Sonchus arvensis	6	17
Tripleurospermum marit. v. inod.	5	18
Galium vaillantii	2	23
Others	132	95
Total	484	609

The weather conditions in 1961—63 at the Department of Plant Husbandry (Tikkurila) and at some of the stations were as follows:

Location	Temp. May—Sept., °C Mean 1921—1950	Deviations 1961	1962	1963	Precip. May—Sept., mm Mean 1921—1950	Deviations 1961	1962	1963
Tikkurila	13.0	0.3	—1.5	1.7	317	— 9	115	— 45
Mietoinen	13.4	—0.3	—2.0	1.0	285	177	44	— 6
Anjala	13.2	0.0	—1.9	1.2	310	— 39	207	— 45
Pälkäne	13.0	0.1	—1.9	1.1	305	63	27	— 78
Peipohja	12.6	0.2	—1.5	1.2	290	117	42	29
Mikkeli	12.7	—0.1	—2.0	0.8	315	55	78	— 73
Laukaa	12.1	0.2	—1.7	—1.0	332	— 2	4	— 39
Maaninka	12.5	0.1	—1.9	0.7	307	19	21	39

In trial series A and B the plot size was 20—30 m², in series C 12 m². There were 4 replicates in the former two series, while in the latter series the number of replicates was 10 for the untreated and 2 for each of the treatments.

In series A and C the herbicide treatments were performed when the crop plants were at the 4—6-leaf stage. At this time the earliest annual broad-leaf weeds had 2—4 true leaves. In trial series B the treatments were carried out somewhat later, with the cereals being at the early tillering stage and the main broad-leaf weeds having 4—6 true leaves. The treatments consisted of knapsack spraying using 500 litres of water per hectare.

At the Department of Plant Husbandry and at the experiment stations the herbicidal effect of the compounds was determined by counting the weeds both before treatment and 4—5 weeks afterwards. The number of each weed species was determined on a ¼ m² area in each plot. In addition, at harvest time, a weed sample from a 1 m² area in each plot was taken and its air-dry weight determined. The mean values of amounts of weeds listed in the tables represent arithmetic means.

In all the trials the grain yield was determined and calculated for 15 % moisture content. At the Department of Plant Husbandry and at the stations, determinations were also made of the straw yield, 1000-grain weight and hectolitre weight. In addition, visual observations were made on injuries caused by the herbicides as well as their effect on lodging and ripening of the cereals. The mean values for the grain yields in the tables are weighted means.

The statistical significance of the trials was studied by conventional analyses of variance and the differences of treatments by Tukey-Hartley's test at the level of P = 95 %. In the rate of application trials (series C) the response curves were studied by second-degree regression (Snedecor 1956).

Effect on weeds

The relative effect of each treatment on the number of the most abundant weed species at the experiment stations (series A) are presented in Table 2. The counts of the different species indicated that the order of susceptibility of broad-leaf weeds to MCPA — from most to least susceptible — was as follows: Cruciferous species (*Raphanus*, *Erysimum*, *Capsella* and *Thlaspi*), *Chenopodium*, *Fumaria*, *Ranunculus*, *Galeopsis*, *Myosotis*, *Spergula*, *Tripleurospermum*, *Stellaria*, *Viola*, *Lapsana*, *Polygonum*, *Lamium* and *Galium*. Because of the early time of the treatments, MCPA as well as the other herbicides caused tillering in *Sonchus*, and thus the count of its shoots does not give a true picture of the actual effect.

Against most species the mixture MCPA/TBA gave a better control than MCPA alone. Only *Galeopsis*, *Myosotis* and *Spergula* showed slightly higher numbers of surviving plants with MCPA/TBA than with MCPA alone. In the cases of Cruciferous species, *Fumaria*, *Tripleurospermum*, *Stellaria*, *Viola* and *Galium*, the differences were statistically significant.

Mecoprop provided a much better control of *Stellaria*, *Lapsana* and *Galium* than the other herbicides tested. It was slightly better than MCPA against Cruciferous species, *Chenopodium*, *Tripleurospermum* and *Polygonum*, but less effective than MCPA against *Fumaria*, *Galeopsis*, *Myosotis* and *Spergula*. Furthermore, in one trial, mecoprop increased the number of *Lamium*. Apparently destruction of the susceptible species left more room for *Lamium* to emerge. Mecoprop was nearly as ineffective against *Sonchus* as MCPA and MCPA/TBA, but gave a slightly lower

Table 2. Effect of herbicides on the number of the most abundant weed species at experiment stations (series A)

No. of trials	Species (according to susceptibility to MCPA)	Untreated	MCPA	MCPA/TBA	mecoprop	Significance (F-values)	
		No./sq.m	Rel. values, untreated = 100			Untreated — treated	Between treatments
9	*Cruciferae*	63	13	8	8	***	*
18	*Chenopodium album*	99	20	12	16	***	
2	*Fumaria officinalis*	20	27	10	34	***	***
2	*Ranunculus* spp.	40	32	31	32	***	
17	*Galeopsis* spp.	199	34	48	63	***	*
2	*Myosotis arvensis*	25	42	65	55	***	
10	*Spergula arvensis*	192	70	79	74	***	
5	*Tripleur. marit. v. in.*	144	70	51	56	**	*
25	*Stellaria media*	240	72	45	16	***	**
15	*Viola arvensis*	56	83	60	82	***	***
4	*Lapsana communis*	52	87	64	29	***	***
11	*Polygonum* spp.	288	87	71	68	***	
3	*Lamium* spp.	83	100	100	138	*	*
4	*Galium vaillantii*	229	101	50	6	***	***
5	*Sonchus arvensis*	135	132	118	92		*

Table 3. Effect of herbicides on the number of weeds in 40 trials at experiment stations (series A)

Location and year of trials		Untreated	MCPA	MCPA/TBA	mecoprop
		No./sq.m	Rel. values, untreated = 100		
Jomala (60°N)	1961	..*)	25	24	17
Tikkurila (60°N)	1961	316	41	16	62
»	1962	224	41	39	80
»	1963	177	46	56	10
Hyrylä (60°N)	1961	276	16	5	6
Mietoinen (60°N)	1961	673	102	70	54
»	1962	464	100	53	54
»	1962	611	63	65	68
»	1962	140	62	31	45
»	1963	114	54	55	47
»	1963	569	88	88	30
»	1963	263	54	35	44
Anjala (61°N)	1961	311	34	22	53
»	1962	984	17	26	18
»	1963	1 708	46	47	57
Leteensuo (61°N)	1961	818	25	28	34
Pälkäne (61°N)	1961	900	15	14	7
»	1962	655	72	68	40
»	1963	614	65	60	41
Peipohja (61°N)	1961	440	49	45	64
»	1962	629	89	66	46
»	1963	410	58	57	41
Mikkeli (62°N)	1961	632	42	26	62
»	1962	122	65	35	19
»	1963	254	46	49	35
Tohmajärvi (62°N)	1961	208	37	37	44
»	1962	336	73	70	99
Laukaa (62°N)	1961	299	44	26	33
»	1962	267	46	44	35
»	1963	252	57	50	39
Ylistaro (63°N)	1962	630	24	15	60
»	1963	1 149	91	63	110
Maaninka (63°N)	1961	624	64	13	48
»	1962	104	67	39	36
»	1963	229	50	43	40
Toholampi (64°N)	1963	780	26	24	43
»	1963	852	37	40	46
Pelso (65°N)	1962	3 488	84	59	26
Ruukki (65°N)	1962	1 124	78	74	76
»	1963	1 092	81	78	81
Mean		609	54	45	46

*) Original counting data are lost.

number of surviving plants. Except for *Chenopodium*, *Myosotis* and *Spergula*, the above differences were statistically significant.

The effect of different herbicides on the total number of weeds at the experiment stations (series A) is presented in Table 3. The effectivity of the products and their relative superiority varied considerably in the different trials. Evidently this was due to differences in the weed population as well as partly to the different conditions or different growth stages at the time of treatment. On an average, MCPA/TBA and mecoprop were as good as, or slightly better than, MCPA.

The effect of different rates of treatment on the total numbers of weeds in series C is presented graphically in Fig. 2. The MCPA/TBA mixture at all rates was superior to the other herbicides. As for MCPA and mecoprop, the data for these two compounds were in some cases contradictory. Increasing the rates of the herbicides up to 1 kg/ha resulted in a more rapid increase in their effectivity than above this amount. Concerning mecoprop, the rates

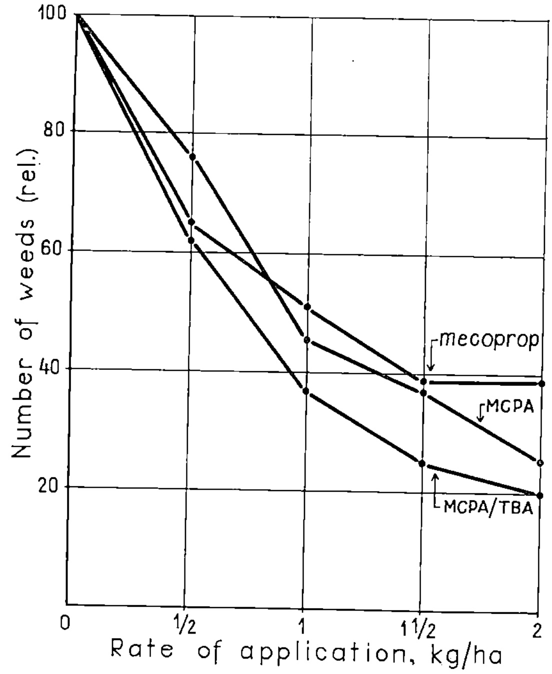


Fig. 2. Effect of rate of application on the number of weeds in 9 trials at the Department of Plant Husbandry (series C). Mean of untreated = 186/sq.m. The rate of mecoprop refers to the active isomers or *d*-mecoprop.

refer to the active isomers, or *d*-mecoprop; the actual amount of technical mecoprop is twice as much.

The effect of different herbicides on the air-dry weight of weeds in series A is shown in Table 4. These data show the final results of the treatments. The effectivity of all the herbicides proved much better than could have been expected on the basis of the weed counts made 6—8 weeks earlier. Also in this case, there were considerable variations in the extent of control and the order of superiority of the different herbicides, a result evidently due to the same reasons as previously mentioned. The over-all result was somewhat surprising in that MCPA/TBA was not more effective than MCPA alone; on the other hand, mecoprop gave a considerably better control than the other compounds tested.

The effect of different rates on the air-dry weight of weeds in series C is graphically presented in Fig. 3. These results were similar to those obtained in series A and showed that the

Table 4. Effect of herbicides on the air-dry weight of weeds in 28 trials at experiment stations (series A)

Location and year of trials		Untreated	MCPA	MCPA/TBA	mecoprop
		g/sq.m	Rel. values, untreated = 100		
Tikkurila	1961	117	15	10	2
»	1962	97	66	83	25
»	1962	11	9	16	9
»	1963	82	36	97	26
»	1963	87	13	27	17
Mietoinen	1962	204	74	16	8
»	1962	627	33	13	26
»	1962	195	31	15	15
»	1963	284	29	12	12
»	1963	316	74	41	31
»	1963	97	32	14	7
Anjala	1962	198	18	16	5
»	1963	109	16	46	42
Pälkäne	1962	79	71	43	52
»	1963	207	26	29	25
Peipohja	1962	118	64	68	42
»	1963	132	63	65	27
Mikkeli	1962	180	48	67	16
»	1963	131	14	20	5
Tohmajärvi	1962	52	19	42	40
Laukaa	1962	22	47	20	27
»	1963	42	24	17	24
Ylistaro	1962	200	26	18	23
»	1963	210	110	126	90
Toholampi	1963	300	20	18	32
»	1963	795	9	12	11
Pelso	1962	256	50	54	18
Ruukki	1963	203	57	56	59
Mean		191	39	38	26

final control was better than could have been expected from the weed counts made earlier. Furthermore, mecoprop gave a better control than the other compounds at all rates but the smallest. It thus appears that under the conditions in Finland mecoprop provides better control of weeds in spring cereals than MCPA or MCPA/TBA. However, since its effect is slow-acting, its superiority does not become evident until later in the summer. In both series A and C the two compounds MCPA and MCPA/TBA appeared to be approximately of equal value. A comparison of the different rates used shows the fact that even the smallest amounts of herbicides, corresponding to only ½ kg/ha active ingredients, gave a rather good control of weeds. In other words, the curve showing the weight of weeds in response to varying rates of herbicides (Fig. 3) is steeper than that for the number of weeds (Fig. 2). Increasing the rates above ½ kg/ha thus resulted only in a relatively small improvement in final effectivity of the herbicides.

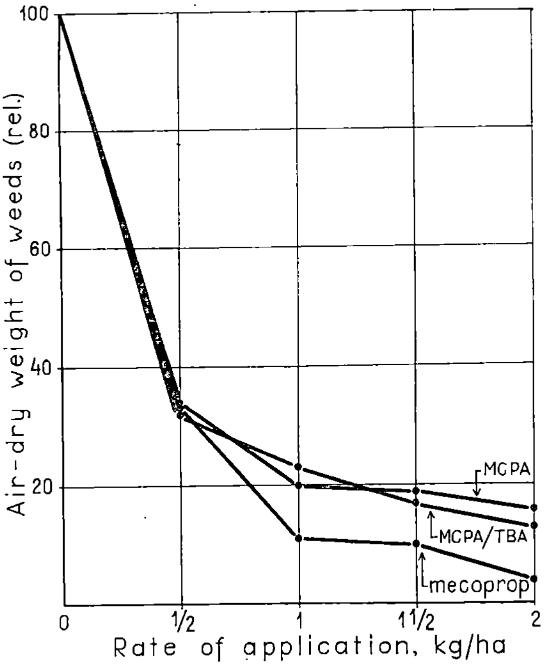


Fig. 3. Effect of rate of application on the air-dry weight of weeds in 9 trials at the Department of Plant Husbandry (series C). Mean of untreated = 72 g/sq.m.

Effect on grain yields

The average effect of the different herbicides on the grain yields of oats, barley and spring wheat in series A and B is presented in Tables 5 and 6. In series A the average yield increase of oats caused by MCPA was 11 % or 322 kg/ha. MCPA/TBA and mecoprop gave slightly higher yields, the increases being 14 and 15 %. However, the differences between the three herbicides were not statistically significant. For barley the increase in yield as a result of MCPA

Table 5. Average grain yields in 47 trials at experiment stations (series A)

No. of trials	Crop	Treatment		Grain yield kg/ha	increase	rel.
16	Oats	Untreated		3 031	—	100
		MCPA	1 kg/ha	3 353	322	111
		MCPA/TBA	1 »	3 480	449	115
		mecoprop	2 »	3 445	414	114
9	Barley	Untreated		2 803	—	100
		MCPA	1 kg/ha	3 078	275	110
		MCPA/TBA	1 »	2 905	102	104
		mecoprop	2 »	3 019	216	108
22	Spring wheat	Untreated		2 434	—	100
		MCPA	1 kg/ha	2 567	133	105
		MCPA/TBA	1 »	2 301	—133	95
		mecoprop	2 »	2 645	211	109

F-values Oats: Untreated-treated 21.44***, between treatments < 1
Barley: » 5.47*, » 1.42
Wheat: » 1.05, » 13.68***

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Table 6. Average grain yields in 43 trials at private farms (series B)

No. of trials	Crop	Treatment		Grain yield		
				kg/ha	increase	rel.
16	Oats	Untreated		2 414	—	100
		MCPA, sodium	1 kg/ha	2 669	255	111
		» , potassium	1 »	2 708	294	112
		mecoprop, potassium	2 »	2 695	281	112
		» »	3 »	2 698	284	112
10	Barley	Untreated		2 662	—	100
		MCPA, sodium	1 kg/ha	2 823	161	106
		» , potassium	1 »	2 796	134	105
		mecoprop, potassium	2 »	2 813	151	106
		» »	3 »	2 818	156	106
17	Spring wheat	Untreated		1 625	—	100
		MCPA, sodium	1 kg/ha	1 919	294	118
		» , potassium	2 »	1 975	350	121
		mecoprop, potassium	2 »	2 007	382	123
		» »	3 »	2 009	384	124

F-values Oats: Untreated-treated 16.29***, between treatments <1
Barley: » 5.76*, » <1
Wheat: » 84.34***, » 1.49, MCPA-mecoprop 3.81*

treatment was 10 % (275 kg/ha), while mecoprop gave 8 % and MCPA/TBA 4 %. The first two differed significantly from the untreated. In spring wheat MCPA increased the yield 5 % (133 kg/ha) and mecoprop 9 % whereas MCPA/TBA decreased the yield 5 %. All these differences were statistically significant.

In series B the results for oats and barley were similar to those in series A. All the herbicides gave yield increases for oats of 11—12 % (255—294 kg/ha) and for barley 5—6 % (134—161 kg/ha). However, the differences between the herbicides were not significant. In the case of wheat, the yield increases in series B were remarkably large, amounting to 18—24 % or 294—384 kg/ha. Mecoprop was, as in series A, significantly superior to MCPA on wheat.

Comparison of the average yield increases in the two trial series (Table 5 and 6) reveals substantial differences only in the case of wheat.

Table 7. The effect of herbicides on grain yield at different levels of weed infestation in series A

Crop and degree of weed infestation no./sq.m	No. of trials	Yield increase or decrease							
		MCPA		MCPA/TBA		mecoprop		mean	
		kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Oats:									
—250	4	332	9	594	16	378	10	435	12
251—500	5	214	6	326	9	363	10	301	9
501—750	3	316	9	441	13	368	11	375	11
—750	4	474	31	460	30	500	33	478	31
Barley:									
—500	5	124	3	8	0	115	3	82	2
501—	4	463	30	218	14	343	22	342	22
Spring wheat:									
— 250	4	194	8	— 78	— 3	139	6	85	3
251— 500	6	107	4	— 35	— 1	191	8	88	4
501— 750 1)	(7)	(167)	(6)	(5)	(0)	(281)	(12)	(151)	(6)
—1 000	2	123	8	80	5	267	18	157	11

1) Two trials where MCPA/TBA caused extreme yield decreases of 32—58 % are omitted in this class.

Table 8. The effect of herbicides on grain yield at different yield levels in series A

Crop and yield level kg/ha	No. of trials	Yield increase or decrease							
		MCPA		MCPA/TBA		mecoprop		mean	
		kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Oats:									
—1 000	2	359	51	277	40	483	69	373	53
1 010—2 000	1	1 258	76	944	57	1 086	66	1 096	67
2 010—3 000	5	217	9	386	15	285	11	296	12
3 010—4 000	3	511	15	624	18	443	13	526	15
4 010—5 000	4	241	6	546	13	489	11	325	8
5 010—6 000	1	—106	— 2	0	0	159	3	17	0
Barley:									
—1 000	2	536	55	424	43	472	48	477	49
1 010—2 000	1	597	31	— 135	— 7	308	16	257	13
2 010—3 000	3	—103	— 4	— 81	— 3	— 76	— 3	— 87	— 3
3 010—4 000	1	780	20	234	6	468	12	493	13
4 010—5 000	1	139	3	370	8	554	12	354	8
5 010—6 000	1	201	4	— 151	— 3	—100	— 2	— 51	— 1
Spring wheat:									
—2 000	6	86	5	— 28	— 2	173	10	77	5
2 010—3 000 [1])	(11)	(190)	(8)	(—57)	(—9)	(276)	(11)	(74)	(7)
3 010—4 000	2	266	8	181	5	189	5	212	6
4 010—5 000	1	— 41	— 1	— 285	— 7	— 81	— 2	—136	— 3

1) See footnote in Table 7.

The untreated plots also showed wide divergences in wheat yields: series A yielded 2 430 kg/ha and B only 1 650 kg/ha. There is reason to believe that weeds are more noxious and competitive in low-yielding stands, and consequently herbicidal treatment causes greater yield increases in such stands, as occurred in the case of wheat in series B.

A more detailed study of this aspect is provided by the data in Tables 7, 8 and 9. Table 7 shows a high positive correlation between the number of weeds and the yield increase in series A. In other words, the greater the number of weeds, the larger the yield increase caused by the herbicides. At the lowest weed levels the yield increase was quite small or did not exist at all. In

Table 9. The effect of herbicides on grain yield at different yield levels in series B

Crop and yield level kg/ha	No. of trials	Yield increase or decrease					
		MCPA		mecoprop		mean	
		kg/ha	%	kg/ha	%	kg/ha	%
Oats:							
—2 000	3	344	26	269	20	307	23
2 010—3 000	10	356	15	438	18	397	17
3 010—4 000	2	— 35	— 1	— 97	— 3	— 66	— 2
4 010—5 000	1	—130	— 3	—460	— 11	—295	— 7
Barley:							
1 010—2 000	2	313	20	373	24	343	22
2 010—3 000	6	108	4	197	7	103	4
3 010—4 000	1	320	10	—115	— 4	102	3
4 010—5 000	1	—115	— 3	—275	— 6	—195	— 4
Spring wheat:							
—1 000	2	258	55	370	79	314	67
1 010—2 000	12	342	21	391	24	367	23
2 010—3 000	3	282	11	359	15	321	13

Table 10. Effect of rate of application (X) on the grain yields (Y) in 9 trials at the Department of Plant Husbandry (series C). Yields of untreated oats 4 330 kg, barley 4 510 kg, wheat 2 900 kg/ha]

Crop	Treatment	Equation	Y max. %	X optim. kg/ha
Oats (Pendek)	MCPA	$Y = 33.46X - 13.43X^2$	+20.19	1.25
	MCPA/TBA	$Y = 39.80X - 18.00X^2$	+22.00	1.11
	d-mecoprop	$Y = 32.32X - 12.86X^2$	+20.84	1.25
Barley (Pirkka)	MCPA	$Y = 15.40X - 6.00X^2$	+ 9.88	1.28
	MCPA/TBA	$Y = 9.88X - 5.14X^2$	+ 4.75	0.96
	d-mecoprop	$Y = 13.34X - 4.57X^2$	+ 9.73	1.46
Spring wheat (Diamant)	MCPA	$Y = 7.91X - 4.86X^2$	+ 3.22	0.97
	MCPA/TBA	$Y = 4.34X - 4.57X^2$	+ 1.03	0.47
	d-mecoprop	$Y = 8.03X - 1.71X^2$	(+ 9.43)	(2.35)

the case of wheat, MCPA/TBA caused appreciable yield decrease at the lowest weed levels of this series. Unfortunately no weed counts were made in series B.

Tables 8 and 9 show a negative although not very close correlation between yield level and yield increase in both trial series A and B, i.e. the lower the yield level, the larger the yield increase caused by the herbicides. At the highest levels there were only minimal increases or quite often decreases in yield.

Despite the somewhat diverging data for wheat in series B, it appears — assuming that the yields of the different cereals are similar and reasonable high — that the herbicides in question give the largest yield increases for oats and the smallest for wheat. This is also substantiated by the results obtained in series C, in which many different rates were tested. These trials, the results of which are given in Table 10 and Figs. 4, 5 and 6, reveal important data on the response of weedy cereal stands to herbicides.

The theoretical maximum increase in the yield of Pendek oats — computed by means of second degree regression — was 20—22 % in the rate of treatment trials in series C. There was no significant difference between the different herbicides, although the response curve for MCPA/TBA is slightly steeper than the others. The optimum rate of MCPA/TBA was 1.11 kg/ha, or slightly less than that for MCPA and *d*-mecoprop, 1.25 kg/ha (i.e. 2.5 kg technical mecoprop).

The response curves for Pirkka barley were less steep than those for oats. The theoretical maximum yield increase was just under 10 % for MCPA and mecoprop and only 4.75 % for MCPA/TBA. This fact agrees well with the results of trial series A and indicates that MCPA/TBA is more toxic to barley than MCPA alone or mecoprop. The optimum rates of MCPA and *d*-mecoprop were about the same, 1.28—1.46 kg/ha, while that of MCPA/TBA was much smaller, only 0.96 kg/ha.

The curves showing the increase in the yield of Diamant wheat in response to different herbicide rates were especially interesting. MCPA caused an increase in yield at the most about 3 %, and the optimum amount of the herbicide was only 0.97 kg/ha. This seems to indicate that MCPA may be more toxic to wheat than to the other cereals. Consequently, with the exception of low-yielding stands where the effect of weeds is unusually great (series B), MCPA may not be able to provide more than a small increase in the yield of wheat.

MCPA/TBA proved to be even more toxic to Diamant wheat than MCPA alone. The theoretical maximum yield increase resulting from this mixture was only 1 % at an optimum rate of 0.47 kg/ha. Higher rates than 1 kg/ha caused considerable decreases in yield. These data agree with those in series A, where 1 kg/ha of MCPA/TBA resulted in an average decline in yield of 5 %. Both these trial series thus show that MCPA/TBA is too toxic to spring wheat to

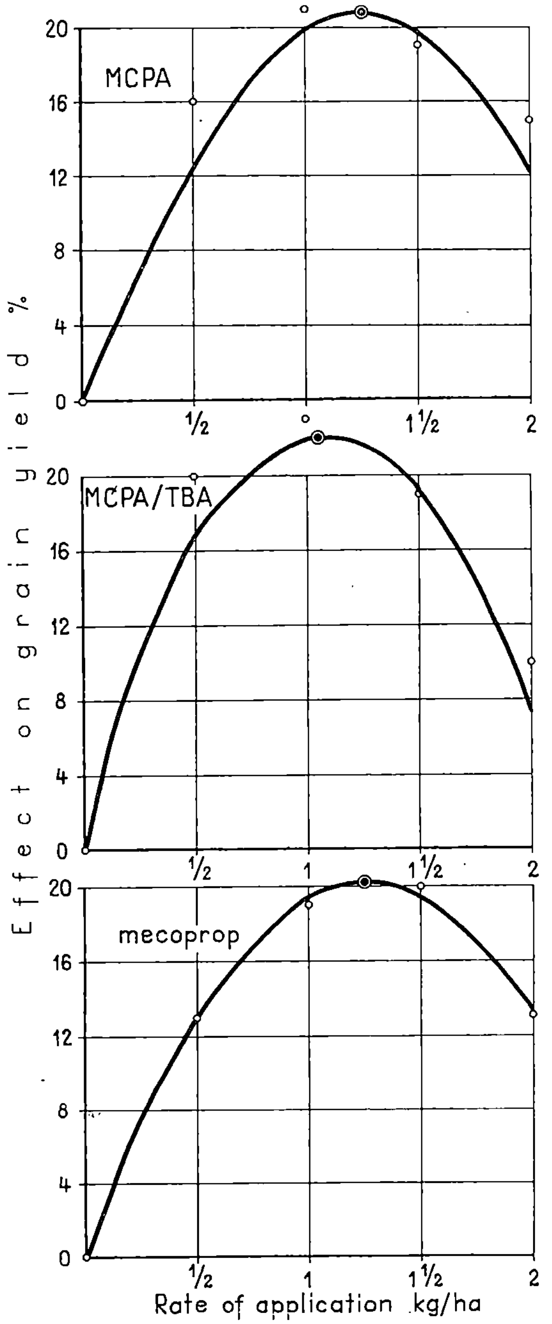

Fig. 4. Effect of rate of application on the grain yield of Pendek oats in 3 trials at the Department of Plant Husbandry (series C) in 1961—63. The curves are second-degree regressions. The small circles show the means of the original data. The apex of each parabola is marked by a black circle and indicates the maximum yield increase and optimum rate (cf. Table 10).

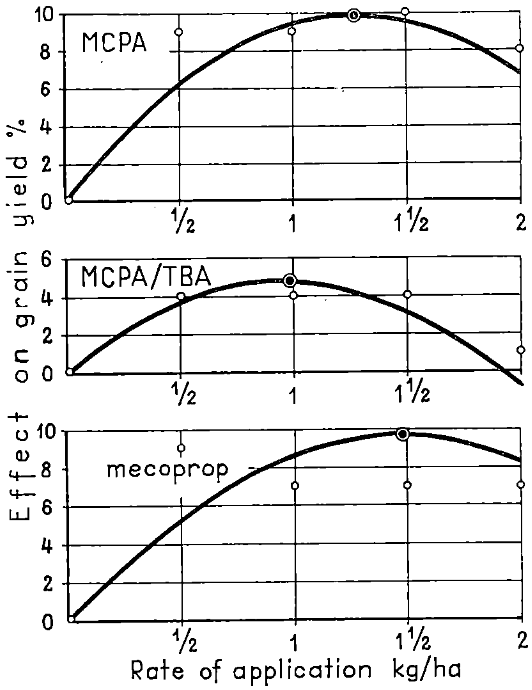

Fig. 5. Effect of rate of application on the grain yield of Pirkka barley in 3 trials at the Department of Plant Husbandry (series C).

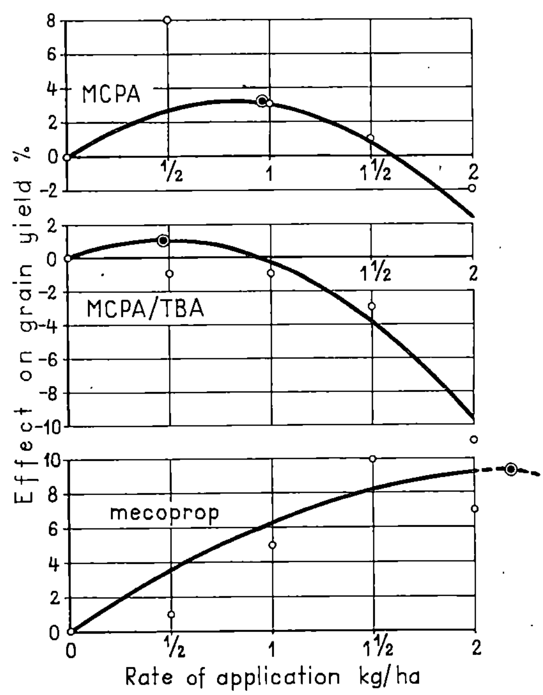

Fig. 6. Effect of rate of application on the grain yield of Diamant wheat in 3 trials at the Department of Plant Husbandry (series C).

provide appreciable yield increases. Instead, considerable yield reductions are quite probable.

Mecoprop had a better effect on Diamant wheat than the other herbicides, giving a theoretical maximum yield increase of about 9.5 %. The theoretical optimum rate of *d*-mecoprop was 2.35 kg/ha, corresponding to 4.70 kg/ha technical mecoprop, an amount which exceeded those used in these trials. It is obvious from these results and the data from series A and B that mecoprop is less toxic to wheat than the other two herbicides, and consequently its use will lead to greater yield increases than MCPA or MCPA/TBA.

Additional observations

The effect of different herbicide rates on the 1 000-grain weight in trial series C is shown in Table 11. It can be seen that in general the effect on the 1 000-grain weight was similar to that on the grain yield but smaller. The largest increase in Pendek oats and Pirkka barley was 1.3—1.4 g, or not quite 4 %, while in Diamant wheat it was only 0.3 g, or about 1 %. The only reductions in 1 000-grain weight occurred in wheat; the greatest such reduction was 0.8 g (nearly 3 %), produced by the largest rates of MCPA and MCPA/TBA.

The effect of different rates on the hectolitre weight in trial series C is presented in Table 12. The changes occurring in this property closely resembled those in 1 000-grain weight but were still smaller. The maximum increases in hectolitre weight as a result of herbicide treatment were 0.5 kg (1 %) for Pendek oats, 1.2 kg (2 %) for Pirkka barley and 0.2 kg (0.3 %) for Diamant wheat. The maximum decreases were correspondingly 0.6 kg (1 %), 0.2 kg (0.3 %) and 0.8 kg (1 %) for the three cereals.

The effect of different rates on the straw yield (Table 13) also showed positive correlation with the changes in the grain yield, although some noteworthy exceptions occurred. The maximum straw yield increases for oats were only 10—12 %, or about one-half the maximum increases in grain yield. For barley and wheat the situation was somewhat different. MCPA caused increases in straw yield which were proportional to those in grain yield. On the other hand, MCPA/TBA produced relatively higher increases and mecoprop relatively lower increases than could be expected on the basis of their effect on the grain yield.

Table 11. Effect of rate of application on 1 000 grain weight in 9 trials at the Department of Plant Husbandry (series C)

Treatment		Oats	Barley	Spring wheat
Untreated		35.2	39.7	32.7
MCPA	0.5 kg/ha	35.5	40.7	32.6
	1.0 »	35.6	41.0	33.0
	1.5 »	35.6	40.6	32.1
	2.0 »	35.5	40.5	31.9
MCPA/TBA	0.5 kg/ha	35.3	40.1	33.0
	1.0 »	35.5	40.9	32.9
	1.5 »	36.5	40.9	32.0
	2.0 »	35.4	41.1	31.9
mecoprop	1.0 kg/ha	35.8	40.5	33.0
	2.0 »	35.7	39.8	32.8
	3.0 »	35.2	39.8	32.6
	4.0 »	35.1	39.8	32 8

Table 12. Effect of rate of application on grain hl-weight in 9 trials at the Department of Plant Husbandry (series C)

Treatment		Oats	Barley	Spring wheat
Untreated		47.9	62.1	77.2
MCPA	0.5 kg/ha	48.3	62.0	76.6
	1.0 »	48.3	62.1	76.5
	1.5 »	48.3	62.2	76.6
	2.0 »	47.8	62.4	76.4
MCPA/TBA	0.5 kg/ha	47.8	62.0	77.0
	1.0 »	47.9	63.3	76.9
	1.5 »	47.6	63.0	76.8
	2.0 »	47.7	62.7	76.4
mecoprop	1.0 kg/ha	48.1	62.5	77.4
	2.0 »	48.4	62.4	77.3
	3.0 »	48.3	62.2	77.2
	4.0 »	47.3	61.9	76.8

Table 13. Effect of rate of application on straw yield in 9 trials at the Department of Plant Husbandry (series C)

Treatment		Oats	Barley	Spring wheat
		kg/ha		
Untreated		4 880	4 900	5 660
		Relative values		
MCPA	0.5 kg/ha	102	100	102
	1.0 »	107	103	105
	1.5 »	111	108	108
	2.0 »	109	102	95
MCPA/TBA	0.5 kg/ha	104	105	98
	1.0 »	111	103	109
	1.5 »	112	104	110
	2.0 »	109	106	103
mecoprop	1.0 kg/ha	101	100	99
	2.0 »	112	103	99
	3.0 »	111	99	106
	4.0 »	103	96	105

Scorch injuries to the crop plants as well as length of straw, lodging, deformed heads and ripening were estimated by visual observations.

MCPA/TBA was the only herbicide which caused scorch injuries, and these occurred only in wheat and barley. The maximum damage, estimated as the proportion of brown leaf area in the total leaf area, was about 5 % in wheat and 2 % in barley. Such scorch injury first appeared about three days after treatment and remained visible for about one week.

The straw length of wheat was found to be shortened about 5 cm by MCPA/TBA when the rate was 1 kg/ha or higher. In such stands there was less lodging than in normal stands. This compound also slightly decreased the amount of lodging in barley and oats. Although the improvement in lodging resistance produced by MCPA/TBA was small, this effect can be considered as an advantage, especially in Finland, where the straw of cereals tends to be longer and weaker than in more southern countries.

Contrary to MCPA/TBA, mecoprop apparently had a slight stalk-weakening influence which was most pronounced in wheat and least in oats. In one of the wheat trials at the Satakunta Experiment Station, all the mecoprop-treated plots were badly lodged, while the other plots were completely erect.

Deformed heads produced by the herbicides were quite common in wheat, rare in barley and absent in oats. The deformed heads were like those described in the literature (e.g. Pedersen *et al.* 1948, Åberg *et al.* 1948, Andersen and Jensen 1950, Petersen 1959), being branched, curved, or with their tips unemerged from the sheath. Characteristic of wheat was also the outward spreading position of the spikelets, giving the head a more or less rough appearance. The deformations caused by MCPA were generally the most severe and those by mecoprop the mildest.

In trial series C the highest herbicide rates tended to delay ripening of the cereals, mecoprop having the strongest influence. Of the different cereals, wheat was the most sensitive and oats the least sensitive.

Discussion

The experimental material of the present study was quite extensive, comprising a total of 91 trials. The geographical distribution of the trials covers the entire area in Finland where cereals are grown. Furthermore, the trials were conducted in three different years, so that the effect of chance weather conditions on the mean results was reduced.

The trials of series A and C were situated on fields of several experiment stations and of the Department of Plant Husbandry which were in better condition than normal fields. Consequently the average yield level in these trials was higher than the average for the country. Also in series B, at private farms, the average yield level of oats and barley was higher than the average for the country. However, the yield level varied widely in all the trials. This is an advantage, and gives an opportunity to obtain information on the effect of herbicides at different yield levels. Similarly, the degree of weed infestation as well as the composition of weed populations varied widely, thus giving an opportunity to study the effect of herbicides at different weed levels and against different weed species.

The main shortcomings in this investigation can probably be considered the lack of variety comparisons and different times of treatment. In series A and B all the cereal varieties commonly grown in the country were included. However, without special variety trials it is too difficult to establish how far the different varieties show different responses. The times of treatment in all the trial series were early, although in series B slightly later than in the other two. Hence, the results obtained are valid only for early spraying. However, such is the usual practice in Finland as well as in Scandinavia. Early spraying is carried out because it provides the best control against annual weeds. It is known that the response of cereals varies according to the time of treatment. The effect of spraying time is especially great when MCPA/TBA is used (GRANSTRÖM and MATTSON 1964). In the case of MCPA alone, significant differences have also been found (e.g. ANDERSEN and HERMANSEN 1950, HAGSAND 1954, PETERSEN 1959). However, under Finnish conditions the effect of time of MCPA treatment has been relatively small (MARJANEN 1962).

In comparing the herbicidal effects of the three compounds tested with previous reports in the literature, it can be stated that the effect of MCPA was generally to be expected. Only in the case of *Fumaria* and *Myosotis* did it provide relatively better control than mentioned by previous investigators (cf. SCHMIDT 1954, PETERSEN 1960, VIDME 1961 a, 1961 b, MUKULA 1962, 1964, BREITENSTEIN 1963, GRANSTRÖM and AAMISEP 1965, WOODFORD and EVANS 1965).

To some degree the results for MCPA/TBA also corresponded to expectations, i.e. this product controlled most broad-leaf weeds better than MCPA (cf. PFEIFFER 1958). However, it was not quite as effective in controlling *Polygonum* as had been expected. Furthermore, TBA did not improve the effect of MCPA against *Galeopsis* and *Spergula*, which are two of the most important annual weeds in Finland (cf. MUKULA *et al.* 1963). Neither did MCPA/TBA give better control against *Myosotis*, *Ranunculus* or *Lamium* than MCPA alone. Therefore, the superiority of MCPA/TBA over MCPA seems rather insignificant.

The effect of mecoprop was quite similar to that mentioned in the literature. This was especially clear in its excellent control of *Stellaria* and *Galium* (LUSH, LEAFE and MAYES 1958). Similarly, its control of *Lapsana* was to be expected, although this had previously been reported only in Sweden and Finland (MUKULA 1962 and 1964, GRANSTRÖM 1964, GRANSTRÖM and AAMISEP 1965). The superiority of mecoprop over MCPA in controlling Cruciferous species, *Chenopodium* (cf. VIDME 1961 a) and *Tripleurospermum* (e.g. LUSH, LEAFE and MAYES 1958, KÖYLIJÄRVI 1962, GRANSTRÖM and MATTSON 1964) was also generally recognized. On the other hand, the better control of *Polygonum* given by mecoprop in comparison with MCPA contradicted with previous studies in Finland MUKULA and PIRTTILÄ 1959, MUKULA 1964), although agreeing with English investigations (WOODFORD and EVANS 1965). Evidently the exact response of the individual *Polygonum* species in Finland to herbicides is a subject requiring more detailed study.

The fact that mecoprop gave a poorer control of *Galeopsis* than MCPA had been previously reported in Norway (VIDME 1961 a), but in the present trials the difference was greater than expected. Mecoprop's relatively poorer control of *Myosotis* had been previously established in Norway (ibid.) and Sweden (GRANSTRÖM and AAMISEP 1965), but it was not statistically significant in the present study. The weak effect of mecoprop against *Fumaria* was a new observation and contradicted with reports in the literature. The increase in numbers of *Lamium* as a result of mecoprop treatment can be attributed to destruction of other species which consequently left space for the emergence of *Lamium*.

The fact that the final herbicidal effectivity of mecoprop was still better than what could have been expected on the basis of the above observations was evidently due to the slow action of this compound.

Although both MCPA/TBA and mecoprop provided a control which on the average was better than that of MCPA, it must be kept in mind that their effect on broad-leaf weeds was far from complete, some species even remaining fully unchecked. Therefore over a long period of time, large-scale replacement of MCPA by MCPA/TBA or mecoprop would not lead to the desired results, i.e. to a decrease in the degree of weed infestation but instead to a change in the weed population. In certain cases MCPA/TBA or mecoprop may provide a temporary solution, but from the standpoint of spring cereal production as a whole, new herbicides are needed which would control a broader spectrum of dicotyledonous weeds.

In considering the effect of the three herbicides on cereal yields as compared with data from previous investigations, both similar and diverging results were obtained. The higher yield increase of oats than of barley and spring wheat were to be expected (cf. e.g. GRANSTRÖM 1956, VIDME 1959, MARJANEN 1962). Similarly, the greater toxicity to wheat of MCPA/TBA than MCPA had earlier been observed in England (EVANS and HOLROYD 1962), Scandinavia (e.g. PETERSEN 1960, VIDME 1961 c, AAMISEP and GRANSTRÖM 1964, THORUP 1964) and Finland (KÖYLIJÄRVI 1962), but the lower mean yields of the treated plots than the untreated ones were not expected. The unsatisfactory influence of MCPA/TBA on barley yields was previously known at least in Sweden (AAMISEP and GRANSTRÖM 1964), but the difference between this mixture and MCPA in the present trials was greater than had been anticipated. The better effect of mecoprop than MCPA on wheat had previously been observed only in Finland (KÖYLIJÄRVI 1962), although its superiority to MCPA/TBA for wheat treatment was known also in other countries.

The positive correlation between weed level and yield increase caused by the herbicides is quite understandable (GRANSTRÖM 1962) and agrees well with the results obtained e.g. in Denmark (PETERSEN 1960). Similarly, the negative correlation between yield level and yield increase agrees well with the results obtained in Sweden (GRANSTRÖM and MATTSON 1964). This phenomenon seems to be typical of weedy cereal stands. Apparently the well-known opposite phenomenon that healthy cereal plants themselves are less injured by herbicides than cereals in poor condition (SUOMELA and PAATELA 1962) is less dominating and thus is not necessarily evident in weedy cereal stands.

Although there are many other factors besides the monetary value of the expected yield increase which have a bearing on the profitability of herbicide treatment of cereals, it is enlightening to compare the suitability of various herbicides from this standpoint, taking into consideration the costs of treatment. The following table gives the average treatment costs of the three products in Finland during the years 1961—63 as well as the average profit obtained from the yield increases in trial series A (wheat calculated as bread grain).

	MCPA 1 kg/ha	MCPA/TBA 1 kg/ha	mecoprop 2 kg/ha
Cost, Finnmarks: [1])			
herbicide	11	32	32
treatment	7	7	7
total	18	39	39
Value of yield increase, Finnmarks:			
oats	96	134	124
barley	94	34	72
spring wheat	66	—66	105
Net profit Finnmarks:			
oats	79	95	85
barley	77	—5	33
spring wheat	49	—105	66

[1]) Finnmark = £—2 s. or $ —:30.

For oats, all the treatments were very profitable. MCPA/TBA gave the largest net profit and MCPA the smallest, but the differences between them were negligible.

For barley the best result was obtained by using MCPA, although the beneficial effect was not as great as for oats. The net profit with mecoprop was less than half that with MCPA, while MCPA/TBA caused a definite net loss.

Wheat responded least to herbicidal treatment. Mecoprop was most economic, while MCPA/TBA caused a particularly large loss.

On the basis of the above comparisons, it would seem justifiable to replace MCPA by MCPA/TBA or mecoprop on oats and by mecoprop on wheat. However, in evaluating these results it should be remembered that the fields in trial series A and C were not representative of the whole country. As stated on p. 259, the most important weed species were well represented and the number of weeds only slightly exceeded the normal. The average cereal yields, however, were higher than normal. Under such conditions the yield increases which can be expected from herbicide treatment are smaller than usual (cf. p. 265).

Considering the aspect of safety, it can finally be stated that all three herbicides are relatively harmless to the operator and moreover they do not, as far as is known, leave residues in grain. MCPA and mecoprop are rapidly decomposed, while TBA residues in straw and soil are more persistent, thus constituting a potential hazard especially in straw (ANDERSSON 1964).

Summary

In the years 1961—63 a study consisting of 91 field trials was carried out jointly by the Department of Plant Husbandry, experiment stations and the Bureau of Local Experiments on the use of MCPA, MCPA plus 2,3,6-TBA (4 : 1) and mecoprop for weed control in spring cereals. The results obtained were as follows:

1. The order of susceptibility to MCPA of the broad-leaf weeds occurring in the trials was: Cruciferous species (*Raphanus*, *Erysimum*, *Capsella* and *Thlaspi*), *Chenopodium*, *Fumaria*, *Ranunculus*, *Galeopsis*, *Myosotis*, *Spergula*, *Tripleurospermum*, *Stellaria*, *Viola*, *Lapsana*, *Polygonum*, *Lamium* and *Galium*. MCPA at 1 kg/ha caused an average decrease in total numbers of broad-leaf weeds to 54 % of the control; the corresponding air-dry weight of weeds was decreased to 38 %.

2. MCPA/TBA at a rate of 1 kg/ha was more effective than MCPA alone against most of the weeds except *Ranunculus*, *Galeopsis*, *Myosotis*, *Spergula*, *Lamium* and *Sonchus*. MCPA/TBA 1 kg/ha reduced the numbers of weeds to 45 % of the control and the air-dry weight to 35 %.

3. Mecoprop, also, at 2 kg/ha was more effective against most weed species than MCPA at 1 kg/ha. It was particularly effective in controlling *Stellaria*, *Lapsana* and *Galium*. It was poorer than MCPA against *Fumaria* and *Galeopsis*. The number of *Lamium* increased slightly after mecoprop treatment. The average total number of weeds was depressed to 46 % and their weight to 26 %.

4. At the experiment stations the three herbicides produced increases in grain yield of oats amounting to 11—15 % (322—414 kg/ha). On private farms, MCPA and mecoprop resulted in oat yield increases averaging 11—12 % (255—294 kg/ha). At the Department of Plant Husbandry, the theoretical optimum rates of the herbicides on Pendek oats were: MCPA 1.25 kg/ha, MCPA/TBA 1.11 kg/ha and mecoprop 2.50 kg/ha (= 1.25 kg active isomers).

5. The yields of barley at the experiment stations were increased as follows: by MCPA 10 % (275 kg/ha), by MCPA/TBA 4 % (102 kg/ha) and by mecoprop 8 % (216 kg/ha). On private farms the increases were: MCPA 5—6 % (134—161 kg/ha) and mecoprop 6 % (151—156 kg/ha). At the Department of Plant Husbandry the

theoretical optimum rates on Pirkka barley were: MCPA 1.28 kg/ha, MCPA/TBA 0.96 kg/ha and mecoprop 2.92 kg/ha (= 1.46 kg active isomers).

6. The wheat yields at the experiment stations were increased as follows: by MCPA 5 % (133 kg/ha) and by mecoprop 9 % (211 kg/ha). MCPA/TBA caused a reduction of 5 % (133 kg/ha). On private farms the average wheat yield increases resulting from MCPA were 18—21 % (294—350 kg/ha) and from mecoprop 23—24 % (382—384 kg/ha). At the Department of Flant Husbandry the theoretical optimum rates on Diamant wheat were: MCPA 0.97 kg/ha, MCPA/TBA 0.47 kg/ha and mecoprop 4.70 kg/ha (= 2.35 kg active isomers).

7. On all the cereals, the yield increase caused by herbicides was positively correlated with the degree of weed infestation.

8. On all the cereals the yield increase caused by herbicides was negatively correlated with the yield level. Apparently this phenomenon is typical of weedy cereal stands and dominates the fact that healthy cereal plants themselves are less injured by herbicides than cereals in poor condition.

9. The effect of all three herbicides on the 1000-grain weight, hectolitre weight and straw yield was positively correlated with grain yields. MCPA/TBA caused scorch injuries to wheat (at most 3 %) and barley (at most 1 %), produced about a 5-cm shortening of wheat stems, and had a slight lodging-preventative effect in all the cereals. Mecoprop, on the contrary, tended to increase lodging. All the herbicides were responsible for a slight delay in ripening of the cereals. Furthermore, they caused considerable spike deformation in wheat and also a slight amount in barley.

10. On the basis of the yield increases obtained in these trials as well as comparisons of prices of the herbicides, it would seem justifiable to replace MCPA by MCPA/TBA or mecoprop for use on oats and by mecoprop for use on wheat. However, in view of the fact that MCPA/TBA and mecoprop on the average provide only a slightly better weed control than MCPA and do not eradicate all species of broadleaf weeds, the replacement of MCPA by these new products should be considered with reservation. Attempts should instead be made to find new herbicides with a wider range of control for use on spring cereals.

Acknowledgement. — The following persons participated in the trials described in this paper: O. Anttinen, North Ostrobothnia Exp. Station, T. Honkavaara, South Ostrobothnia Exp. Station, E. Huokuna, South Savo Exp. Station, P. Hänninen, Central Finland Exp. Station, H. Marjanen, Bureau for Local Exp., H. Meurman, Karelia Exp. Station, Y. Pessi, Peat Cultivation Society, M. Salminen, North Savo Exp. Station, H. Selenius, Ahvenanmaa Field Trials, M. Takala, Häme Exp. Station, P. Teittinen, Satakunta Exp. Station, A. Valmari, Frost Research Station and E. Varis, Hankkija's Exp. Farm. Valuable advice in statistical analyses of the data was given by H. Tähtinen. For the assistance of the above persons, the authors express their sincere thanks.

REFERENCES

Aamisep, A. & Granström, B. 1964. Nya kemiska medel i kampen mot ogräs. Aktuellt från Lantbrukshögskolan 20: 1—20.

Andersen, S. & Hermansen, J. 1950. Effect of hormone derivatives on cultivated plants. Kgl. Vet. o. Landbohøjsk. Årsskrift 1950: 141—203.

ANDERSSON, Å. 1964. Ogräsmedel gör halmen skadligt. Hall. Hush.sällsk. tidskr. 7, 6: 15.

BREITENSTEIN, W. 1963. Bort med ogräsen. Svenska Lantbr.sällsk. förb. B 32: 1—104.

DEWEY, O. 1960. Soil persistence and biological breakdown of 2, 3, 6-trichlorobenzoic acid. Med. Landbouwhogesch. Gent 24: 899—904.

EVANS, S. A. & HOLROYD, J. 1962. Mecoprop and a mixture of MCPA and 2, 3, 6-TBA for the control of weeds in cereals. Exp. Husbandry 7: 32—39.

GRANSTRÖM, B. 1956. Ogräsbekämpning i vårsådda grödor. (Summary: Weed control in spring sown crops.) Stat. jordbr.förs. Medd. 65: 1—17.

—»— 1962. Studies över ogräs i vårsådda grödor. (Summary: Studies on weeds in spring sown crops.) Ibid. 130: 1—188.

—»— 1964. Kemiska ogräsbekämpning. Jord-Gröda-Djur 1964: 104—118.

—»— & AAMISEP, A. 1965. Nya kemiska medel mot ogräs 1964. Aktuellt från Lantbrukshögskolan 48: 1—21.

—»— & MATTSON, R. 1964. Ogräsbekämpning i höstvete. Ibid. 19: 1—17.

The Grower 1963. TBA may persist for years. The Grower 60: 189.

HAGSAND, E. 1954. Hormonderivatens inverkan på stråsäd och lin efter besprutning vid olika tidpunkter. K. Lantbr.akad. tidskr. 93: 235—281.

KÖYLIJÄRVI, J. 1962. Tuloksia rikkaruohojen kemiallisesta torjunnasta Lounais-Suomen koeasemalla. (Summary: Results of weed control trials in Southwest-Finland.) Maatal. ja koetoim. 16: 120—139.

LUSH, G. B. 1957. The herbicidal activity of some substituted alpha phenoxy propionic acids notably alpha 4-chloro 2-methyl phenoxypropionic acid. Proc. 4th Int. Congr. Crop. Prot. 1: 519—521.

—»— & LEAFE, E. L. 1956. A new development in selective weed control. Proc. 3rd Brit. Weed Contr. Conf., p. 625, 633.

—»— & — & MAYES, A. S. 1958. Further work with CMPP in cereal crops. Proc. 4th Brit. Weed Contr. Conf., p. 44—48.

MARJANEN, H. 1962. MCPA-valmisteiden vaikutuksesta kevätviljojen satoon. (Summary: The effect of MCPA on the grain yields of spring cereals.) Ann. Agric. Fenn. 1: 1—10.

MUKULA, J. 1962. Rikkaruohojen kemiallinen torjunta. Kasv.suoj.seur. julk. 25: 1—71.

—»— 1964. Rikkaruohot ja niiden torjunta. 140 p. Kirjayhtymä, Helsinki.

—»— & LALLUKKA, R. & RAATIKAINEN, M. 1963. Kevätviljamaiden rikkaruohot ja niiden runsaus v. 1963. Koetoim. ja käyt. 20: 34—35.

—»— & PIRTTILÄ, H. 1959. Monokloretikkahapon (MCA) käyttömahdollisuuksista kasvinviljelyssä. (Summary: Sodium monochloroacetate as a selective weed killer and plant defoliant.) Maatal. ja koetoim. 13: 47—53.

PEDERSEN, A. & ANDERSEN, S. & HERMANSEN, J. 1948. Hormonderivaternes virkning paa kulturplanterne. (Summary: Effect of hormone derivatives on cultivated plants.) Kgl. Vet. o. Landbohøjsk. Aarsskrift 1948: 101—147.

PETERSEN, H. I. 1959. Nogle ukrudtsbekaempelsesmidlers virkning på kornarternes spiring, udbytte og kvalitet. Tidsskr. Planteavl 63: 197—284.

—»— 1960. Ukrudtsplanter og ukrudtsbekaempelse. 144 p. København.

PFEIFFER, R. K. 1958. Some aspects of the use of MCPA/2, 3, 6-TBA mixtures for selective weed control in cereals. Proc. 4th Brit. Weed Contr. Conf., p. 54—69.

SCHMIDT, O. 1954. Vergleichende Untersuchungen über die herbizide Wirkung der synthetischen Wuchsstoffe 2, 4-D und MCPA. Mitt. Biol. Zentralanstalt Land- u. Forstw. Berlin-Dahlem 77: 1—119.

SNEDECOR, G. W. 1956. Statistical methods. 5th Ed. 535 p. Iowa.

SUOMELA, H. & PAATELA, J. 1962. The influence of irrigation, fertilizing and MCPA on the competition between spring cereals and weeds. Weed. Res. 2: 90—99.

Tidsskrift for Planteavl 1960 & 1963. Specialmidler anerkendt af Statens Forsøgsvirksomhed i Plantekultur til bekaempelse af ukrudt og til tvangsmodning. Tidsskr. Planteavl. 63: 804—811, 66: 756—767.

THORUP, S. 1964. Ukrudtet og dets bekaempelse i 1963—64. Tolvmandsbladet 1964, 4. Saertryk.

VIDME, T. 1959. Forsøk med kjemiske midler mot ogras i kornåker 1948—1956. Forskn. o. fors. landbr. 10: 127—157.

—»— 1961a. Kjemiske middel mot ogras. Landbr.dep. opplysningstjänste, Småskrift 61, 4: 1—28.

—»— 1961b. Ugrasboka. 156 p. Oslo.

—»— 1961c. Oral communication.

WALTHER, K. 1959. Fenoksismörsyrors och fenoksipropionsyrors verkan på kulturväxter och ogräs. (Summary: The effect of phenoxybutyric acids and phenoxypropionic acids on cultivated plants and weeds.) Växtodling 10: 188—207.

WOODFORD, E. K. & EVANS, S. A. 1965. Weed control handbook. 434 p. Oxford.

ÅBERG, E. & HAGSAND, E. & VÄÄRTNOU, H. 1948. Hormonderivat i kampen mot ogräs. Växtodling 3: 8—64.

SELOSTUS

MCPA:n, MCPA:n ja 2,3,6-TBA:n sekä mekoproopin käyttö rikkaruohojen torjuntaan kevätviljoissa

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Herbisidejä ryhdyttiin Suomessa käyttämään peltoviljelyksillä vuosina 1948—50. Menetelmä yleistyi aluksi suhteellisen hitaasti ja vielä 1950-luvun lopulla oli herbisideillä vuosittain käsitelty peltoala vain 70 000—100 000 ha. Vasta 1961 aloitetun ns. valtakunnallisen rikkaruohosodan puitteissa tapahtui tällä alalla voimakas läpimurto (MUKULA 1962). Herbisidien käyttö lisääntyi tällöin entisestään yli kaksinkertaiseksi. Vuonna 1965 käsitelty peltoala oli jo 450 000 ha, josta kevätviljoja 425 000 ha. Tämä vastasi noin 40 % kevätviljan viljelyalasta Suomessa.

Miltei yksinomaisena torjunta-aineena on kevätviljoissa käytetty MCPA:ta. Tämä valmiste tehoaakin hyvin useimpiin maassamme yleisiin 2-sirkkaisiin rikkaruohoihin. Lisäksi se on ruiskutteena helppokäyttöinen, hinnaltaan halpa, viljoille suhteellisen vaaraton ja hajaantuu sekä maassa että kasvisolukossa melko nopeasti. MCPA:lla 1950-luvulla saadut keskimääräiset sadonlisäykset ovat olleet kauralla noin 300 kg/ha, ohralla 200 kg ja vehnällä 230 kg/ha (MARJANEN 1962).

MCPA:ta kestävien 2-sirkkaisten rikkaruohojen määrä on kevätviljoissamme ollut keskimäärin 20 % rikkaruohojen kokonaismäärästä (MUKULA *et al.* 1963). Kestävien lajien määrän todettiin kuitenkin jo 1950-luvulla alkaneen huolestuttavasti lisääntyä sellaisilla peltolohkoilla, joilla tätä valmistetta oli käytetty useana vuonna peräkkäin. Lisäksi oli rikkaruohokasvuston eräissä tapauksissa jo alunperin todettu koostuvan pääasiallisesti MCPA:ta kestävistä 2-sirkkaisista lajeista. On selvää, ettei MCPA:n käyttö tällaisissa olosuhteissa vastaa tarkoitustaan. Ongelman ratkaisemiseksi ryhdyttiin Suomessa, kuten muissakin maissa, etsimään uusia herbisidejä, jotka yksinään tai MCPA:n kanssa seoksina tuhoaisivat sellaiset 2-sirkkaiset lajit, joihin MCPA yksinään ei tehoa. Ensimmäiset tällaiset herbisidit olivat 2,3,6-TBA, josta seuraavassa käytetään lyhennystä TBA sekä mekoprooppi. Näitä valmisteita koskevat tekniset tiedot on esitetty taulukossa 1 s. 257.

TBA on sisävaikutteinen lehtiherbisidi kuten MCPA, mutta vaikuttaa melko voimakkaasti myös maasta käsin ja on sekä maassa että kasvisolukossa huomattavasti MCPA:ta pysyvämpi. Sitä käytetään yleisesti MCPA:n kanssa seoksena (4 : 1). Mekoprooppi muistuttaa vaikutustavaltaan MCPA:ta, mutta koostuu useammista isomeereistä, joista vain 50 % on tehoavia.

Kasvinviljelyslaitoksella 1950-luvun lopulla suoritettujen alustavien kokeiden perusteella oli Kasvinsuojelulaitos myöntänyt myyntiluvan eräälle MCPA:n ja TBA:n seosta sisältävälle valmisteelle sekä useille mekoprooppivalmisteille 1959—61. Jatkotutkimuksia varten suorittivat Kasvinviljelylaitos, koeasemat ja Paikalliskoetoimisto 1961—63 yhteensä 91 kenttäkoetta kyseisten kolmen valmisteen käyttökelpoisuuden selvittämiseksi kevätviljamaiden rikkaruohontorjunta-aineina.

Kokeissa esiintyneiden 2-sirkkaisten rikkaruohojen herkkyysjärjestys MCPA:lle herkimmästä lukien oli seuraava: ristikukkaiset (*Raphanus*, *Erysimum*, *Capsella* ja *Thlaspi*), *Chenopodium*, *Fumaria*, *Ranunculus*, *Galeopsis*, *Myosotis*, *Spergula*, *Tripleurospermum*, *Stellaria*, *Viola*, *Lapsana*, *Polygonum*, *Lamium* ja *Galium*. Kaksisirkkaisten rikkaruohojen kokonaislukumäärä väheni 1 kg/ha vastaavalla MCPA-käsittelyllä käsittelemättömään verrattuna keskimäärin 53 %:iin. Kaksisirkkaisten rikkaruohojen ilmakuiva paino väheni tällä käsittelyllä 38%:iin.

MCPA/TBA-seos tehosi sitä 1 kg/ha käytettäessä useimpiin kaksisirkkaisiin rikkaruohoihin hiukan paremmin kuin vastaava määrä pelkkää MCPA:ta. Poikkeuksena olivat *Ranunculus*, *Galeopsis*, *Myosotis*, *Spergula* ja *Lamium*. Kaksisirkkaisten rikkaruohojen kokonaislukumäärä väheni MCPA/TBA käsittelyllä käsittelemättömään verrattuna 45 %:iin ja ilmakuiva paino 35 %:iin.

Myös mekoprooppi tehosi sitä 2 kg/ha käytettäessä useihin lajeihin hiukan paremmin kuin 1 kg/ha MCPA:ta. Erityisen hyvä oli mekoproopin teho *Stellaria*an, *Lapsana*an ja *Galium*iin. MCPA:ta heikommin se tehosi *Fumaria*an. *Lamium*in lukumäärään mekoprooppi vaikutti lievästi lisäävästi. Kaksisirkkaisten rikkaruohojen kokonaismäärä väheni mekoprooppikäsittelyn vaikutuksesta 46 %:iin ja ilmakuiva paino 26 %:iin.

Kauran jyväsatoon MCPA ja MCPA/TBA sekä mekoprooppi vaikuttivat lisäävästi koeasemien kokeissa keskimäärin 11—15 % eli 322—414 kg/ha. Paikalliskokeissa, joissa olivat mukana vain MCPA ja mekoprooppi, olivat kauran jyväsadon lisäykset keskimäärin 11—12 % eli 255—294 kg/ha. Kasvinviljelylaitoksen käyttömääräkokeissa saatiin eri herbisidien teoreettisiksi optimikäyttömääriksi Pendek-kauralla seuraavat annokset: MCPA 1.25 kg, MCPA/TBA 1.11 kg ja mekoprooppi 2.50 kg/ha (= 1.25 kg tehoavia isomeerejä).

Ohran jyväsatoa eri käsittelyt lisäsivät koeasemien kokeissa keskimäärin seuraavasti: MCPA 10 % eli 275 kg, MCPA/TBA 4 % eli 102 kg ja mekoprooppi 8 % eli 216 kg/ha. Paikalliskokeissa MCPA antoi sadonlisäystä 5—6 % eli 134—161 kg ja mekoprooppi 6 % eli 151—156 kg/ha. Kasvinviljelylaitoksen käyttömääräkokeissa saatiin eri herbisidien teoreettisiksi optimikäyttömääriksi Pirkka-ohralla seuraavat annokset: MCPA 1.28 kg, MCPA/TBA 0.96 kg ja mekoprooppi 2.94 kg/ha (= 1.46 kg tehoavia isomeerejä).

Kevätvehnän jyväsatoa käsittelyt lisäsivät koeasemien kokeissa keskimäärin seuraavasti: MCPA 5 % eli 133 kg ja mekoprooppi 9 % eli 211 kg/ha. MCPA/TBA aiheutti vehnän jyväsadon alentumista 5 % eli 133 kg/ha. Paikalliskokeissa olivat MCPA:n antamat vehnän jyväsadon lisäykset keskimäärin 18—21 % eli 294—350 kg/ha ja mekoproopin antamat 23—24 % eli 382—384 kg/ha. Kasvinviljelylaitoksen käyttömääräkokeissa saatiin eri herbisidien teoreettisiksi optimikäyttömääriksi Timantti-vehnällä seuraavat annokset: MCPA 0.97 kg, MCPA/TBA 0.47 kg ja mekoprooppi 4.70 kg/ha (= 2.35 kg tehoavia isomeerejä).

Kaikissa viljoissa todettiin positiivinen korrelaatio rikkaruohojen määrän ja herbisidien aiheuttaman jyväsadon lisäyksen välillä. Viljojen satotason ja herbisidien aiheuttaman jyväsadon lisäyksen välillä todettiin negatiivinen korrelaatio. Tämä lienee tyypillinen rikkaruohoisille viljakasvustoille ja peittää päinvastaisen korrelaation, joka vallitsee rikkaruohottomissa olosuhteissa.

Kaikki kokeillut herbisidit vaikuttivat viljojen 1 000 jyvän painoon, hehtolitran painoon ja olkisatoon yleensä samansuuntaisesti kuin jyväsadon määrään, mutta paljon heikommin. Poikkeukset tästä säännöstä olivat melko vähäisiä. MCPA/TBA aiheutti lieviä polttovioituksia vehnässä ja ohrassa, lievää korren lyhenemistä vehnässä sekä lievää lakoutumisen estymistä kaikissa viljoissa. Mekoprooppi puolestaan edisti hiukan lakoutumista. Kaikki valmisteet viivästyttivät lievästi viljojen tuleentumista. Lisäksi ne aiheuttivat yleisesti tähkien epämuodostumista vehnässä ja hiukan myös ohrassa.

Kokeissa saatujen sadonlisäysten sekä hintavertailujen perusteella näyttää siltä, että kauran suhteen MCPA:n korvaaminen MCPA/TBA:lla tai mekoproopilla olisi perusteltavissa, samoin vehnän suhteen MCPA:n korvaaminen mekoproopilla. Kun ottaa kuitenkin huomioon, että MCPA/TBA ja mekoprooppi tehoavat rikkaruohoihin keskimäärin vain hiukan paremmin kuin MCPA eivätkä tuhoa kaikkia 2-sirkkaisia rikkaruoholajeja, on MCPA:n laajamittaiseen korvaamiseen niillä suhtauduttava varauksin. Tutkimuksia teholtaan monipuolisempien herbisidien löytämiseksi kevätviljoille olisi näin ollen jatkettava.

ANNALES AGRICULTURAE FENNIAE, VOL. 4: 277—289 (1965)

Seria AGROGEOLOGIA, -CHIMICA ET -PHYSICA N. 20
Sarja MAAPERÄ, LANNOITUS JA MUOKKAUS n:o 20

ON THE EXCHANGE CHARACTERISTICS OF SOME CLAY SOILS IN THE MIDDLE UUSIMAA

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Received November 2, 1965

The clay soils of Southern Finland have already been investigated earlier, particularly with respect to their general properties and chemical composition (e.g. AARNIO 1938, SALMINEN 1935, 1939, VUORINEN 1939), as well as to their mineralogical composition (VÄYRYNEN 1929, SOVERI 1950, 1956). Observations on the cation exchange capacity of Finnish clays and clay soils have also been reported in several connections (KIVINEN 1938, AARNIO 1942, TERÄSVUORI 1959, HEINONEN 1960, *etc.*). Data on the easily soluble cation fraction of clay soil profiles have likewise been published (PUROKOSKI 1959).

The clay soils of the district of Middle Uusimaa are characteristically represented for the area of *Kerava—Nickby;* Soil map, recently published (VIRRI 1964). The purpose of the present study is to throw more light on the nature of these clays and in particular on their cation exchange characteristics, these clay soils being agriculturally important in the southern coastal district of the country.

A review in detail for the area has been made in connection with the Soil map report; *Kerava—Nickby*, as well as elsewhere (VIRKKALA 1959). The area forms a unit of six individual agrogeological maps, each covering one hundred square kilometers. The moraine hills and cultivated clay soil plains are the two typical landscape forming factors. About 32 % of the whole area and 73 % of the arable land are classified as clay soils (Fig. 1). The region is located below the geologically named »higher Litorina coast» and it has therefore until lately been covered by the former Baltic Sea. The highest altitude is found in the northeastern corner of the area where the fields are located at about 55—60 meters above the sea level.

The clays of the region generally possess the characteristics of heavy glacial clay, with a considerably high content of less than 2 μ particles. Silty and sandy clays are sometimes found where the borders of the plains are affected by coarser material. In the southern part, near the coast of the Gulf of Finland, the gyttja clays and gyttjas, on the other hand, dominate the river valley plains.

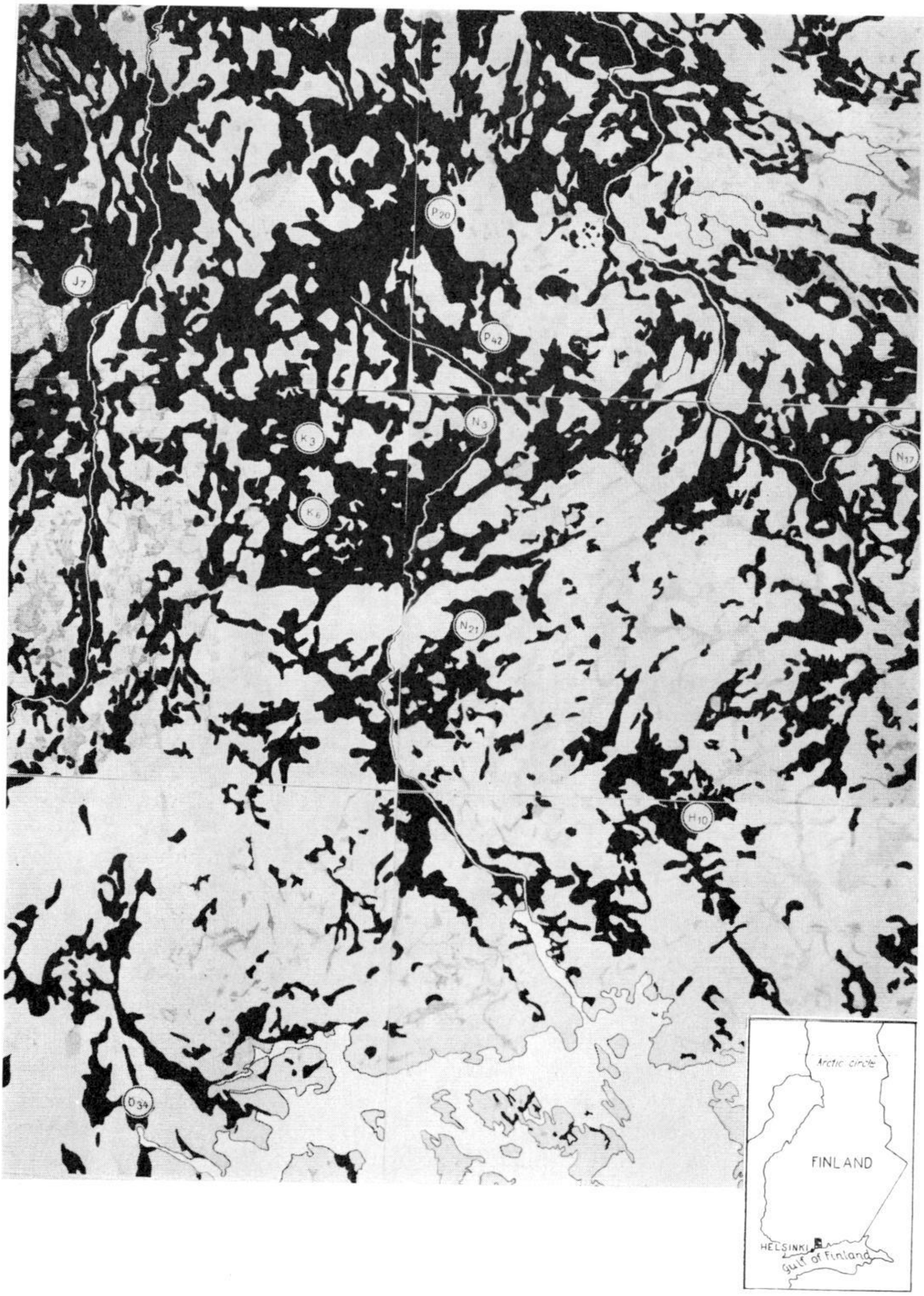

Fig. 1. Clay soils in the Kerava—Nickby area and the locations of the profiles under study.
Kuva 1. Maaperäkartta: Keravan — Nickbyn savialueet ja näytepisteiden sijainti.

Sample material

Ten clay soil profiles were taken for the present study. Six of them are typical heavy clays (profiles: Järvenpää-7, Kerava-3 and 6, Nickby-3 and 21, and Pornainen-42), two of them represent lighter clays (Hangelby-10 and Pornainen-20), and two profiles rich enough in gyttja material to be classified as gyttja (muddy) clays (Nickby-17 and Östersundom-34). Most of the sampling sites are located in the valley plains of the *Sipoo River*, one of the *Kerava-River*. The first gyttja clay site is near the *Mäntsälä-River* and the second is in the neighbourhood of the sea coast.

The profile samples were collected according to the practice followed in soil survey work. Three samples were taken at each site: the topsoil, hardpan [1]) and subsoil.

[1]) The popular term *hardpan* is here used for the name of the subsurface layer located below the topsoil (or plow-layer).

Experimental

Soil samples

The soil samples were pre-treated by air-drying, homogenizing and by being passed through a 2 mm sieve. The particle size distribution analysis were carried out using nonsieved soil. The organic matter was decomposed with hydrogen peroxide. Similar decomposing of soil organic matter was used for separating the clay fraction.

Exchange determinations

Pre-washed (60 % ethanol/water) samples were used for leaching the exchangeable cations with *N* ammonium acetate (pH adjusted to 7.0). The leaching was carried out by both percolation (Schollenberger et Simon 1945) and centrifugation. Metallic cations were determined by flamephotometry (Vuorinen and Mäkitie 1951, 1955, Jackson 1958).

Exchangeable hydrogen was determined by Brown's (1943) method with *N* ammonium acetate. The equilibrium pH values were corrected to pH 7.0 by means of the neutralization titration curves of each sample (Mäkitie 1965).

Exchangeable aluminium of *N* potassium chloride leachate was determined colorimetrically with aluminon (Jackson 1958).

Cation exchange capacity was determined in addition to the summation of the individual cations (CEC, Table 1), by leaching with *N* ammonium acetate (pH adjusted to 7), and also by exchanging with *N* potassium chloride. The ammonium ions liberated were then analyzed by Kjeldahl-distillation. The rapid method of Brown (1943) was used for estimating the »permanent» exchange capacity to near pH 2.7 (depending on the pH of equilibrium in each case).

Neutralization titration curves were obtained from soil suspension and also from acidified and washed samples. The neutralization (5 gr. of soil sample and 50 ml. water, titrated with 0.1 *N* sodium hydroxide solution) was carried out in 100 ml. polyethylene jars and the fully equilibrated pH readings were obtained after each amount of base was added. Observations were made every second day after the period of repeated shaking until the readings became constant.

All the measurements were obtained by means of a Radiometer PHM 4c potentiometer with a glass electrode and open bridge saturated potassium chloride reference electrode.

Additional determinations were carried out as follows:

Analysis of particle size distribution by the »pipette method» with sodium hexametaphosphate as the dispersing agent.
Organic matter content by sulphuric acid — chromic acid oxidation with moderate external heating (Organic matter = 1.73 x organic carbon).
Silicate analysis of the samples was carried out gravimetrically, according to common procedure.

Table 1. Characteristics of the profiles

Taulukko 1. Profiilien ominaisuuksia

Soil profiles — *Maaprofiilit*			Particle size distribution (%) *Kivennäisfraktion raekoostumus (%)*				O.M. % *Orgaaninen aines*	pH susp. (1 : 2.5)		Exchangeable cations to pH 7; meq. per 100 g soil *Vaihtuvat kationit pH 7:ssä*					»S»	CEC *Vaihto-kapasiteetti*	Base satur. % *Emäskyllästys-aste*
Location — *Sijainti*	Soil type — *Maalaji*)*	Depth cm *Syvyys*	< 0.002	0.002—0.02	0.02—0.2	0.2—2.0 mm		H_2O	*N* KCl	H^+	Ca^{++}	Mg^{++}	K^+	Na^+			
J_7, Järvenpää	AS, Heavy clay	0—20	73.7	23.4	1.8	1.5	4.0	5.8	4.43	7.4	8.8	4.2	0.3	0.2	13.5	20.9	64.6
	AS, »	30—40	79.2	15.1	3.4	2.3	0.6	5.6	4.86	6.5	14.3	4.8	0.6	0.2	19.9	26.4	75.4
	AS, »	80—100	70.1	24.9	4.8	0.2	1.0	5.7	4.50	7.0	14.7	3.7	0.5	0.1	19.0	26.0	73.1
K_3, Kerava	AS, Heavy clay	0—20	78.5	17.0	2.2	2.3	14.1	5.1	3.98	21.7	13.9	3.7	0.5	0.2	18.3	40.0	45.8
	AS, »	20—40	70.0	26.8	3.2	—	2.0	5.4	4.04	8.7	10.3	5.2	0.4	0.2	16.1	24.8	64.9
	AS, »	40—60	76.3	23.1	0.6	—	1.8	5.7	4.49	7.3	11.9	6.1	0.8	0.6	19.4	26.7	72.7
K_6, Kerava	AS, Heavy clay	0—20	50.4	32.6	12.1	4.9	6.6	5.4	4.05	9.0	10.7	2.7	0.6	0.2	14.2	23.2	61.2
	AS, »	20—40	75.5	17.3	5.2	2.0	1.9	5.2	4.38	11.3	10.4	4.0	0.8	0.3	15.5	26.8	57.8
	AS, »	40—60	84.8	13.6	1.6	—	1.6	5.7	4.77	6.0	15.5	8.8	0.8	0.4	25.5	31.5	81.0
N_3, Nickby	AS, Heavy clay	0—20	53.8	31.4	10.7	4.1	4.0	5.0	3.89	14.4	5.0	2.5	0.4	0.1	7.9	22.3	35.4
	AS, »	20—40	69.4	24.7	5.3	0.6	1.4	5.2	3.85	9.8	6.2	5.8	0.4	0.1	12.6	22.4	56.3
	AS, »	40—50	77.6	19.8	2.2	0.4	1.4	5.3	3.98	9.5	7.5	6.0	0.5	0.2	14.2	23.7	59.9
N_{21}, Nickby	AS, Heavy clay	0—20	76.4	20.0	2.5	1.1	11.5	5.5	4.30	20.6	12.5	4.3	0.3	0.1	17.2	37.8	45.5
	AS, »	20—40	71.5	28.1	0.4	—	3.3	5.8	4.21	9.1	10.0	5.1	0.1	0.2	15.5	24.6	63.0
	AS, »	40—60	72.0	25.0	3.0	—	2.1	5.9	4.39	7.7	10.6	5.4	0.3	0.4	16.7	24.4	68.4
P_{42}, Pornainen	AS, Heavy clay	0—20	49.6	31.1	8.1	11.2	5.4	5.3	4.09	16.7	5.0	3.5	0.7	0.1	9.3	26.0	35.8
	AS, »	20—40	57.0	32.2	6.3	4.5	1.9	5.5	3.99	11.2	4.5	4.2	0.3	0.2	9.2	20.4	45.1
	AS, »	40—60	76.5	20.7	2.8	—	1.0	5.8	4.22	8.1	11.2	7.1	0.5	0.3	19.1	27.2	70.2
P_{20}, Pornainen	HsS, Silty clay	0—20	54.6	33.4	10.8	1.2	9.9	5.1	3.94	23.8	5.0	2.8	0.5	0.1	8.5	32.3	26.3
	HsS, »	20—40	55.1	36.4	7.6	0.9	1.5	5.4	3.98	11.0	4.1	3.5	0.2	0.2	7.9	18.9	41.8
	HsS, »	40—50	43.0	42.6	12.6	1.8	0.7	6.0	4.46	5.6	8.1	5.2	0.1	0.3	13.7	19.3	71.0
H_{10}, Hangelby	HtS, Sandy clay	5—10	49.0	25.9	19.3	5.8	6.0	5.2	4.15	9.4	5.9	2.1	0.7	0.0	8.7	18.1	48.1
	HtS, »	15—25	50.4	27.8	19.6	2.2	4.6	5.1	4.03	9.9	4.7	4.7	0.6	0.0	10.0	19.9	50.3
	HsS, Silty clay	35—45	57.2	29.5	13.3	—	2.3	5.2	3.99	8.5	5.9	3.7	0.6	0.0	10.2	18.7	54.5
$Ö_{34}$, Östersundom	HtS, Sandy clay	0—20	49.9	21.1	27.3	1.7	7.1	5.5	4.38	10.2	11.3	3.0	0.5	0.3	15.1	25.3	59.7
	LjS, Gyttja clay	20—40	67.7	22.6	9.2	0.5	4.5	5.0	3.85	14.4	7.4	3.2	0.5	0.3	11.4	25.8	44.2
	LjS, »	40—60	67.3	23.2	8.9	0.6	4.1	4.7	3.57	20.1	2.5	3.6	0.8	0.5	7.4	27.5	26.9
N_{17}, Nickby	LjS, Gyttja clay	0—20	80.5	16.9	0.7	1.9	15.1	5.1	3.96	28.9	10.6	4.3	0.5	0.4	15.8	44.7	35.3
	LjS, »	20—40	76.0	19.8	3.4	0.8	4.1	4.9	3.82	25.5	4.7	4.0	0.5	0.5	9.7	35.2	27.6
	LjS, »	40—60	74.5	22.8	3.7	—	2.2	4.9	3.81	14.4	5.0	4.4	0.6	0.5	10.5	24.9	42.2

*) without O.M. — *huomioon ottamatta humusta*

Results and discussion

The clay soils under study were relatively heavy. An average figure of 61.6 % represents the content of less than 2 μ particles in the topsoil samples, calculated on the mineral matter fraction basis. The corresponding value for the subsoil is 69.9 %. The clay percentages of the whole soil are 56.7 % and 68.7, respectively. Silt (2—20 μ) is represented by an average of 23.3—25.3 % throughout the profile layers (Table 1).

The average content of organic matter in the soil samples is 8.4 % (from 4.0 % to 15.1 %) for the topsoil and 1.8 % (0.7 %—4.1 %) for the subsoils.

The profiles according to their general exchange characteristics, are grouped into »rich» and »poor» clays. Although this kind of classification is somewhat arbitrary it has proved to be appropriate. These differences are also reflected in other analytical data.

Acidity characteristics

The clay soil profiles under study represent the typical acid soils of the area. A less acid reaction is generally found in the subsoil in comparison to the reaction in the surface, except in the gyttja soil profiles, where the reverse order is characteristic.

The pH values in water suspension (1:2.5 per volume) are in correlation with the base saturation and to some extent with the actual amount of exchangeable hydrogen, amount of which in that pH can be estimated from the exchange acidity figures (Table 2). The former relation is also shown in Fig. 2. The low values of pH_{H_2O} indicate the occurrence of exchangeable aluminium too. However, the content of aluminium in exchangeable form plus total exchangeable hydrogen can better be correlated with the corresponding $pH_{N\,KCl}$ values (Fig. 3).

Table 2. Exchange characteristics of the clay profiles

Taulukko 2. Saviprofiilien kationinvaihto-ominaisuuksia

			Depth cm *Syvyys*	Exchange acidity meq per 100 g soil *Vaihtohappamuus mekv./100 g maata*: Exchangeable *Vaihtuva* Al+++ (a)	Exchangeable *Vaihtuva* H+ (b)	Additional acidity to pH 7 *Lisähappamuus pH 7:ssä* (c)	CEC in soil meq per 100 g *Maan vaihtokapasiteetti mekv./100 g*: »Permanent» at pH 2.7 »*Vakio» pH 2.7:ssä* (d)	Additional »pH-dependent» to pH 7 *pH:sta riippuvainen lisä pH 7:ssä* (e)	CEC in organic fraction of soil meq per 100 g *Org.fraktion vaihtokap.mekv./100 g*: In org. fraction *Org.fraktiossa* (f)	In humus *Humuksessa* (g)	CEC in clay meq per 100 g *Saven vaihtokap. mekv./100 g*: In clay fraction of soil *Savifraktiossa* (h)	In clay matarial, < 2 µ *Savessa < 2 µ* (i)
J-7	AS,	Heavy clay	0—20	1.2	1.3	4.9	7.8	11.0	5.3	133	13.5	18.3
		»	30—40	0.3	1.6	4.6	11.3	13.7	1.8	300	23.2	29.3
		»	80—100	0.5	5.8	0.7	10.5	14.2	2.7	270	22.0	31.4
K-3	AS,	Heavy clay	0—20	7.7	3.6	10.4	11.8	23.6	18.6	132	16.8	21.4
		»	20—40	3.1	2.2	3.4	10.6	14.1	4.8	240	19.9	28.4
		»	40—60	0.6	1.2	5.5	11.4	14.9	5.3	294	21.0	27.5
K-6	AS,	Heavy clay	0—20	5.3	2.3	1.4	11.4	11.0	10.2	154	12.2	24.2
		»	20—40	1.7	1.8	7.8	10.5	14.9	5.0	263	20.4	27.0
		»	40—60	0.3	1.1	4.6	13.2	16.8	5.7	356	24.3	28.7
N-3	AS,	Heavy clay	0—20	4.3	5.7	4.4	7.7	14.5	10.8	270	11.4	21.2
		»	20—40	3.2	5.4	1.2	8.6	13.0	5.0	357	16.6	23.9
		»	40—50	3.0	4.4	2.1	10.2	12.8	6.1	436	16.9	21.8
N-21	AS,	Heavy clay	0—20	2.0	3.5	15.1	15.2	23.0	18.4	160	19.8	25.9
		»	20—40	1.2	2.6	5.3	11.9	11.3	9.8	297	13.4	18.7
		»	40—60	0.7	2.3	4.7	13.1	13.3	8.5	405	17.9	24.9
P-42	AS,	Heavy clay	0—20	3.8	4.7	8.2	9.0	16.6	11.6	215	14.0	28.2
		»	20—40	3.4	4.0	3.8	8.0	14.4	8.2	432	14.2	24.9
		»	40—60	1.3	3.0	3.8	12.8	13.4	4.7	470	21.5	28.1
P-20	HsS,	Silty clay	0—20	7.1	10.0	6.7	11.4	23.0	21.3	215	13.1	24.0
		»	20—40	4.8	4.8	1.4	7.3	11.3	5.0	263	13.6	24.7
		»	40—50	1.1	2.6	1.9	11.4	6.6	3.2	457	14.8	34.4
H-10	HtS,	Sandy clay	5—10	2.0	3.2	4.2	9.1	11.2	10.7	178	9.6	19.6
		»	15—25	3.6	4.3	2.0	7.8	11.2	8.4	183	10.6	21.0
	HsS,	Silty clay	35—45	3.0	4.0	1.5	7.7	10.3	5.0	217	13.0	22.7
Ö-34	HtS,	Sandy clay	0—20	1.4	1.2	7.6	9.0	16.0	13.4	189	11.6	23.2
	LjS,	Gyttja clay	20—40	8.9	4.1	1.4	8.9	15.3	10.7	238	13.5	19.9
		»	40—60	9.4	8.5	2.2	6.9	20.3	12.8	312	14.4	21.4
N-17	LjS,	Gyttja clay	0—20	6.9	8.8	13.2	14.7	32.3	29.6	196	17.4	21.6
		»	20—40	7.6	8.6	9.3	10.3	25.7	15.8	385	20.2	26.6
		»	40—60	7.1	6.3	1.0	9.6	21.0	8.9	405	21.7	29.1
						of total exch. acidity *kokonaishappamuudesta* %		of total CEC *koko vaihtokapasiteetista* %			Averages *Keskiarvot*	
Averages of the profiles — *Profiilien keskiarvot:*												
Topsoils — *pintamaat*						46.9		61.9	15.0		13.9	
Hardpans — *jankot*						34.2		59.8	7.5		16.6	
Subsoils — *pohjamaat*						29.7		56.4	6.3		18.8	
All — *kaikki*												24.7

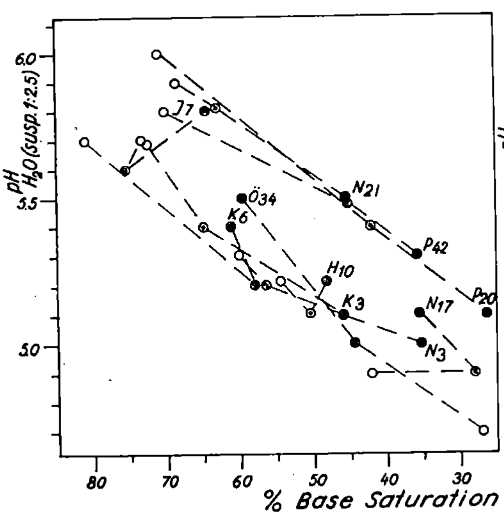

Fig. 2. Relationship between pH_{H_2O} values and percentage base saturation.
Kuva 2. pH_{H_2O} *arvot emäskyllästysasteen funktiona.*

● = topsoil — *pintamaa,*
⊙ = hardpan — *jankko,*
○ = subsoil — *pohjamaa.*

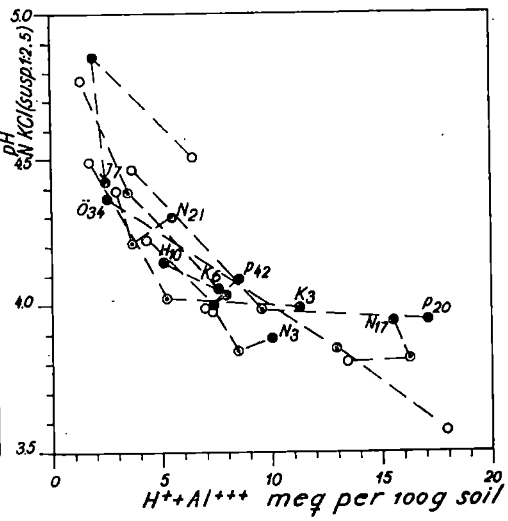

Fig. 3. Relationship between $pH_{N\ KCl}$ values and exchange acidity of the soil.
Kuva 3. $pH_{N\ KCl}$ *arvot vaihtohappamuuden funktiona.*

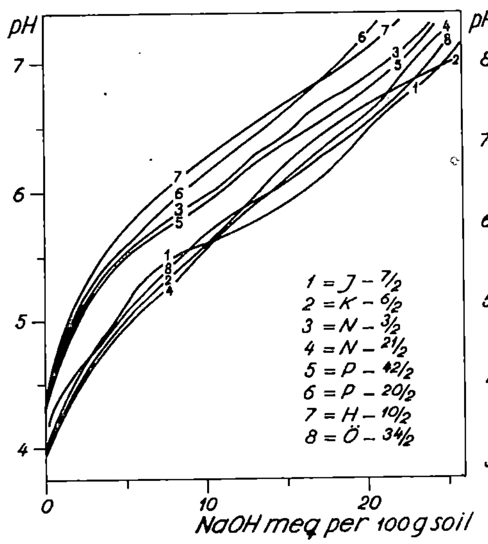

Fig. 4. Titration curves of some clays.
Kuva 4. Eräiden savien titrauskäyrät.

Curves — *Käyrät:*

No 1 = J — 7/2 Heavy clay — *Aitosavi*
No 2 = K — 6/2 » »
No 3 = N — 3/2 » »
No 4 = N — 21/2 » »
No 5 = P — 42/2 » »
No 6 = P — 20/2 Silty clay — *Hiesusavi*
No 7 = H — 10/2 Sandy clay — *Hietasavi*
No 8 = Ö — 34/2 Gyttja clay — *Liejusavi*

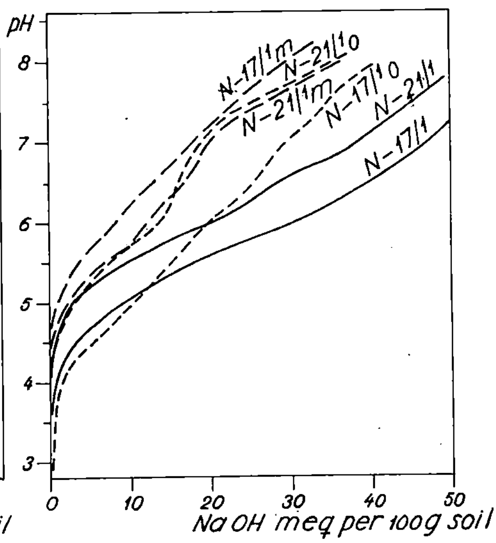

Fig. 5. Titration curves for two topsoils rich in organic matter and the curves for their mineral *(m)* and organic *(o)* fractions, respectively.
Kuva 5. Kahden runsasmultaisen pintamaan titrauskäyrät ja vastaavasti niiden kivennäis (m) — ja eloperäisten (o) fraktioiden käyrät

Samples — Näytteet:
N — 17/1 = Gyttja clay — *Liejusavi*
N — 21/1 = Heavy clay = *Aitosavi*

Table 3. Average data for the clay profile groups

Taulukko 3. Keskiarvotulokset saviprofiiliryhmissä

Profile groups *Profiili ryhmät*			Distribution of soil material *Maa-aineksen prosentuaalinen jakautuminen*			pH (susp. 1 : 2.5)		Al+++ meq per 100 g soil	Exchange acidity to pH 7 meq per 100 g soil *Vaihtohappamuus pH 7:ssä*	Base saturation *Emäskyllästysaste*	Exchangeable cations at pH 7 *Vaihtuvien kationien prosentuaalinen jakautuminen pH 7:ssä*			»S» value meq per 100 g soil *»S» arvo*	CEC to pH 7 meq per 100 g soil *Vaihtokapasiteetti pH 7:ssä*
			Clay % *Savi*	Organic matter % *Org. aines*	Less reactive remainder % *Heikosti reagoiva jäännös*	H_2O	*N* KCl			%	Ca %	Mg %	Alkalies *Alkaalit* %		
»Rich» clays »*Hyvät*» *savet* J_7,K_3,K_6,N_{21}	4	topsoil — *pintamaa*	63.9	9.1	27.0	5.4	4.2	4.1	14.7	54.3	72.3	23.8	3.9	15.8	30.6
		hardpan — *jankko*	72.7	2.0	25.3	5.5	4.3	1.6	8.9	65.3	66.9	28.8	4.3	16.8	25.7
		subsoil — *pohjamaa*	74.6	1.6	23.8	5.8	4.5	0.5	7.0	73.8	64.4	30.6	5.0	20.2	27.2
»Poor» clays »*Heikot*» *savet* H_{10},N_3,P_{20},P_{42}	4	topsoil — *pintamaa*	48.7	6.3	45.0	5.2	4.0	4.3	16.1	36.4	60.9	31.6	7.5	8.6	24.7
		hardpan — *jankko*	56.7	2.4	40.9	5.3	4.0	3.8	10.5	48.4	49.3	45.8	4.9	9.9	20.4
		subsoil — *pohjamaa*	62.7	1.4	35.9	5.6	4.1	3.5	7.9	63.9	57.1	38.5	4.4	14.3	22.2
Gyttja clays *Liejusavet* $N_{17},Ö_{34}$	2	topsoil — *pintamaa*	58.3	11.1	30.6	5.3	4.1	4.2	19.6	47.5	71.0	23.5	5.5	15.5	35.0
		hardpan — *jankko*	68.9	4.3	26.8	4.9	3.8	8.3	20.0	35.9	56.7	34.7	8.6	10.6	30.5
		subsoil — *pohjamaa*	68.8	3.2	28.0	4.8	3.7	8.3	17.3	34.6	40.7	45.3	14.0	9.0	26.2

The difference between pH_{H_2O} and $pH_{N\,KCl}$ is relatively constant, the average being 1.2—1.3 pH units throughout the profiles.

The exchangeable acidity to pH 7 represents the total acidity of the soil. It can be divided into exchangeable hydrogen displaced by *N* salt solution of a strong acid (potassium chloride), aluminium exchanged in corresponding conditions, and into so-called additional, pH-dependent acidity to a standard pH (pH 7), as shown in Table 2. In the clay soils of the material under study, the pH-dependent acidity is mainly due to organic matter. It is caused by the weakly dissociable (carboxyl and strongly acidic hydroxyl) groups of the organic matter. The dissociation and hydrolysis of the compounds in the mineral fraction are the main cause of the rest of total acidity. The pH-dependent acidity is therefore in a clear relation to the organic matter content.

The average from the acidity data are presented in Table 3, showing the relationship between the apparent acidity and exchangeable acidity. The »better» clay soils are less acid and naturally contain less exchangeable aluminium. The two gyttja clay profiles differ clearly from the other clays.

The neutralization titration of clay suspension with a strong base gives an estimation of the exchange acidity, as demonstrated in the curves of some of the samples in Fig. 4. The neutralizable share of acidity in the organic matter, which is dominant in topsoil samples is clearly shown in Fig. 5, in which some of the titration curves of the organic and mineral fraction have been separately illustrated.

Exchangeable cations

Calcium forms the main part of exchangeable metallic cations (Table 1). The molar ratio of Ca:Mg varies, but is commonly near three to one in the topsoils generally limed and in the subsoils it is often near one. The alkalies are bound in the exchange complex only in a minority, as shown in the mean values of cation percentages in Table 3.

The sum of metallic cations varies within the limits of 7.9 to 18.3 milliequivalents per 100 g of soil in topsoils and of 7.4—25.5 in subsoils. The amount of exchangeable metallic cations increases with the increasing depth of the soil layers, except with the gyttja clays in which the topsoil contains relatively more calcium (Tables 1 and 3). The mean values for topsoils, hardpans and subsoils are 12.9, 12.8 and 15.6 milliequivalents metallic cations per 100 g soil, respectively.

The mean values of cation exchange capacity to pH 7 in different layers of increasing depth are 29.1, 24.5 and 25.0 milliequivalents per 100 g soil. The percentage base saturation is in the topsoils of the »rich» clays on the average 54.3 while in the »poor» clays it is regularly less, the mean value being 36.4. The base saturation increases with increasing depth, except in the case of the gyttja clays.

Some of the results of a closer study on the character of the exchange capacity in these clays are shown in Table 2.

The cation exchange capacity to pH 7 is here considered to be formed from so-called »permanent» exchange capacity at a lower pH and also from additional »pH-dependent» exchange capacity to the neutral reaction. On the average 40 % of the whole capacity is due to the permanent charges at pH 2.7 (as here determined by Brown's method), while 60 % of it depends on the reaction up to the standard pH 7 (Table 2, columns d-e). The values of the »permanent» exchange capacity vary from 6.9 to 15.2 milliequivalents per 100 g soil and depend on the amount of clay material present. The mean value is 10.3 milliequivalents per 100 g soil at pH 2.7. The relationship with the sum of the exchangeable aluminium and alkaline earths is shown in Fig. 6. The regression equation $y = 3.72 + 0.40\ x$; $r = 0.66^{***}$ represents this relationship. The »pH-dependent» exchange capacity depends greatly on the amount of organic matter in the soil. The relationship with the cation exchange capacity in the organic fraction in shown in Fig. 8, and can be expressed by the regression equation, $y = 5.53 + 1.06\ x; = 0.83^{***}$. For the topsoils only, a better correlation is found when the equation, $y = 2.64 + 1.04\,x$; $r = 0.96^{***}$ is used.

The total cation exchange capacity to pH 7 due the organic matter in the soil is on the average higher than that due to the clay material in the topsoils (Table 2, columns f and h). In subsoils, however, the clay fraction represents 75 % of the whole capacity of the soil.

A mean value of 184 milliequivalents per 100 g humus was found in topsoils where more organic matter was present. This figure is somewhat lower than the value reported by Heinonen (1960).

The results of the cation exchange capacity determinations in the clay material of the soils are listed in the last columns of Table 2. The clay fraction, less than 2 microns, contains 13.9 milliequivalent cations per 100 g of soil in the topsoils. The average amount generally increases with the depth and is 18.8 milliequivalents in the subsoils, where more clay is present. When

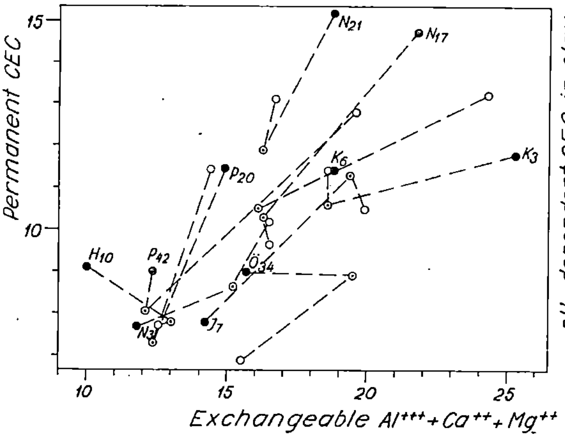

Fig. 6. Relationship between the »permanent CEC» and the sum of exchangeable aluminium, calcium and magnesium in milliequivalents per 100 g soil.
Kuva 6. Maan »pysyvä vaihtokapasiteetti» vaihtuvan alumiinin, kalsiumin ja magnesiumin summan funktiona milliekvivalenteissa 100 g:ssa maata.

● = topsoil — *pintamaa,*
⊙ = hardpan — *jankko,*
○ = subsoil — *pohjamaa.*
Regression found, y = 3.72 + 0.40 x; r = 0.66***

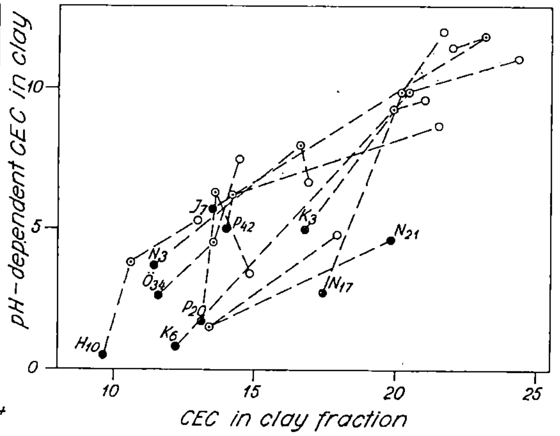

Fig. 7. Relationship between the so-called pH-dependent CEC and the total CEC in clay fraction in milliequivalents per 100 g clay. (Regression: y = —5.29 + 0.70 x; r = 0.84***).
Kuva 7. Niinsanottu pH:sta riippuvainen vaihtokapasiteetti kokonaisvaihtokapasiteetin funktiona milliekvivalenteissa 100 g:ssa savea.

the values are calculated according to the clay material itself a mean value of 24.7 is found (from 18.3 to 34.4), and this indicates the nature of the clay minerals (Table 2, column i). Assuming that the »permanent» exchange capacity of the soil is caused by the clay fraction only, the »pH-dependent» exchange capacity to pH 7 in the clay can be obtained (Table 2; value h - value d). This additional exchange capacity is in relationship to the whole capacity in the clay fraction in accordance with the regression equation, y = 5.29 + 0.70 x; r = 0.84*** (Fig. 7).

In order to discover the relationship between the exchange properties and the quality of the clay material and the clay minerals present, chemical and mineralogical determinations of some separated clay fractions of the hardpan samples were carried out (Table 4).

The data shows that all these clays are mainly of the same composition of mica and related clay minerals, as has earlier been reported (Soveri 1950, 1956). The molar rations between silica and aluminium as well as silica and sesquioxides indicate the existence of three-sheet layer minerals. That illitic minerals are apparently present, is also confirmed by the high ratio between potassium and sodium (Grim 1953).

The X-ray diffraction analysis verifies the existence of mica and feldspar as main compo-

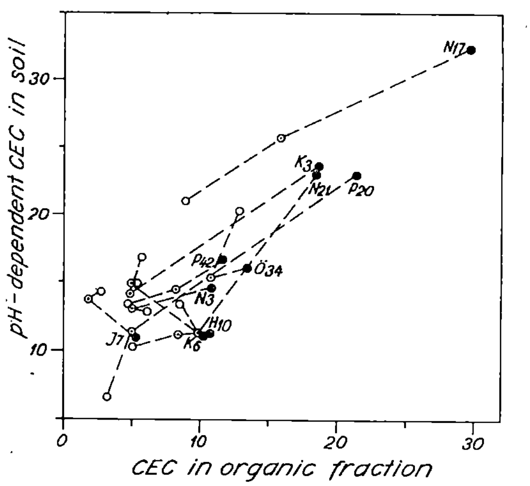

Fig. 8. Relationship between the pH-dependent CEC in soil and total CEC in organic fraction.
Kuva 8. pH:sta riippuvainen vaihtokapasiteetti saven orgaanisen fraktion vaihtokapasiteetin funktiona.

Regressions found, all samples *(kaikki näytteet)*
y = 5.53 + 1.06 x; r = 0.83***
and topsoils *(● = pintamaat)*
y = 2.64 + 1.04 x; r = 0.96***.

Table 4. Chemical and mineralogical data for some clays
Taulukko 4. Eräiden savien kemiallisia ja mineralogisia analyysituloksia

No	Depth cm *Syvyys*	Clay type *Savilaji*	Percentage composition in clay *Prosentuaalinen kokoomus savessa*					Molar ratios *Moolisuhteet*			Mineralogical composition *Mineraloginen kokoomus*				
			SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	SiO_2/Al_2O_3	SiO_2/R_2O_3	K_2O/Na_2O	Mica *Kiille*	Feldspar *Maasälpä* Na- K-	Chlorite *Kloriitti*	Vermiculite *Vermikuliitti*	Quartz *Kvartsi*
J-7	30—40	AS	52.80	20.17	12.51	3.39	1.66	4.44	3.18	1.33	++ (w)	++		+	+
K-6	20—40	AS	52.30	17.05	15.37	4.58	1.64	5.21	3.31	1.88	++ (w)	+ +	++		
N-21	20—40	AS	55.92	20.66	9.30	1.97	1.07	4.59	3.57	1.24	++ (w)	+			++
N-3	20—40	AS	49.94	21.09	13.23	4.45	1.39	4.01	2.87	2.14	++	+ +	++		+
P-42	20—40	AS	52.16	19.38	12.70	4.30	2.13	4.57	3.21	1.35	+++	+ +	+		++
P-20	20—40	HsS	47.40	21.44	17.16	1.04	0.29	3.76	2.49	2.20	++ (w)				
H-10	15—25	HtS	53.58	20.64	11.80	3.10	0.98	4.42	3.23	2.06	+++	+	++		++
Ö-34	20—40	LjS	54.16	23.02	11.80	0.94	0.45	3.99	3.00	1.43	++	+ +	+		+ +
		(Av.) — *(Keskim.)*						(4.37)	(3.11)	(1.70)					

(w) = weathered
rapautunut

nents. Neither were any clear kaolinitic nor montmorillonitic reflections observable. Chlorites were present in many samples and quartz is naturally also included in the clay fraction.

No clear relationship between the composition and exchange characteristics was found. The »rich» clays do contain more weathered mica and feldspars and the cation exchange capacity is higher in these samples as well. The capacity values, from 18.7 to 29.3 are in accordance with the apparent mixtures of minerals mentioned, where illitic types are dominant.

Summary

The cation exchange characteristics of some clay soil samples of the Soil map; *Kerava—Nickby* area in Southern Finland have been studied. These clay soils are generally heavy clays which are acid and on an average only half base-saturated. Less acid stage is, however, found with increasing depth.

A clear relationship between the soil reaction and base saturation, as well as with the exchangeable hydrogen, was found.

The exchangeable metallic cations are composed mainly of calcium and magnesium and the ratio between them approaches one to one with increasing depth. The sum of metallic cations in the exchange complex increases with increasing depth as well.

The cation exchange capacity to pH 7 depends on the amount of organic matter present. Mean values for the whole capacity are 29.1 milliequivalents per 100 grammes for topsoils and 25.0 for subsoils.

A classification of the sample material into »rich» and »poor» clays shows that the former ones are less acid and that they contain more clay fraction and organic matter as well as more exchangeable metallic cations.

The »better» clay samples contain in their mineral fraction relatively more weathered mica and feldspars, this having been proved by X-ray diffraction analysis.

Acknowledgement — The X-ray diffraction analyses were kindly carried out at the laboratory of the Geological Survey of Finland by Mr. J. J. H y y p p ä.

REFERENCES

AARNIO, B. 1938, Über die Tone Finnlands und ihre Eigenschaften. Selostus: Suomen savista ja niiden ominaisuuksista. Agrogeol. publ. 46: 1—27.

—»— 1942. —»— II. Die austauschbaren Basen. Selostus: II. Vaihtuvat emäkset. Ibid. 53: 1—24.

BROWN, I. C. 1943. A rapid method of determining exchangeable hydrogen and total exchangeable bases of soils. Soil Sci. 56: 353—357.

GRIM, R. E. Clay Mineralogy: McGraw-Hill Publ. Co Ltd. London 1953.

HEINONEN, R. 1960. Über die Umtauschkapazität des Bodens und verschiedener Bodenbestandteile in Finnland. Z. Pfl. Ernähr. Düng. 88: 49—59.

JACKSON, M. L. Soil Chemical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. 1958.

KIVINEN, E. 1938. Über die austauschbaren Basen in finnischen Tonböden. Selostus: Emästen vaihdosta savimaissamme. Agrogeol. publ. 44: 1—10.

MÄKITIE, O. 1965. On determination of the lime requirement of soils Ann. Agric. Fenn. 4: 238—252.

PRATT, P. F. 1961. Effect of pH on the cation exchange capacity of surface soils. Soil Sci. Soc. Amer. Proc. 25: 96—98.

PUROKOSKI, P. 1959. Über leichtlösliche Ca-, K-und P-ionen in finnischen Tonprofilen. Selostus: Helppoliukoisista Ca-, K- ja P-ioneista suomalaisissa saviprofiileissa. Acta Agr. Fenn. 94: 87—100.

SALMINEN, A. 1935. On the weathering of rocks and the composition of clays. Ann. Acad. Sci. Fenn., Ser. A. 44.6, and Agrogeol. publ. 40: 1—149.

—»— 1939. Suomalaisten savien kivennäiskoostumuksesta. Summary: On the mineral composition of Finnisch clays. S. Kemistilehti A 12: 2—7.

SCHOLLENBERGER, C. J. & SIMON, R. H. 1945. Determination of exchangeable bases in soil-ammonium acetate method. Soil Sci. 59: 13—24.

SOVERI, U. 1950. Differential thermal analyses of some quaternary clays of Fenno-scandia. Ann. Acad. Sci. Fenn., Ser. A. III. 23.

—»— 1956. The mineralogical composition of argillaceous sediments of Finland. Ibid. 48. pp. 32.

TERÄSVUORI, A. 1959. Über das Bestimmen des Kationensorptionskapazität und Basensättigungsgrades des Bodens. Selostus: Maan kationien pidätyskyvyn ja emäskyllästysasteen määrittämisestä. Valt. maatal. koetoim. julk. 175: 1—80.

VIRKKALA, K. 1959. Suomen geologinen kartta 1:100 000, lehti 2043 Kerava, pp. 91. Helsinki.

VIRRI, K. 1964. Kerava—Nickby. Summary: Soil map of Kerava—Nickby. Ann. Agric. Fenn. 3, suppl. 2: 1—54. (Agrogeol. karttoja 20).

VUORINEN, J. 1939. Untersuchungen über die Koagulation des schweren Glazialtons. Selostus: Jäykän glasiaalisaven koagulaatioita koskevia tutkimuksia. Agrogeol. publ. 50: 1—114.

—»— & MÄKITIE, O. 1951. On determination of calcium direct from soil extract by means of spectrophotometer with flame attachment. S. Kemistilehti 23 B: 7—14.

—»— & MÄKITIE, O. 1955. The method of soil testing in use in Finland. Selostus: Viljavuustutkimuksen analyysimenetelmästä. Agrogeol. publ. 63: 1—43.

VÄYRYNEN, H. 1929. Über den Chemismus der finnischen Kaolinvorkommen verglichen mit Verwitterungssedimenten. Bull. comm. geol. Finl. 87: 128—158.

SELOSTUS

Keski-Uusimaan savimaiden kationinvaihto-ominaisuuksista

OSMO MÄKITIE ja KALEVI VIRRI

Maatalouden tutkimuskeskus, Maantutkimuslaitos, Tikkurila

Tutkimuksessa on käsitelty Keravan—Nickbyn agrogeologisen maaperäkartoitusalueen savien ominaisuuksia erityisesti niiden vaihtuvien kationien osalta. Aineistona on ollut 10 alueelta koottua saviprofiilia.

Alueen tunnusomaisina savina ovat aitosavet, jotka rannikolla vaihtuvat liejuisiksi ja liejusaviksi. Aineiston keskimääräinen saviprosentti on 61.6—69.9 pintamaasta pohjamaahan siirryttäessä.

Käsitellyt savimaat ovat suhteellisen happamia ja niiden emäskyllästysaste pH 7:ssä on keskimäärin 45.8 — 52.6 — 62.0 % (pinta — jankko — pohjamaa). Selvä vuorosuhde on olemassa maan reaktion ja emäskyllästysasteen välillä, samoin kuin maan elektrolyytti- pH:n ja vaihtohappamuuden välillä.

Kalsium ja magnesium muodostavat tunnetusti pääosan vaihtuvien emästen määrissä. Niiden keskeinen suhde on 3:1 pintamaissa ja lähestyy suhdetta 1:1 profiilien pohjamaissa. Vaihtuvien emästen summa on suhteellisen pieni, keskimäärin 12.9 — 12.8 — 15.6 (pinta — jankko — pohjamaa) milliekvivalenttia 100 g:ssa maata.

Vaihtokapasiteetin kokonaisarvot pH 7:ssä ovat keskimäärin 29.1 — 24.5 — 25.0 (pinta — jankko — pohjamaa) milliekvivalenttia 100 g:ssa maata. Vaihtokapasiteetti riippuu (pH 7:ssä) selvästi orgaanisen aineksen määrästä maassa. Sen sijaan saveksen kationinvaihtokapasiteetin arvot ovat aineiston puitteissa tasaisia, keskimäärin 24.7 milliekvivalenttia 100 g:ssa savifraktiota (koko aineisto 18.3—34.4). Röntgendiffraktioanalyysi osoitti saveksen yleisesti koostuneen kiille- ja maasälpämineraaleista, mikä on tunnusomaista meikäläisille saville.

Aineiston savimaat voidaan ominaisuuksiensa mukaan jakaa »hyviin» ja »heikkoihin». Ensinmainittu ryhmä edustaa emäskyllästysasteeltaan ja vaihtokapasiteetiltaan suurempia lukuarvoja osoittavia savimaita, joissa toisaalta orgaanisen aineksen määrä ja savimineraalien rapautuneisuus ovat osaltaan myötävaikuttamassa. Selvää ryhmäerottelua on kuitenkin vaikea suorittaa, ja liejusavissa ominaisuudet ovat niin ikään poikkeavia.

ANNALES AGRICULTURAE FENNIAE, VOL. 4: 290—298 (1965)

Seria AGROGEOLOGIA, -CHIMICA ET -PHYSICA N. 21
Sarja MAAPERÄ, LANNOITUS JA MUOKKAUS n:o 21

OUTOKUMMUN KAIVOKSEN YMPÄRISTÖN HIVENAINE-PITOISUUKSISTA

Summary: **Trace element levels in the vicinity of Outokumpu copper mine**

ESKO LAKANEN

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Saapunut 13. 11. 1965

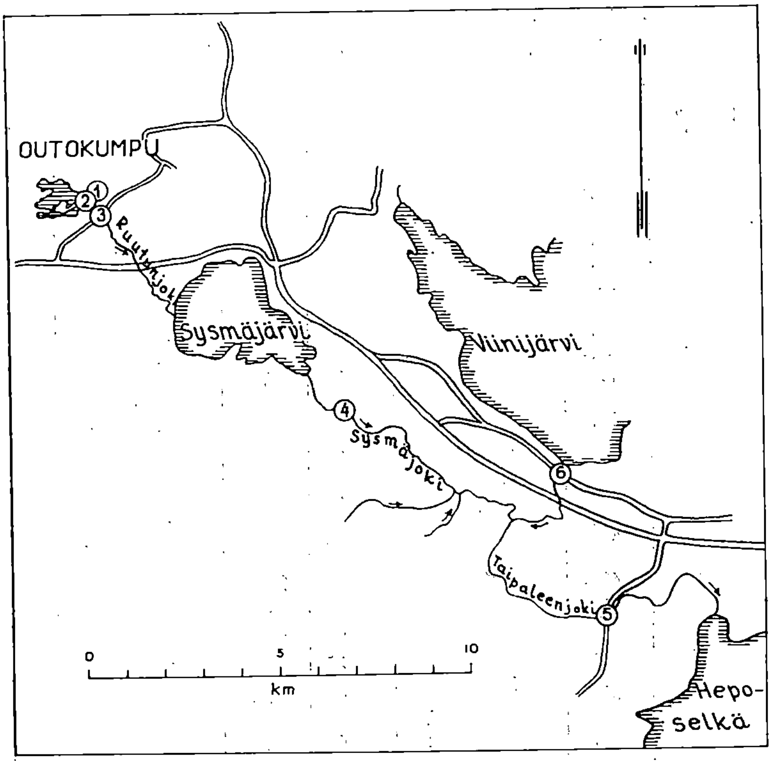
Outokummun kuparikaivos kuuluu edelleen Euroopan suurimpiin. Malmi sisältää luonnollisesti muitakin raskasmetalleja (Fe, Mn, Zn, Ni, Co jne.). Jääkauden sirottelemia malmilohkareita on löydetty runsaasti kaivosalueen lähiympäristöstä. Mannerjäätikön liikkumissuunnan mukaisesti vedet virtaavat kaivosalueelta kaakkoon vieden mukanaan kaivostoiminnasta peräisin olevia jätevesiä.

Seuraavassa tarkastellaan alueen maaperän, kasvien ja vesien hivenainepitoisuuksia. Tämänkaltainen hivenainetutkimus on aiheellinen pyrittäessä selvittämään jäteveden mahdollisia haittavaikutuksia alueen maaperään ja kasvillisuuteen, joiden kautta haitta kohdistuu myös eläimiin ja ihmisiin. Tutkimus antaa myös yleiskuvan alueen hivenainepitoisuuksista, joihin alueen kallioperällä on ilmeinen vaikutus. Yleiskuva on hyödyksi tutkittaessa maaperän hivenainepitoisuuksia muualla Suomessa.

Aineisto ja sen analysointi

Tutkittu alue esitetään kuvassa 1, josta myös ilmenee pintavesien kulku. Pintavesien näytteenottopaikat on numeroitu 1—6. Jäljempänä taulukoiduissa analyysituloksissa ovat näytteet G 21601—49 väliltä kaivos — Sysmäjärven suu ja näytteet G 21650—56 tästä alaspäin.

Tutkimuksen laajuuden ja monitahoisuuden takia jouduttiin näytteiden otto ja analysointi suorittamaan heinäkuun 1964 ja maaliskuun 1965 välisenä aikana. Samasta syystä ei jokaisesta näytepisteestä voitu suorittaa kaikkia seuraavassa esitettyjä analyyseja. Maan viljavuusanalyysi suoritettiin Suomessa käytössä olevan menetelmän mukaisesti (Vuorinen ja Mäkitie 1955). Hivenaineiden helppoliukoinen fraktio määritettiin spektraalianalyyttisesti samaa uuttonestettä(0.5 N CH_3COOH, 0.5 N CH_3COONH_4, pH 4.65) käyttäen (Lakanen 1963). Helppoliukoiset sulfaatit saostettiin $BaSO_4$:na samasta uutteesta. Em. spektraalianalyysia sovellettiin myös vesien hivenainepitoisuuksien määrittämiseen. Vesien Ca- ja K-määritykset suoritettiin liekkifotometrisesti sekä Mg-määritykset kompleksometrisesti titraten. Maan hivenaineiden totaalimäärät määritettiin spektraalianalyyttisesti (Lappi ja Mäkitie 1954).



Kuva 1. Tutkittu alue.
Fig. 1. The investigated area.

Tulokset ja niiden tarkastelu

Jäteveden koostumus

Jätevedet sisältävät malmille tyypillisiä komponentteja. Vesien koostumukseen vaikuttavat myös rikastusprosessissa käytetyt lisäaineet, käytössä oleva rikastustekniikka ja ympäristötekijät. Kaivoksen lähellä sijaitseva vanha jätekenttä likaa voimakkaasti pohjavesiä, jotka liikkuvat syvällä hitaasti Sysmäjärveä kohti. Kaivoksen varsinaiset jätevedet juoksevat nykyisin rikastamosta Jyrinlietukka-lammen kautta Ruutunjokeen ja sen alapuolisiin vesistöihin. Veden koostumus eri näytteenottopaikoissa ilmenee taulukosta 1. Taipaleenjoen näytteen (6) koostumukseen ei jätevedellä ole vaikutusta.

Taulukko 1. Jäteveden koostumus ja sen vaikutus pintaveden laatuun
Table 1. The composition of waste water and its effect on the quality of surface water

Paikka *Place*	pH	mg/l								
		SO_4	Ca	Mg	Fe	Mn	Zn	Ni	Co	Cu
1 (a)	4.9	1 800	590	80	80	3.4	2.8	0.35	0.17	0.08
2 (b)	2.9	1 900	640	55	50	5.3	4.0	0.60	0.44	0.35
3 (c)	4.3	1 600	430	170	26	2.6	4.0	0.60	0.15	0.10
4 (c)	4.4	420	120	34	1.2	1.3	2.0	0.20	0.10	0.06
5 (c)	6.7	60	22	6	0.4	0.2	0.05	0.01	0.002	0.01
6 (c)	7.6	16	8	4	0.3	<0.05	<0.05	0.004	<0.002	0.01

a 27. 11. 1964, 5. 3. 1965
b 27. 11. 1964
c 3.—4. 12. 1965

Taulukko 2. Hivenaineiden totaalimäärät maassa

Table 2. Total amounts of trace elements in soil

Näyte *Sample*	Maalaji*) *Soil type*	Tuhka % *Ash*	ppm								
			Co	Cr	Cu	Mn	Mo	Ni	Pb	V	Zn
G 21611	KHt	83.2	8	110	26	630	8	50	26	100	44
18	»	91.8	7	98	9	490	5	36	19	120	23
20	»	87.3	9	110	31	620	5	44	21	83	31
26	»	94.9	10	110	7	410	5	55	14	84	29
30	»	94.1	10	110	8	630	5	53	17	130	33
G 21617	HHt	79.7	26	80	29	1 400	11	48	12	130	150
50	»	87.2	13	140	16	690	5	60	18	120	31
53	»	79.4	15	210	28	790	5	77	11	150	37
G 21654	Hs	87.1	14	120	14	710	5	40	15	150	43
55	»	87.9	13	150	25	600	6	63	15	140	39
G 21601	Jm	45.8	7	43	90	850	6	37	8	71	23
36	»	46.8	19	65	200	760	11	120	11	100	60
48	Lj	45.8	8	18	34	390	3	47	3	24	23
G 21602	Mm	49.7	8	88	36	1 100	4	36	15	70	23
9	»	65.4	8	63	31	340	6	33	22	47	23
15	»	66.2	16	110	56	1 500	5	50	11	150	73
21	»	58.2	32	31	200	1 000	23	40	25	76	110
22	»	74.6	13	39	38	880	17	23	21	91	43
28	»	58.9	11	180	65	500	10	39	23	100	32
35	»	56.8	9	79	200	290	5	68	15	120	36
39	»	50.4	13	62	66	720	5	73	14	82	36
40	»	70.9	8	54	44	460	—	38	14	67	32
49	»	33.0	2	37	56	74	4	19	9	42	9
56	»	57.1	8	82	23	560	5	31	18	97	20
G 21610	LCt	43.0	17	44	130	1 300	5	35	36	71	74
12	»	24.9	5	66	17	470	4	39	8	50	17
13	»	21.3	4	40	17	180	2	12	6	130	33
24	»	21.3	6	18	110	1 200	34	13	25	76	48
27	»	7.5	2	25	49	67	4	9	8	25	12
29	»	46.3	7	150	95	530	5	26	35	160	28
85273	KHt	95.5	18	120	27	870	5	66	17	140	38
85274	HHk	96.3	8	42	10	240	5	22	14	58	25

*) KHt = *Coarser finesand*
HHt = *Finer finesand*
Hs = *Silt*
Jm = *Lake mud*
Lj = *Mud*
Mm = *Mould*
LCt = *Ligno Carex peat*

Pintavesien analyysit antavat selvän kuvan jäteveden tyypillisten komponenttien kulkeutumisesta alapuolisiin vesistöihin. Pelkkä laimenusefekti on vallitseva. Rauta on poikkeus. Kun vesi viipyy Sysmäjärvessä, sen Fe-pitoisuus alenee voimakkaasti saostumisen johdosta.

Viljavuustutkimus

Tutkitun alueen kivennäismaat ovat pääasiallisesti hietamoreenia ja sisältävät paikoitellen hiukan hiesua. Taulukoissa on käytetty yksinkertaisia merkintöjä KHt, HHt ja Hs. Eloperäi-

Taulukko 3. Hivenaineiden helppoliukoiset määrät maassa
Table 3. Easily soluble amounts of trace elements in soil

Näyte *Sample*	Maalaji *Soil type*)*	Tilav.p. g/ml *Vol. weight*	mg/l maata — *mg/l of soil*									
			Co	Fe	Cu	Mn	Mo	Ni	Pb	V	Zn	SO_4
G 21611	KHt	0.82	0.11	160	0.70	33	0.016	0.64	0.51	—	10.3	70
18	»	0.98	0.14	75	1.10	11	0.005	0.31	0.38	—	1.2	40
20	»	0.94	0.12	21	0.60	19	0.003	0.74	0.68	—	2.8	60
26	»	1.20	0.27	38	0.50	11	0.003	0.78	0.46	0.017	0.5	80
30	»	0.97	0.13	85	0.55	13	0.007	0.90	0.27	0.009	0.7	50
G 21617	HHt	0.88	0.31	140	0.47	24	0.014	0.90	0.24	—	4.2	110
50	»	0.72	0.18	120	0.60	23	0.009	1.20	0.27	0.024	1.4	190
53	»	0.56	0.25	220	0.28	27	0.017	1.30	0.20	0.032	1.2	—
G 21654	Hs	0.61	0.22	150	0.37	20	0.014	1.40	0.24	—	1.1	—
55	»	0.72	0.17	72	0.78	14	0.008	1.10	0.43	—	1.1	25
G 21601	Jm	0.41	0.13	150	0.39	42	0.018	0.62	0.47	0.056	1.3	60
36	»	0.39	0.73	250	0.67	53	0.035	3.60	0.36	0.100	6.4	250
48	Lj	0.66	0.18	150	0.55	27	0.017	1.40	0.46	0.052	1.0	—
G 21602	Mm	0.50	0.05	50	0.42	26	—	0.27	0.46	0.014	2.1	30
9	»	0.56	0.27	86	0.19	30	0.010	0.30	0.38	—	2.4	120
15	»	0.70	0.32	100	1.15	32	0.006	0.27	0.36	0.060	3.8	110
21	»	0.59	0.10	10	1.09	19	0.004	0.57	1.15	0.008	13.2	—
22	»	0.35	0.06	8	0.61	11	—	0.18	0.65	—	2.4	—
28	»	0.54	0.35	160	0.51	23	0.018	0.49	0.67	0.039	5.9	60
35	»	0.48	0.17	77	0.84	13	0.008	1.20	0.53	0.011	0.8	80
39	»	0.45	0.45	240	0.57	65	0.029	1.80	0.38	0.074	4.1	260
40	»	0.65	0.18	96	0.68	18	0.010	1.40	0.46	0.021	3.5	130
49	»	0.44	0.10	42	0.63	4	0.005	0.66	1.00	0.051	0.7	—
56	»	0.43	0.17	120	0.47	25	0.012	0.77	0.45	0.011	2.0	—
G 21610	LCt	0.44	0.07	48	0.42	18	0.004	0.31	0.46	—	7.9	—
12	»	0.37	0.11	140	0.15	36	0.014	0.49	0.36	0.028	0.6	180
13	»	0.25	0.20	150	0.28	17	0.013	0.38	0.45	0.160	3.3	60
24	»	0.35	0.07	80	0.28	35	0.037	0.21	0.52	0.210	4.4	200
27	»	0.26	0.07	38	0.19	7	0.004	0.14	0.37	0.036	0.7	60
29	»	0.39	0.10	160	0.53	19	0.014	0.22	0.85	0.058	3.3	60
85273	KHt	1.07	0.17	35	0.75	17	—	0.90	0.60	—	1.2	120
85274	KHk	1.10	0.06	5	0.43	13	—	0.30	0.61	0.009	7.2	—

*) *For soil type abbreviations see Table 2.*

siä maita edustavat Mm, LCt ja Jm. Alue on märkää, osittain veden vaivaamaa.

Viljavuusanalyysien (ei taulukoitu) mukaan ravinnepitoisuudet ovat harvoja poikkeuksia lukuun ottamatta niin alhaisia, että ne jäävät alle koko Suomen keskiarvojen (Kurki 1963). Kalin ja fosforin puute on aivan ilmeistä. Alueen alhaisimmat pH-arvot saatiin maista, joita ei ole kalkittu lainkaan tai on kalkittu vain vähän.

Hivenaineiden totaalimäärät maassa

Kallioperä, maaperän luonne ja maalaji kuvastuvat hivenaineiden totaalimäärissä. Pitoisuudet luonnehtivat lähinnä näiden aineiden reservejä, sillä vain murto-osa totaalimääristä on kasveille välittömästi käyttökelpoisessa muodossa. Tähän vaikuttavat ennen kaikkea mineraalinen koostumus ja orgaanisen aineksen määrä (Sillanpää 1962). Totaalimäärät 0—20 cm:n kerroksessa esitetään maalajeittain taulukossa 2. Kaksi viimeistä näytettä ovat vertailunäytteitä tutkitun alueen ulkopuolelta.

Verrattaessa tuloksia muualta Suomesta saatuihin (Vuorinen 1958) todetaan mm.: Karkeat kivennäismaat (KHt, HHt, Hs) edustavat niille tyypillisiä hivenainepitoisuuksia. Nikkelin taso (50—60 ppm) on keskimääräistä hiukan kor-

Taulukko 4. Hivenaineiden totaalimäärät maaprofiileissa
Table 4. Total amounts of trace elements in soil profiles

Näyte *Sample*	Maalaji *Soil type*)*	Tuhka % *Ash*	Syvyys cm *Depth*	ppm								
				Co	Cr	Cu	Mn	Mo	Ni	Pb	V	Zn
G 21610	LCt	43.0	0—20	17	44	130	1 300	5	35	36	71	74
	»	12.1	20—40	2	12	66	370	4	30	7	23	10
	»	13.8	40—60	2	14	100	240	4	25	5	44	11
G 21612	LCT	24.9	0—20	5	66	17	470	4	39	8	50	17
	»	5.6	20—40	1	6	7	190	1	11	2	13	17
	»	5.7	40—60	1	6	7	200	1	11	2	11	10
	»	5.5	60—80	1	7	8	310	1	11	2	12	9
G 21613	LCt	21.3	0—20	4	40	17	180	2	12	6	130	33
	»	8.5	20—40	2	30	17	130	2	9	9	100	69
	»	9.4	40—60	1	40	28	160	4	9	2	100	8
	»	11.8	60—80	3	50	34	190	6	17	2	100	16
G 21618	KHt	91.8	0—20	7	98	9	490	5	36	19	120	23
	HHt	93.8	20—40	15	95	10	1 600	<5	30	20	160	30
	»	96.1	40—60	17	110	21	900	<5	40	20	170	28
	»	97.5	60—80	13	150	25	940	8	51	24	180	29
G 21622	Mm	74.6	0—20	13	39	38	880	17	23	21	91	43
	LCt	10.0	20—40	1	10	17	50	31	5	3	47	7
	»	11.9	40—60	1	18	40	65	23	9	6	130	9
	KHt	98.9	70—80	6	59	3	570	—	15	20	130	22
G 21624	LCt	21.3	0—20	6	18	110	1 200	34	13	25	76	48
	»	24.6	20—40	2	16	64	170	41	17	6	190	47
	»	58.2	40—60	3	49	55	220	62	20	19	350	68
	KHt	99.2	70—80	—	31	6	420	<5	14	20	94	23

*) *For soil type abbreviations see table 2.*

keampi, mutta viljellylle kerrokselle täysin normaali (SWAINE 1955).

Suurin osa eloperäisten maiden (Lj, Jm, Mm, LCt) tuloksista edustaa suomalaisille viljelysmaille tyypillisiä hivenainepitoisuuksia. Joukossa on kuitenkin muutamia selvästi muita korkeampia pitoisuuksia, mikä kuvastaa orgaanisen aineksen kykyä sitoa ja pidättää hivenaineita, jotka ovat vapautuneet rapautuneesta mineraaliaineksesta tai ovat jäteveden tuomia. Lukuisissa maissa suoritettujen analyysien mukaan maan kuparipitoisuus vaihtelee välillä 2—100 ppm (SWAINE 1955). Suomalaisten maiden Cu-pitoisuus on tavallisesti 10—35 ppm maalajista riippuen. Outokummun alueella on maan kuparin määrä täten selvästi normaalia suurempi. Vielä suurempien Cu-pitoisuuksien esiintyminen paikoin on todennäköistä. Eräiden näytteiden Cu-määrä on puolestaan jopa keskimääräistä pienempi. Maan hivenaineiden totaalimäärille on tyypillistä pitoisuuksien suuri vaihtelu.

Eloperäisten maiden mangaanin, nikkelin ja sinkin pitoisuudet ovat muun Suomen tasoa lievästi korkeammat. Malmi sisältää myös näitä hivenaineita. Maaperän geologinen alkuperä saattaa vaikuttaa ratkaisevasti hivenainepitoisuuksiin (MITCHELL 1964). Näytteet G 21621—24 sisältävät normaalia enemmän molybdeenia, joka ei ole malmille tai jätevedelle tyypillinen komponentti. Näytteet ovat Partalanmäen läheisyydestä, minkä alueen kallioperän koostumus näkyy muissakin analyysituloksissa.

Hivenaineiden helppoliukoiset määrät maassa

Helppoliukoinen fraktio luonnehtii kasveille käyttökelpoisia hivenaineita paremmin kuin totaalimäärä. Pitoisuus kasvaa mm. totaalimäärän, orgaanisen aineksen ja kosteuden lisääntyessä. pH:n aleneminen lisää myös liukoisuutta

Taulukko 5. Hivenaineiden helppoliukoiset määrät maaprofiileissa

Table 5. Easily soluble amounts of trace elements in soil profiles

Näyte *Sample*	Maalaji *Soil type*)*	Tilav.p. g/ml *Vol. weight*	Syvyys cm *Depth*	pH	mg/l maata — *mg/l of soil*										
					SO_4	Ca	Fe	Mn	Zn	Ni	Pb	Cu	Co	V	Mo
G 21610	LCt	0.44	0—20	5.80	—	4 300	48	18	7.9	0.31	0.46	0.42	0.07	—	0.004
	»	0.24	20—40	5.80	60	2 727	16	9	0.5	0.20	0.16	0.23	0.02	—	0.004
	»	0.22	40—60	5.65	50	2 200	26	22	0.5	0.25	0.30	0.15	0.02	0.063	0.005
G 21612	LCt	0.37	0—20	5.00	180	1 825	140	36	0.6	0.49	0.36	0.15	0.11	0.028	0.014
	»	0.24	20—40	4.50	—	925	85	21	0.5	0.34	0.15	0.20	0.06	0.025	0.009
	»	0.23	40—60	4.75	30	925	85	35	0.5	0.26	0.17	0.14	0.05	0.023	0.010
	»	0.30	60—80	5.05	—	1 000	100	50	0.5	0.23	0.11	0.13	0.04	0.020	0.014
G 21613	LCt	0.25	0—20	4.55	60	1 000	150	17	3.3	0.38	0.45	0.28	0.20	0.160	0.013
	»	0.26	20—40	4.25	70	1 200	66	26	1.7	0.30	0.13	0.14	0.14	0.300	0.007
	»	0.29	40—60	4.55	270	1 850	35	41	0.5	0.14	0.10	0.10	0.05	0.880	0.001
	»	0.27	60—80	4.70	930	2 025	30	28	0.5	0.20	0.27	0.14	0.09	0.440	0.004
G 21618	KHt	0.98	0—20	5.35	40	475	75	11	1.2	0.31	0.38	1.10	0.14	—	0.005
	HHt	1.30	20—40	5.40	140	50	120	5	0.5	0.33	0.38	0.80	0.06	—	0.008
	»	1.21	40—60	5.50	—	65	120	5	0.5	0.30	0.42	0.80	0.08	—	0.010
	»	1.18	60—80	5.70	180	175	85	17	0.5	0.46	0.34	0.75	0.20	—	0.009
G 21622	Mm	0.35	0—20	6.70	—	9 600	8	11	2.4	0.18	0.65	0.61	0.06	—	<0.001
	LCt	0.23	20—40	4.75	180	2 325	51	4	0.5	0.08	0.33	0.29	0.14	0.028	0.013
	»	0.26	40—60	4.20	1 520	2 025	53	7	0.5	0.13	0.40	0.22	0.22	0.300	0.014
	KHt	1.58	70—80	4.25	690	350	160	1	0.5	0.20	0.29	0.28	0.27	0.210	0.019
G 21624	LCt	0.35	0—20	5.00	200	3 450	80	35	4.4	0.21	0.52	0.28	0.07	0.210	0.037
	»	0.29	20—40	4.80	230	1 675	50	11	2.9	0.23	0.30	0.18	0.07	0.240	0.018
	»	0.44	40—60	5.20	540	1 600	15	13	2.9	0.25	0.57	0.17	0.09	0.530	0.016
	KHt	1.18	70—80	4.25	1 270	300	130	3	<0.5	0.46	1.05	0.84	0.21	0.110	0.029

*) *For soil type abbreviations see Table 2.*

(poikkeuksena Mo) (Sillanpää 1962, Mitchell 1964). Tutkitun alueen normaalia korkeampi kosteus yhdessä alhaisen pH:n ja korkean humuspitoisuuden kanssa lisäävät maassa olevien hivenaineiden kasveille käyttökelpoisia määriä. Taulukossa 3 esitetään hivenaineiden helppoliukoisten määrien ohella samalla uuttomenetelmällä saadut SO_4 -pitoisuudet.

Keskimääräiset pitoisuudet noudattavat samaa suuntaa kuin totaalimäärät. Verrattaessa tuloksia muualta Suomesta saatuihin (Sillanpää ja Lakanen 1966) todetaan helppoliukoista kuparia olevan normaalia enemmän. Myös nikkeli ja rauta edustavat keskiarvoja korkeampaa tasoa. Yksittäisissä tapauksissa eri hivenaineiden pitoisuudet vaihtelevat melkoisesti. Kohonneet määrät ovat eräissä tapauksissa jäteveden aiheuttamia. Pintamaiden sulfaattipitoisuudet ovat alhaisia ja vähäisiä rannikkoseudun rikkipitoisiin maihin verrattuina (Purokoski 1959).

Maaprofiilien analyysit

Profiilitutkimuksella seurataan tavallisesti eri aineiden huuhtoutumista pintakerroksista alaspäin. Tutkimus selventää vastaavasti eri komponenttien kulkeutumista alhaalta ylöspäin ja kuvastaa tällöin myös likaantuneiden pohjavesien tunkeutumista ylempiin maakerroksiin. Kaivoksen vanhan jätekentän likaamaa pohjavettä tihkuu paikoitellen aina viljeltyyn kerrokseen saakka. Mukana kulkeutuu myös jätevedelle tyypillisiä komponentteja, mihin vaikuttavat näiden aineiden konsentraatio, kemiallinen luonne ja maalajin taipumus sitoa ja pidättää näitä aineita.

Profiilitutkimus suoritettiin vain muutamista näytteenottokohdista. Hivenaineiden totaalimäärät esitetään taulukossa 4 ja helppoliukoiset määrät (muilla määrityksillä täydennettyinä) taulukossa 5.

Taulukko 6. Eri aineiden pitoisuuksia nurmiheinäin kuiva-aineessa

Table 6. The contents of some constituents in the dry matter of mixed herbage plants)*

	%			ppm	
	Vaihtelu *Variation*	K.a. *Mean*		Vaihtelu *Variation*	K.a *Mean*
K	0.84—3.03	1.78	Mn	33—538	112
Ca	0.27—1.30	0.62	Fe	41—230	64
P	0.10—0.30	0.23	Zn	21—109	39
Mg	0.14—0.45	0.25	Cu	6.1—13.5	8.8
S	0.16—0.29	0.20	Mo	0.2—5.3	1.3
			Co	0.04—1.20	0.17

*) *The determinations are made by State Laboratory of Agricultural Chemistry, Helsinki.*

Tuloksista nähdään mm. että G 21610 ja —12 ovat turveprofiileja, joissa kivennäisaineksen pitoisuus kasvaa pintaa kohden. Pintakerroksen hivenainepitoisuudet ovat tällöin korkeimmat. G 21613:n liukoisessa fraktiossa SO_4 ja Ca lisääntyvät alaspäin mentäessä, samoin vanadiini, jonka pitoisuudet ovat normaalia korkeammat. Muiden hivenaineiden pitoisuudet alenevat syvyyden kasvaessa. G 21618:ssa kasvavat useimpien hivenaineiden totaalimäärät alaspäin mentäessä. Tämä kuvastaa mineraaliaineksien muuttumista. G 21622 ja —24 ovat mielenkiintoisia profiileja, joissa on sekä jäteveden että lähiympäristön kallioperän vaikutusta. Jäteaineiden likaamaa pohjavettä on noussut pintaan päin, mikä näkyy kasvavista SO_4- ja Fe-pitoisuuksista alaspäin mentäessä. Liukoisen raudan määrää lisää tosin aleneva pH. Näytteiden vanadiini- ja erityisesti molybdeenipitoisuus ovat sangen korkeita. Tämä johtuu ilmeisesti läheisen Partalanmäen kallioperän koostumuksesta.

Useammat ja syvemmälle ulottuvat profiilitutkimukset antaisivat kuvan siitä, missä kohdin tuntuu likaantuneen pohjaveden vaikutus ja kuinka lähelle pintaa vaikutus ylettyy.

Muita analyyseja

Tutkitulla alueella on vuosien kuluessa suoritettu runsaasti pohjavesien analyyseja sekä peruskallioon tai pohjamoreeniin ulottuvista pohjavesiputkista saaduista näytteistä että kaivovesistä. Heinä—syyskuussa 1964 otettiin myös maanäytteitä vastaavat pohjavesinäytteet n. 0.7—3 metristä, keskimäärin 1.5 metristä. Hivenainemääritykset suoritettiin Maantutkimuslaitoksella helmikuussa 1965. Tuloksista mainittakoon: Fe < 0.1—17 mg/l, k.a. 3 mg/l. Mn < 0.02—2 mg/l, k.a. 0.3 mg/l. Zn < 0.05—0.30 mg/l, k.a. 0.1 mg/l. Cu < 0.01—0.15 mg/l, k.a. 0.03 mg/l. Ni < 0.002—0.130 mg/l, k.a. 0.01. Co < 0.001 —0.024 mg/l, keskimäärin n. 0.001 mg/l. Pb ja V keskimäärin <0.01 mg/l ja Mo < 0.005 mg/l.

Myös eräiden kaivovesien hivenainepitoisuudet määritettiin. Taipaleenjoen pohjoisrannan kaivovedet sisälsivät poikkeuksellisen runsaasti maaperästä liuenneita aineita. Oloissamme ainutlaatuisia lienevät erään kaivon hivenainepitoisuudet: Fe 70—80, Mn, Zn, Ni 2—5, Co 0.2—0.5 ja Cu 0.1—0.2 mg/l. Pohjavesien laatu huononee (kovuus, Fe-pitoisuus jne.) Sysmäjärven alueelta Taipaleenjoelle mentäessä. Vastaavasti Ca/Mg-suhde laskee keskimäärin 2.4:stä 1.4:ään, mikä selittynee maaperän luonteen muuttumisesta.

Kasvimateriaalin hivenainepitoisuudet täydentävät maasta suoritettujen hivenainemääritysten antamaa kuvaa ja ovat yksi kriteerio nautintakelpoisuutta arvioitaessa. Valtion maatalouskemiallinen laboratorio on määrittänyt pää- ja hivenravinnepitoisuudet nurmiheinästä samoilta paikoilta, mistä maanäytteet ovat peräisin. Asianomaisella luvalla esitetään analyysitulosten keskiarvot ja vaihtelurajat oheisessa taulukossa 6.

Botaaninen koostumus on kirjava (apila, timotei, lauha, sara, nata, leinikki, voikukka jne.), mikä osaltaan lisää analyysitulosten vaihtelua ja vaikeuttaa tason arviointia. Vertailu puhtaan suomalaisen timotein hivenainepitoisuuksiin (LAKANEN, julkaisemattomia tuloksia) osoittaa mm., että mangaanin pitoisuus on lievästi korkeampi. Yksi näyte (538 ppm) edustaa normaalia korkeampaa Mn-pitoisuutta. Raudan keskiarvo on alhaisempi. Alueen maaperätekijät (kosteus, orgaaninen aines, alhainen pH ja redokspotentiaali) suosivat mangaanin ottoa, joka saattaa alentaa Fe-pitoisuutta. Sinkin keskiarvo on normaali. Yksi näyte edustaa korkeampaa pitoisuutta. Kuparin pitoisuus on keskimääräistä korkeampi, mikä on täysin luonnollista. Mo-pitoisuudet ovat muuten normaaleja, paitsi Partalanmäen tienoon 5 ppm-taso, joka on poikkeuksellisen korkea ja nostaa keskiarvoakin. Koboltin taso on korkeampi kuin timoteilla.

Verrattaessa tuloksia esim. skotlantilaisen laidunruohon hivenainepitoisuuksiin (MITCHELL 1963) todetaan, että vain kuparin ja molybdeenin pitoisuudet ovat selvästi korkeampia kuin Skotlannissa, missä tyypillisiä pitoisuuksia ovat Cu 4.5 ja Mo 0.43 ppm.

Tiivistelmä

Tutkimuksessa on tarkasteltu Outokummun kaivoksen lähiympäristöstä kaakkoon suuntautuvan alueen hivenainepitoisuuksia maassa, kasveissa ja vesissä. Malmi on lisännyt ympäristön hivenainepitoisuuksia. Selvimmin se näkyy maaperän ja kasvimateriaalin muun Suomen tasoa korkeampina Cu-pitoisuuksina. Suuret paikalliset vaihtelut ovat tyypillisiä erityisesti maassa olevan kuparin totaalimäärille.

Muutamien muidenkin hivenaineiden (Co, Mn, Mo, Ni, V, Zn) pitoisuudet maassa, kasveissa tai vesissä ovat paikoin muun Suomen tasoa korkeammat, mihin maa- ja kallioperän mineraalikoostumuksen lisäksi vaikuttavat eräissä tapauksissa kaivoksen jätevedet. Tyypillisiä kallio- ja maaperästä aiheutuvia poikkeuksellisia hivenainepitoisuuksia ovat mm. Partalanmäen tienoon korkeat Mo- ja V-pitoisuudet sekä Taipaleenjoen pohjoispuolelta todetut korkeat Ni- ym. pitoisuudet.

Jäteveden vaikutus nähdään selvästi kaivosalueen lähiympäristön pinta- ja pohjavesien analyysituloksista. Paikoin se ilmenee myös maan helppoliukoisten ja kasvien hivenaineiden pitoisuuksien kohoamisena. Suoritettua laajempi profiilitutkimus antaisi selvän kuvan siitä, missä kohdin tuntuu likaantuneen pohjaveden vaikutus ja kuinka lähelle pintaa vaikutus ylettyy.

Maan hivenaineanalyysien perusteella ei vielä nykyään kyetä määrittämään riittävän tarkasti kaikkien kasveille käyttökelpoisten hivenaineiden ali- tai ylimääriä. Kasvimateriaalin analysointi antaa tästä kuvan, varsinkin rehun käyttökelpoisuutta arvioitaessa. Tutkitun alueen kasvimateriaalin hivenainepitoisuuksien keskiarvoja voidaan pitää normaaleina. Eräät yksittäiset analyysitulokset edustavat normaalia korkeampia pitoisuuksia. Myrkyllisen korkeita pitoisuuksia ei todettu.

Tutkimukseen liittyvät analyysityöt Maantutkimuslaitos on suorittanut O u t o k u m p u Oy:n tähän tarkoitukseen lahjoittamin määrärahoin.

KIRJALLISUUTTA

KURKI, M. 1963. Suomen peltojen viljavuudesta vuosina 1955—1960 Viljavuuspalvelu Oy:ssä tehtyjen tutkimusten perusteella. Referat: Über die Fruchtbarkeit des finnischen Ackerbodens auf Grund in den Jahren 1955—1960 durchgeführten Bodenfruchtbarkeitsuntersuchungen. Viljavuuspalvelu Oy. 107 s. Helsinki.

LAKANEN, E. 1962. On the analysis of soluble trace elements. Ann. Agric. Fenn. 1: 109—117.

LAPPI, L. & MÄKITIE, O. 1954. Quantitative spectrographic determination of minor elements in soil samples. Acta Agric. Scand. 5: 69—75.

MITCHELL, R. L. 1963. Soil aspects of trace element problems in plants and animals. J. Roy. Agric. Soc. 124: 75—86.

Mitchell, R. L. 1964. Trace elements in soils (Ed. Bear: Chemistry of the soil). p. 320—368, New York.

Purokoski, P. 1959. Rannikkoseudun rikkipitoisista maista. Referat: Über die Schwefelhaltigen Böden an der Küste Finnlands. Agrogeol. julk. 74: 1—27.

Sillanpää, M. 1962a. Trace elements in Finnish soils as related to soil texture and organic matter content. J. Sci. Agric. Soc. Finl. 34: 34—40.

—»— 1962b. On the effect of some soil factors on the solubility of trace elements. Selostus: Eräiden maaperätekijöiden vaikutuksesta hivenaineiden liukoisuuteen. Agrogeol. julk. 81: 1—24.

Sillanpää, M. & Lakanen, E. 1966. Readily soluble trace elements in Finnish soils. Ann. Agric. Fenn. 5 (painossa).

Swaine, D. J. 1955. The trace-element content of soils. Commonw. Bur. Soil Sci. Techn. Comm. 48. 157 p.

Vuorinen, J. 1958. On the amounts of minor elements in Finnish soils. J. Sci. Agric. Soc. Finl. 30: 30—35.

—»— & Mäkitie, O. 1955. The method of soil testing in use in Finland (Selostus: Viljavuustutkimuksen analyysimenetelmästä). Agrogeol. julk. 63: 1—44.

SUMMARY

Trace element levels in the vicinity of Outokumpu copper mine

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In this paper the amounts of trace elements in the soil, water and vegetation in the vicinity of the copper mine at Outokumpu, Finland, are reported. Data of some other determinations are also presented. The area under investigation is shown in Fig. 1.

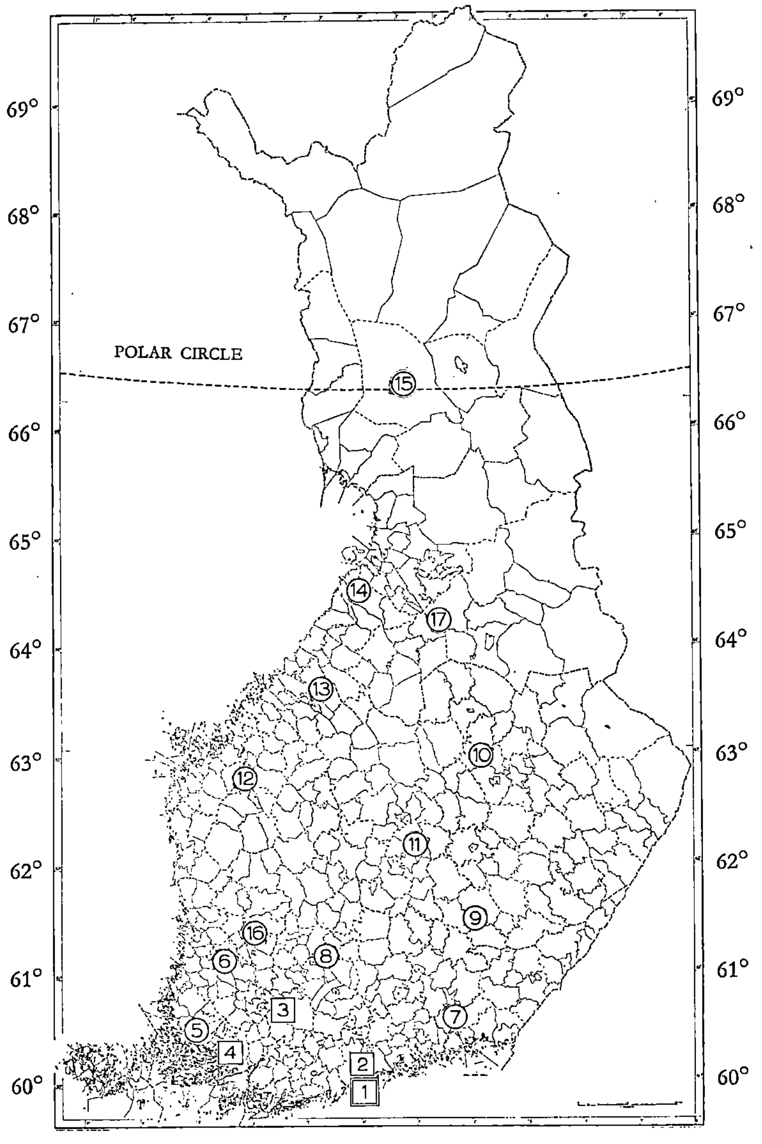
Outokumpu is one of the biggest copper mines in Europe. The ore also contains some other heavy metals (Fe, Mn, Ni, Co, Zn). Numerous pieces of the ore were scattered during the glacial period in the direction northwest—southeast. The waste waters from the ore concentration plant are relatively rich in trace elements (Table 1). These waters mix with the surface waters flowing to the southeast.

The total amounts of trace elements in the surface soils (0—20 cm) are presented in Table 2. Coarser finesand, finer finesand and silt exhibit the average trace element level of these soil types elsewhere in Finland. The amounts of nickel are slightly higher, however. The soil organic matter has a great ability to fix trace elements liberated by the weathering of the minerals or brought by the waste waters. This is seen from the results, there being a high trace element content in some samples. The level of copper is clearly higher than normal. The other trace element values differ only slightly from the amounts found elsewhere in Finland. There are three samples from a restricted area, however, that have unusually high Mo contents.

The readily soluble amounts of trace elements in the soil were extracted with acid ammonium acetate (0.5N CH_3COOH, 0.5N CH_3COONH_4, pH 4.65). The results (Table 3) show the same general tendency as the total amounts. The amounts of readily soluble sulphates remain very low.

Analytical data of a few soil profiles (Tables 4 and 5) provide information about the formation and development of the soil. The influence of the contaminated ground waters on the readily soluble fraction of the soil constituents is distinct in some profiles.

The amounts of trace elements in the mixed herbage plants vary considerably (Table 6). Some samples have a higher trace element content than normal.



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Helsinki 1966. Valtioneuvoston kirjapaino