

# PHOSPHORUS CONDITIONS AT VARIOUS DEPTHS IN SOME MINERAL SOILS

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Received May 5, 1963

The amounts and forms of the plant nutrients present in various layers of soils may vary considerably. This is particularly true with respect to those nutrients which, as nitrogen, sulphur and phosphorus, largely occur in the surface layers in organic forms. The texture and, especially, the structure of the soil may be different at the different depths, and the activity of microorganisms and plant roots also markedly affects the soil conditions in the layers where they are present. The acidity of the soil is one of the properties which often changes with the depth, and corresponding changes are likely to be found in the forms of the nutrients.

Relatively few data have been published concerning the phosphorus conditions at various depths in our soils. The total content of phosphorus does not show any distinct tendency in its variation with the depth, but the part of it which will occur in organic forms is in the mineral soils largest in the surface layer, while it in the peat soils, usually, increases with the depth (5, 7, 9). With the exception of some test values, the information of the forms of inorganic phosphorus in our soils seems to be almost completely confined to the topsoil.

In the present paper attention is paid to the forms of inorganic phosphorus at various depths of the mineral soils studied. The phosphorus conditions are also characterized by some test values.

## *Material and methods*

The soil samples studied in the present work were collected from various parts of the country. There are twelve pairs of samples representing the plough layer and the subsoil of cultivated mineral soils, and twelve pairs of samples from the corresponding layers in virgin mineral soils, it is from the depths of 0 to 20 cm and of 20 to 40 cm. Twenty cultivated soils were sampled deeper, or down to the depth of 60 cm or 70 cm, one even to 2 m.

The soil pH was measured in a 1 : 2.5 suspension in 0.02 N CaCl<sub>2</sub> by the glass electrode. Aluminium and iron were extracted by Tamm's acid ammonium oxalate solution, aluminium was determined by the Aluminon method and iron by the sulfosalicylic acid procedure after the destruction of the organic matter by ignition.

The fractions of inorganic phosphorus were determined by the method of CHANG and JACKSON (2), instead of neutral NH<sub>4</sub>F-solution a slightly alkaline extractant was used.

The number 1 test by BRAY and KURTZ (1) was modified by changing the ratio of extraction to 1 to 10. The acetic acid soluble phosphorus was determined by extracting the samples for half an hour in the ratio of 1 to 10 with 0.5 N acid.

The «exchangeable phosphorus», the corresponding phosphorus concentration in the solution, and the indicator of the phosphate retention capacity of the soil were determined according to the somewhat modified method proposed by TERÄSVUORI (12).

### Results

The distribution of inorganic phosphorus into the different fractions at various depths of two virgin soils from Tohmajärvi is shown by the data recorded in Table 1. The sandy till soil represents a strongly podsolized forest soil, in which the layer from 10 to 18 cm is the bleached A<sub>2</sub>-horizon, and the layer from 20 to 30 cm is the enriched B-horizon. This is distinctly revealed by the contents of ammonium oxalate soluble aluminium and iron in these layers as compared with those in the other layers. The content of extractable inorganic phosphorus is not high in the surface layer, yet markedly higher than in the impoverished second layer. Also in respect to inorganic phosphorus, the enrichment of the B-horizon (from 20 to 30 cm) is obvious. In the three layers down to 30 cm, the largest part of the extracted inorganic phosphorus is bound to iron, either as the alkali-soluble form or in the reductant soluble fraction. The ammonium fluoride soluble fraction which is supposed to represent aluminium bound phosphorus is far lower. Downwards from the enrichment layer there is an increase with the depth in the content of acid-soluble phosphorus or Ca-P. With this increase a decrease in the phosphorus bound by the sesquioxides is connected. The amount of the occluded sesquioxide-phosphorus is low in all the layers studied.

The procedure of TERÄSVUORI (12) gave the following phosphorus test values for this podsol profile:

Horizon	Depth cm	x <sub>0</sub> mg/kg	y <sub>0</sub> mg/kg	a
A <sub>1</sub>	0 — 10	35	0.10	103
A <sub>2</sub>	10 — 18	11	0.0007	131
B	20 — 30	96	0.001	642
C	40 — 50	81	0.005	299
C	60 — 70	58	0.02	163

Table 1. Inorganic phosphorus at various depths in two virgin mineral soils

Depth cm	pH	Al mmol/kg	Fe mmol/kg	Inorganic P ppm				
				Al-P	Fe-P	Ca-P	Reduct. soluble	Occluded
<i>Sandy till</i>								
0-10	3.8	89	51	15	23	3	7	1
10-18	4.4	80	36	1	7	1	11	1
20-30	5.3	480	133	34	79	24	48	1
40-50	5.0	170	45	31	49	73	34	1
60-70	4.9	88	21	23	37	140	25	1
<i>Silt- silty clay</i>								
0-15	4.8	81	73	2	38	216	21	3
20-30	6.2	37	27	8	32	517	6	4
40-50	6.4	23	22	0	7	459	18	3
60-70	6.5	29	26	0	7	485	4	1
200-210	6.7	23	15	0	7	560	26	4

$x_0$  means the «exchangeable phosphorus», or phosphorus extracted by alkali.  $y_0$  is the quantity calculated to represent the phosphorus concentration in the solution in equilibrium with  $x_0$ , and Teräsvuori supposes that it in acid soils will approximate to the phosphorus concentration in the soil solution. In the bleached  $A_2$ -horizon,  $x_0$  or the «capacity factor», and  $y_0$  or the «intensity factor» are both very low. In the enrichment layer, B,  $x_0$  is much higher, but owing to the very high value of  $\alpha$ , or the indicator of the capacity of the soil to sorb phosphorus, the corresponding phosphorus concentration in the solution is almost as low as that in the impoverished  $A_2$ -horizon. In this acid soil the phosphorus retention is likely to depend mainly on the contents of active aluminium and iron. The aluminium and iron soluble in acid ammonium oxalate are low in the  $A_2$ -horizon and fairly high the B-horizon. In the layer from 40 to 50 cm the phosphorus conditions are poor, yet somewhat better than in the layers  $A_2$  and B. Some improvement with the depth may be found also according to the amounts of acid ammonium fluoride soluble phosphorus in the BRAY P 1 test: from the minimum of 2 ppm in the B-horizon it increases to 15 ppm in the layer from 40 to 50 cm, and to 26 ppm in the deepest layer sampled. In the  $A_1$  and  $A_2$  horizons this test value is 8 ppm and 3 ppm, respectively. The acetic acid soluble phosphorus is low in all the layers, only from 1 to 4 ppm.

In this podsol profile the distribution of the inorganic phosphorus between the fractions bound by calcium or by the sesquioxides does not seem to be closely connected with the soil acidity. In the second soil, this inconsistency is less distinct: it is true that in the rather acid surface layer the content of the calcium bound phosphorus is fairly high, but it is still far lower than in the only slightly acid or almost neutral deeper layers. It may be mentioned that the pH values in these

layers measured in a water suspension in the ratio of 1 to 2.5 vary from pH 7.1 to pH 7.5. The Al-P fraction is low or negligible in all the layers, and also the fractions connected to iron are small as compared with the Ca-P fraction. At the depth of 2 m the pattern is almost equal to that in the layers from 40 to 70 cm.

TERÄSVUORI's test is not suitable for the non-acid layers of this profile, since it is based on the supposition that the alkali-soluble phosphorus will represent the forms with which the phosphorus in the soil solution will be in equilibrium. Only in the surface layers the results obtained by it may be reliable. These data are the following

Depth	$x_0$ mg/kg	$y_0$ mg/l	$a$
0 — 15 cm	48	0.07	136
20 — 30 »	27	0.20	55

The results of BRAY's test are low in all the layers, from 2 to 4 ppm, but the acetic acid soluble phosphorus increases from 4 ppm in the surface layer to 99 ppm in the layer from 20 to 30 cm, and it is about 140 ppm in all the deeper layers sampled. Thus also the test values indicate a significant difference in the phosphorus conditions of these two soils.

In Table 2 are recorded the results obtained for the twelve pairs of virgin soils, most of them forest soils. Since the sampling depths were the same as those for the twelve pairs of cultivated soils, the »topsoil» from 0 to 20 cm is likely to contain both the  $A_1$ - and  $A_2$ -horizons of the podsol soils while the »subsoil» from 20 to 40 cm may in addition to the B-horizon contain some parts of the A- or C-horizons. In all these soils, with the exception of a typical Litorina soil, Vi 6, the topsoil is more acid than the subsoil. In the till, sand, and fine sand soils all the fractions of inorganic phosphorus are lower in the topsoil than in the subsoil. In the soils of a finer texture, apparently the leaching has been less intensive, and the topsoil may even contain somewhat more Al-P, Fe-P, or Ca-P than does the corresponding subsoil. In most of the samples the part of inorganic phosphorus bound by aluminium is lower than the fractions connected with iron or calcium. The relatively high content of Al-P in the samples Mi 3 b, Mi 1 b, Mi 5 b, and LL 3 b may be accounted to the large amount of ammonium oxalate soluble aluminium in these samples: from 240 to 380 mmol/kg. In spite of the fact that all these soils are distinctly acid, the calcium-bound phosphorus is in one half of the samples equal to or higher than the alkali-soluble phosphorus. In the other half of the samples, the iron bound phosphorus is the most dominant form. In several of the samples the content of the reductant soluble phosphorus is fairly high, but it is of interest to notice that this is not the case in the Litorina soil Vi 6. The occluded phosphorus is usually low.

The three test values of Teräsvuori give some more information of the phosphorus conditions of these soils. The »exchangeable» phosphorus,  $x_0$ , is almost equal to the sum of the Al-P and Fe-P fractions. In all the soils of the coarser texture  $x_0$  is lower in the topsoil than in the corresponding subsoil. The opposite is true with the three samples finer than loam. In most of the samples the corresponding phosphorus concentration in the solution,  $y_0$ , is rather low. Since  $y_0$  does not only

Table 2. Phosphorus conditions in the topsoil (a) and subsoil (b) of some virgin soils.

Kind of soil	Inorganic P ppm						Test values		
	pH	Al-P	Fe-P	Ca-P	Reduct. soluble	Occl.	Teräsvuori		
							$x_0$	$y_0$	$\alpha$
Mi 3 a Till	4.0	12	42	27	80	3	44	0.006	265
b »	5.0	95	137	106	90	6	214	0	972
O 3 a Sand	4.6	21	55	85	8	3	80	0.04	221
b »	5.0	109	173	174	34	3	255	0.24	365
O 5 a »	4.2	19	124	67	16	4	106	0.24	194
b »	4.8	70	145	276	91	4	212	0.12	357
Mi 1 a Fine sand	4.3	17	49	27	46	4	60	0.06	188
b »	5.6	93	92	58	48	4	196	0.004	629
Mi 5 a »	3.9	11	33	4	15	3	51	0.27	106
b »	5.4	95	83	31	31	3	174	0.03	430
O 1 a »	4.0	9	46	41	16	4	55	0.11	174
b Silt	4.8	9	69	299	58	5	64	0.10	138
LL 3 a Loam	4.7	25	85	24	103	11	85	0.12	226
b »	5.1	57	64	40	70	7	123	0.05	138
Ra 5 a Silt	4.5	11	95	278	69	7	111	0.20	221
b »	5.1	10	115	423	85	9	111	0.64	133
Vi 6 a Loam	4.2	66	386	138	14	5	535	0.18	765
b »	3.8	30	557	117	9	13	580	0.10	956
Kö 8 a Loam	4.5	28	113	285	49	6	147	0.28	239
b Clay loam	5.5	12	115	271	92	10	107	0.18	183
LL 9 a Silty clay	4.9	20	45	35	89	11	68	0.74	193
b »	5.3	12	40	50	95	15	43	0.07	136
Vi 2 a Sandy clay	4.8	6	113	209	48	16	112	0.08	252
b Heavy clay	5.2	2	85	189	61	23	67	0.07	190

depend on the value of  $x_0$ , but to a high degree also on the capability of the soil to sorb phosphorus,  $y_0$  may be fairly high in a soil with a low store of exchangeable phosphorus,  $x_0$ , and a low capacity to retain phosphorus,  $\alpha$ , as is the case in the samples Ra 5 b and LL 9 a. The contrary holds true e.g. with the samples Mi 3 b, Mi 1 b, and Vi 6 b. In the Litorina soil Vi 6, and in the soils of a coarser texture the indicator of the phosphate retention capacity,  $\alpha$ , is higher in the subsoil than in the topsoil. This appears to be connected with the higher content of active aluminium and iron in the «subsoil» of the more podsolized soils.

In the twelve pairs of cultivated soils (Table 3) the acidity of the plough layer is, usually, somewhat less than or at least equal to that in the subsoil. An other, even more marked difference between the virgin and cultivated soils is found in the content of aluminium bound phosphorus which in the latter soils in all cases is higher in the plough layer than in the subsoil. In most of the cultivated soils also

Table 3. Phosphorus conditions in the plough layer (a) and subsoil (b) of some cultivated mineral soils

Kind of soil	Inorganic P ppm				Test values <sup>a</sup>					
	pH	Al-P	Fe-P	Ca-P	Bray P I	Acetic acid-P	$x_0$	$y_0$	$\alpha$	
To 7 a	Fine sand till	5.8	492	304	97	220	40	610	0.46	722
b	»	5.2	37	45	62	17	2	104	0.001	480
LL 1 a	Fine sand	5.0	47	85	49	31	3	121	0.29	187
b	»	5.0	17	40	19	11	1	62	0.07	161
Mi 4 a	»	5.6	133	111	189	52	24	207	0.11	380
b	»	5.6	104	101	40	9	1	184	0.01	756
O 4 a	»	5.4	106	208	178	78	6	274	0.98	276
b	Silty clay	4.8	22	114	108	16	1	123	0.22	208
LL 5 a	Loam	4.9	22	100	117	16	2	112	0.32	173
b	»	5.1	13	114	60	7	1	124	0.34	182
LL 11 a	»	4.9	80	177	141	56	4	260	0.42	347
b	»	5.1	39	158	154	22	3	204	0.27	304
Ra 1 a	Silt	5.3	285	316	229	175	25	568	0.96	574
b	»	4.8	37	291	449	20	3	306	0.19	436
Ra 3 a	»	5.3	30	172	262	15	5	188	0.69	216
b	»	5.4	12	167	326	8	11	154	0.39	213
Kä 1 a	Clay loam	5.0	40	100	130	24	4	106	0.39	155
b	Silt	5.1	4	32	195	3	22	23	0.08	74
Aa 1 a	Clay loam	5.5	40	180	140	21	2	182	0.57	221
b	Silty clay	5.0	3	64	35	2	1	51	0.06	169
O 2 a	»	5.1	111	285	168	54	4	396	0.41	504
b	»	4.8	10	116	145	7	1	101	0.10	220
LL 7 a	»	5.2	27	99	162	15	9	121	0.39	179
b	»	5.5	8	56	131	2	9	53	0.08	150

the Fe-P fraction is in the plough layer higher than in the subsoil. With some exceptions this holds true even with the calcium-bound phosphorus. The contents of the reductant soluble phosphorus and the occluded phosphorus in these soils were of the same order as in the virgin samples.

All the test values, except the acetic acid soluble phosphorus in the soils Ra 3, Kä 1, and LL 7, prove that the phosphorus conditions in the plough layer are superior to those in the subsoil. Even when the phosphorus sorption capacity in the plough layer is high, there seems to be a fairly high content of exchangeable phosphorus which is able to maintain a relatively high phosphorus concentration in the solution. In the subsoil, both  $x_0$  and  $y_0$  may be rather low, or of the same order as in the virgin samples.

Some more information may be given by the results obtained for the 20 cultivated soils sampled down to the depth of 60 cm or 70 cm. In Table 4 these

Table 4. Phosphorus conditions at various depths in cultivated mineral soils  
(Average data for groups of five soils).

Depth dm	Inorganic P ppm						Test values (Teräsivuori)		
	pH	Al-P	Fe-P	Ca-P	Reduct. soluble	Oc- cluded	$x_0$	$y_0$	$a$
<i>5 sand and fine sand soils</i>									
0 - 1	5.4	170	160	115	50	5	280	0.18	447
2 - 3	5.0	40	85	90	40	5	110	0.20	445
4 - 5	5.1	35	90	120	45	5	120	0.002	426
6 - 7	5.2	25	50	175	30	0	70	0.02	264
<i>5 loam and silt soils</i>									
0 - 2	5.6	65	140	220	45	10	163	1.09	186
2 - 4	5.5	10	60	245	50	15	55	0.42	137
4 - 6	5.8	0	45	455	70	15	35	0.24	78
<i>5 Glacial clay soils</i>									
0 - 1	5.7	90	320	195	180	60	320	0.95	322
2 - 3	5.7	20	125	145	130	65	110	0.07	261
4 - 5	6.1	15	75	270	135	65	65	0.03	229
6 - 7	6.5	15	70	345	145	65	60	0.02	251
<i>5 Litorina clay soils</i>									
0 - 2	4.6	65	365	185	40	15	385	0.25	687
2 - 4	4.0	30	320	155	20	10	258	0.17	562
4 - 6	4.0	10	330	140	30	20	275	0.06	773

data are reported as the average values of each group of five soils of the same kind. There are, of course, differences between the absolute values in the different soils of the same group, but the corresponding changes with the depth are parallel. The sand and fine sand soils were from Tohmajärvi, Eastern Finland, the loam and silt soils from Central Finland, the Glacial clay soils from Jokioinen, South Finland, and the Litorina soils from the southern coast.

The changes in the acidity with the depth are typical in the two groups of clay soils, in the other groups the pH tends to be lowest in the layer below the topsoil, but the differences are not marked. In all the groups the Al-P fraction is by far the highest in the toplayer, and it decreases with the depth being very low in the deepest layers sampled. The same pattern may be found in the distribution of Fe-P at the various depths, except in the Litorina clays in which the alkali-soluble phosphorus remains high in all the layers. Only in the plough layer of the sand and fine sand soils the content of aluminium bound phosphorus is equal to that of the alkali-soluble form. The latter fraction is dominant in the Litorina soils and in the plough layer of the Glacial clay soils. In all the other cases the largest part of the extracted inorganic phosphorus is found in the fraction of Ca-P. In

the Litorina clays a slight decrease with the depth may be seen in the content of calcium bound phosphorus, in all the other groups the maximum content of Ca-P is in the deepest layer sampled. There seems to be a minimum of Ca-P in the layer from 2 to 3 dm in the sand and fine sand soils and in the Glacial clay soils. Because of the different sampling depths, the possible existence of this minimum in the loam and silt soils cannot be proved. The reductant soluble and occluded phosphorus are low in all the other groups except in the Glacial clays. No tendency in the variation of these fractions with the depth may be found.

According to the test values, the phosphorus conditions are most satisfactory in the top layer of all the groups. Only the acetic acid soluble phosphorus is highest in the deepest layers of the loam and silt soils and the Glacial clay soils, as may be expected on the basis of their high content of calcium bound phosphorus. Because of the rather low values of  $\alpha$  in the loam and silt soils studied, the values of  $y_0$  in the deeper layers is higher than in the corresponding layers of the other groups. In the Litorina clays the large amount of exchangeable phosphorus even in the deeper layers allows, in spite of the very high phosphorus sorption capacity, somewhat higher phosphorus concentrations in the solution than is the case in the deeper layers, of the Glacial clay soils.

### *Discussion*

The similar trends found in the soils studied in the distribution of inorganic phosphorus into various fractions at various depths allow the drawing of certain conclusions even on the basis of the present rather small material. Only the Litorina soils seem to have their own pattern, with the alkali-soluble iron-bound phosphorus dominating down to the deepest layer sampled. In all the other soils the largest part of the extracted inorganic phosphorus in the layers below the depth of 30 cm or 40 cm is bounded to calcium, and usually, there is an increase with depth in this fraction.

According to CHANG and JACKSON (2) the distribution of the inorganic phosphorus is related to the degree of soil chemical weathering during soil development in the sequence: calcium bound phosphorus, aluminium bound phosphorus, iron bound phosphorus, and reductant soluble and occluded phosphorus. The low content of the last fractions, on the one hand, and the fairly high part of calcium bound phosphorus, on the other hand, show that the chemical weathering in most of our soils is not yet at an advanced stage. In the acid surface layers there may be more phosphorus bound to iron and aluminium than to calcium, but this is likely to be at least partly connected with the biological cycle of phosphorus. Numerous microorganisms are known to be able to dissolve apatite like phosphate, and with the aid of microorganisms even the plants may utilize it. When phosphorus is then released from the organic forms in acid soils, it will be bound by aluminium and iron (5), and thus these fractions will be increased at the expense of the calcium bound forms. It may be mentioned that in the surface layer of all the virgin soils and of most the cultivated soils the part of phosphorus which occurred in organic forms was far higher than any of the fractions of inorganic phosphorus.



Some essential differences appear to exist in the fractions of inorganic phosphorus in the virgin and cultivated soils. In the virgin soils the topsoil is very poor in aluminium bound phosphorus. In the intensively podsolized soils the layer from 20 cm to 40 cm usually contains somewhat more of this fraction. In the cultivated soils, on the other hand, the fertilizer phosphorus tends to be accumulated in the surface layer, and often it markedly increases the aluminium bound forms. Also the alkali-soluble phosphorus fraction benefits by the fertilizer phosphorus. In some cases there seems to be an increase even in the calcium bound fraction, but this is likely to happen only as a result of the application of hyperphosphate or other fertilizers containing apatite (8).

The picture given by the present results of the distribution of inorganic phosphorus into various fractions at various depths of the cultivated non-Litorina soils is in accordance with most of the data reported by MADL (11) and HEINEMANN (4) who studied brown earths, pseudogleys and chernozems: the aluminium and iron bound phosphorus is highest in the surface layers and decreases with the depth while the contrary is true with the calcium bound forms. In a typical podsol soil the B-horizon is enriched in respect of all these three fractions at the expense of the bleached A<sub>2</sub>-horizon. But downwards from the B-horizon the distribution pattern is similar to that in the cultivated soils.

The reductant soluble and occluded phosphorus, and the inorganic phosphorus not extracted by the procedure employed, are not likely to play any direct role in the phosphorus nutrition of plants. This will depend on the first three fractions, but to what extent each of them will in different soils release phosphorus to plants is not yet known. According to Mac KENZIE (10), the aluminium bound fraction supplies most of the phosphorus to the soil solution. If this is true, the surface layers of our virgin soils are, in general, very poor in available phosphorus, while the conditions in the second layer may be somewhat better, provided their high content of aluminium and iron will not lead to a strong retention of phosphorus. That this is often the case may be proved by the test values of Teräsvuori.

In the plough layer of the cultivated soils which are intensively fertilized by water-soluble phosphates the accumulation of aluminium bound phosphorus is usually high enough to produce a fairly high phosphorus concentration in the solution even in soils of a high sorption capacity. It may be possible that in some of the cultivated soils the plant have taken up phosphorus also from the upper part of the subsoil, and thus they have decreased the content of aluminium bound phosphorus in this layer.

It was to be expected that the results of the BRAY P 1 test would be correlated with the content of aluminium bound phosphorus, and that the same would hold true between the acetic acid soluble phosphorus and the calcium bound phosphorus. The TERÄSVUORI-test is based on the supposition that in our acid soils the alkali-soluble phosphorus or phosphorus bound to the sesquioxides will be in equilibrium with the phosphorus in the soil solution. There may be some question whether the »x<sub>0</sub>» of this method will represent the amount of phosphate which will determine the corresponding concentration in soil solution. Yet, this method will give more information of the soil phosphorus condition than any of the simple test values. In

most of the soils studied, the Teräsvuori-test shows the probable differences between the phosphorus conditions in the topsoil and subsoil of the virgin and cultivated soils.

### Summary

The fractionation method of CHANG and JACKSON (2) was used for the analysing of the distribution of inorganic phosphorus in the topsoil and subsoil of twelve virgin and twelve cultivated soils from various parts of the country; two virgin soils and twenty cultivated soils were studied down to the depths of 60 cm or 70 cm, one even to 2 m.

In the more intensively podsolized virgin soils the surface layers, particularly the A<sub>2</sub>-horizon, are very poor in all the forms of inorganic phosphorus while the enrichment layer will contain fairly high amounts of iron and aluminium bound phosphorus. The application of fertilizers and the other cultivation managements tend to accumulate aluminium and iron bound phosphorus in the plough layer. In some soils the minimum content of calcium bound phosphorus occurs in the layer below the plough layer, but an increase with the depth seems to be typical to it in all the non-Litorina soils, while the first two fractions usually decrease with the depth. In the Litorina soils the iron bound phosphorus is dominant in all the layers studied, but the content of reductant soluble phosphorus is low in these soils, and their content of calcium bound phosphorus is higher than the content of phosphorus bound by aluminium.

The predominance of calcium phosphate in the subsoil and the rather low content of reductant soluble and occluded fractions indicate that the chemical weathering in most of our soils is not yet at an advanced stage.

The test values determined were in accordance with the results of the fractionation and the estimation of ammonium oxalate soluble aluminium and iron.

### REFERENCES:

- (1) BRAY, R. H. & DICKMAN, S. R. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* 59: 39-45.
- (2) CHANG, S. C. & JACKSON, M. L. 1957. Fractionation of soil phosphorus. *Ibid.* 84: 133-144.
- (3) — & — 1958. Soil phosphorus fractions in some representative soils. *J. Soil Sci.* 9: 109-119.
- (4) HEINEMANN, C-G. 1962. Der Einfluss von Düngung, pH-Wert und Wasserhaushalt auf die P-Verteilung in Böden. *Dissert. Techn. Hochschule Hannover*, 90 p.
- (5) KAILA, A. 1956. Phosphorus in various depths of some virgin peat lands. *J. Sci. Agric. Soc. Finland* 28: 90-104.
- (6) — 1961. Effect of incubation and liming on the phosphorus fractions in soil. *Ibid.* 33: 185-193.
- (7) — 1963. Total phosphorus content of some mineral soils. *Ibid.* 35: 19-26.
- (8) — 1963. Fertilizer phosphorus in various fractions of soil phosphorus. *Ibid.* 35: 36-46
- (9) — 1963. Organic phosphorus in Finnish soils. *Soil. Sci.* 95: 38-44.

- (10) MacKENZIE, A. F. 1962. Inorganic soil phosphorus fractions of Ontario soils as studied using isotopic exchange and solubility criteria. *Can. J. Soil Sci.* 42: 150—156.
- (11) MADL, W. 1960. Bindung und Verteilung des Phosphors in Böden der Bayerischen Moränenlandschaft. *Veröff. Inst. Bodenkunde u. Standortslehre d. Forstl. Forsch. Anst. München.* 175 p.
- (12) TERÄSVUORI, A. 1954. Über die Anwendung saurer Extraktionslösungen zur Bestimmung des Phosphordüngerbedarfs des Bodens, nebst theoretischen Erörterungen über den Phosphorzustand des Bodens. *Publ. Staatl. Landw. Versuchswesens in Finnland Nr 141.* Helsinki, 64 p.

## SELOSTUS:

### KIVENNÄISMAITTEN ERI KERROSTEN FOSFORITILANTEESTA

ARMI KAILA

*Yliopiston maanviljelyskemian laitos, Helsinki*

Käyttämällä CHANGIN ja JACKSONIN fraktioimismenetelmää sekä TERÄSVUOREN metodia, BRAYN ja KURTZIN P I testiä ja etikkahappoon liukenevan fosforin määrittämistä yritettiin tutkia eräitten kivennäismaittemme eri kerrosten fosforitilannetta. Aineiston muodostivat 12:n viljelysmaan muokkauskerroksen ja jankon näytteet sekä vastaavista kerroksista otetyt 12:n luonnontilaisen maan näytteet. Lisäksi tutkittiin 20:n viljelysmaan näytteet 60 tai 70 cm:iin asti sekä kahden metsämaan näytteet, toisen jopa kahteen metriin.

Voimakkaasti podsoloituneitten maitten pintakerrokset, etenkin valkoomaa-taso, sisältävät hyvin niukasti epäorgaanista fosforia, kun taas rikastumistasossa saattaa olla runsaasti varsinkin alumiinumin ja raudan sitomaa fosforia. Lannoituksen ja muiden viljelystoimenpiteiden vaikutuksesta kertyy muokkauskerrokseen suhteellisen runsaasti näitä fraktioita. Joissakin maissa näytti kalsiumin sitoman fosforin määrä olevan matalimmillaan heti muokkauskerroksen alapuolella, mutta, syvemälle mentäessä sen määrä yleensä kasvoi sekvioksidien sitoman fosforin osuuden vähentyessä. Poikkeuksena ovat Litorina-savet, joissa raudan sitoma fosfori on vallitsevana muotona kaikissa tutkituissa kerroksissa.

Kalsiumin sitoman fosforin suhteellisen suuri osuus useimmissa maissa ja toisaalta okludoituneen fosforin melko pieni määrä osoittavat, että useimpien maittemme kemiallinen rapautuminen ei ole vielä ehtinyt pitkälle.

Testiluvut olivat yleensä sen mukaisia kuin maitten epäorgaanisen fosforin fraktioitten ja ammoniumoksaalaattiin liukenevan raudan ja alumiinumin perusteella saattoi odottaa.