THE FATE OF WATER-SOLUBLE PHOSPHATE APPLIED TO SOME MINERAL SOILS

Armi Kaila

University of Helsinki, Department of Agricultural Chemistry

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In a previous paper (9) results were reported on the distribution of applied water-soluble phosphate in the various fractions of inorganic phosphorus in 180 samples of mineral soils. Samples suspended in KH_2PO_4-solution in the ratio of 1 to 50 of soil to solution retained, on the average, about one half of the applied 250 mg P/kg of soil during a period of contact of 24 hours. On the average, about 56 per cent of the retained phosphorus was found in the fluoride soluble fraction, and about 40 per cent in the alkali soluble fraction when the treated samples were analysed by the method of Chang and Jackson (3) after standing moist for three days since the removal of the phosphate solution by centrifuging. It was emphasized that the results may be significantly different, if the period of contact would be longer, and also, if smaller or larger amounts of phosphate were applied.

In order to get more information about the effect of the rate of the application of the soluble phosphate on the forms in which it will be retained, some further studies were performed. An incubation experiment under the laboratory conditions was carried out, and also the distribution of varying amounts of added phosphate shortly after the application was studied. The results are compared with some data from a couple of field experiments.

Material and methods

The material of the present study consists of twelve samples chosen to represent mineral soils of a largely varying phosphate sorption capacity and of different patterns of phosphate retention. The samples are listed in Table 1 with some of the characteristics important for the present study. Ten of the samples are from the plough layer of arable lands, the sample 4 is from the surface layer of a virgin soil, and the sample 12 originates from the layer of the depth of 20 to 30 cm of a

Table 1. Soil samples

		Clay %	Org. C %	pH	Al ppm	Fe ppm	k	Inorg. P pm, extracted by			
								NH_4Cl	NH_4F	NaOH	H_2SO_4
1. Vi 3a	Clay loam	47	4.3	4.4	7420	22080	1000	0	17	312	99
2. VN 1	»	43	5.8	4.5	6990	17010	820	1	80	512	168
3. VN 2	»	40	4.6	5.1	4300	11170	796	1	154	492	210
4. Vi 2a	Sandy clay	45	1.0	4.8	2650	6650	252	0	5	116	200
5. K 107	Silt	18	2.1	4.7	2330	4250	232	2	37	145	288
6. K 100	»	11	4.8	4.9	2950	4700	201	1	39	137	253
7. K 5	»	18	2.4	5.5	1490	3030	142	2	69	133	390
8. C 7	Sandy clay	47	3.6	6.1	2260	4740	135	3	53	186	438
9. C 1	Fine sand	8	1.9	5.1	2140	2780	130	1	34	61	263
10. C 2	»	0	2.9	5.4	1790	990	93	0	29	12	27
11. K 101	Silt	22	3.5	5.3	1910	3670	90	1	18	76	351
12. To 1b	Silty clay	40	0.5	6.4	990	1520	55	0	6	22	526

virgin soil. Samples 1 and 2 represent the so-called Litorina soils, postglacial marine sediments characterized by a fairly high acidity and high contents of soluble salts and sesquioxides.

The soil pH was measured in 1: 2.5 suspension in 0.01 M $CaCl_2$ by the glass electrode. The content of organic carbon was estimated by the procedure of Walkley, using the iodometric titration, and the content of clay was determined by the common areometer method. 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 indicator of the inorganic-P-sorption capacity was estimated by a procedure based on the Freundlich adsorption isotherm (cf. 7).

The fractionation of inorganic phosphorus was performed by the method of Chang and Jackson (3), instead of the neutral NH_4F-solution a slightly alkaline extractant was used. The occluded forms were not determined.

The samples are listed in the order of the decreasing values of the indicator of the phosphorus sorption capacity, k. In this material it ranges from 1000 to 55. The average value of k in a larger material of our soils was found to be 290 ± 17 in sand and fine sand soils, 201 ± 24 in loam and silt soils, and 308 ± 20 in clay soils (7). It does not appear to be closely connected with the clay content, or with the acidity. On the other hand, the amounts of acid oxalate soluble aluminium and iron seem to be associated with the values of k also in the present material.

The results of the fractionation of inorganic phosphorus reveal some features typical of our soils (8). The content of the NH_4Cl-soluble phosphorus is very low. An extremely low content of NH_4F-soluble phosphorus is found in the samples 4 and 12 from the virgin soils, and this fraction is smaller than that soluble in alkali in all the other soils except in the fine sand sample C 2. The relatively high content of alkali-soluble phosphorus characterizes the samples of Litorina soils, numbers 1 and 2. The occurence of a fairly large part of the inorganic phosphorus in the other samples as the acid-soluble form, may be attributed to the fact that our soils are rather young, and the weathering processes appear to have only sparingly mobilized the original apatite phosphorus to forms bound by iron and aluminium.

The treatments in the incubation experiment were 0, 100, 200, or 500 mg P/kg of soil. 100 g samples of air dry and ground soil were weighed in glass jars, and 50 ml of distilled water, or 50 ml of KH_2PO_4 solutions containing 200, 400, or 1000 mg P/l, respectively, were added. The soils were dried to about the field capacity, mixed well, and incubated under a loose cover for three months at 18—20°C. The samples were air-dried and ground before analysing.

In order to preparate the material for the study of the distribution of the applied phosphorus immediately after the application, 1 g samples of air-dry and ground soil were weighed in a centrifuge tube, and 50 ml of distilled water, or solutions of KH_2PO_4 containing 2, 4, or 10 mg P/l, resp., were added. Thus the applications of phosphorus correspond to those in the incubation experiment. In addition, one sample was treated with phosphate solutions corresponding to applications of 1000, 2000, 5000, or 10000 mg P per kilogram of soil. The suspensions were shaken for two hours, centrifuged, and the fractionation of inorganic phosphorus was carried out.

The increase in the phosphorus content of the various fractions in the samples treated with phosphate as compared with the values obtained for the samples treated with distilled water is taken to indicate the accumulation of the applied phosphate. Mineralization of soil organic phosphorus, or microbiological immobilization of inorganic phosphorus is supposed to be equal in all the treatments, and relatively insignificant. In the incubation experiment it was found that the total amount of phosphorus extracted by the fractionation procedure from the samples incubated for three months without any application of phosphate were 0 to 25 ppm higher than those from the original samples.

Results

The results of the incubation experiment are reported in Table 2. The pH values in the incubated samples differ from the orginal ones only by —0.3 to +0.1 pH units. The changes seem to be independent on the treatments. Thus, differences in the acidity of the variously treated samples are not likely to play any significant role in the distribution of the applied phosphorus.

The recovery of the phosphorus is usually somewhat less than 100 per cent of the amount added. There are no reasons to suppose that this deficit would be caused by an accumulation of phosphorus in the occluded forms. It is probable that losses during the fractionation procedure and a possibly heterogeneous distribution of the added phosphorus in spite of the thorough mixing account for the incomplete recovery.

As could be expected, the largest part of the applied soluble phosphate is recovered in the fluoride-soluble and alkali-soluble forms. Only in a few samples it has remained soluble in ammonium chloride to any marked extent. On the other hand, the acid-soluble fractions has also accumulated very little or not at all of the applied soluble phosphate, except in some samples with a fairly high pH and a low content of iron and aluminium. It is likely that the small increases in this fraction in acid samples may be due to analytical errors.

There are typical differences in the pattern of the distribution of the applied phosphorus between the fluoride-soluble and alkali-soluble forms. The clay loam sample Vi 3a has retained 80 to 90 per cent of the recovered phosphorus in the

Table 2. Distribution of the applied P in various fractions in soil samples incubated for three months

Sample	P ppm applied	pH	P ppm recovered	Per cent of recovered P extracted by			
				NH_4Cl	NH_4F	NaOH	H_2SO_4
1. Vi 3a	100	4.5	95	0	11	88	1
	200	4.5	185	0	15	84	1
	500	4.5	492	0	17	80	3
2. VN 1	100	4.3	102	0	27	73	0
	200	4.3	199	0	32	68	0
	500	4.3	483	1	36	63	0
3. VN 2	100	4.7	104	0	45	55	0
	200	4.7	201	0	51	49	0
	500	4.7	491	2	52	45	1
4. Vi 2a	100	4.9	83	0	29	71	0
	200	4.9	172	0	34	66	0
	500	5.0	461	2	42	54	2
5. K 107	100	4.4	98	2	52	43	3
	200	4.4	178	4	59	35	2
	500	4.4	477	5	63	29	3
6. K 100	100	4.5	93	3	59	35	3
	200	4.5	179	4	64	28	4
	500	4.5	481	6	67	25	2
7. K 5	100	5.2	104	7	56	36	1
	200	5.2	204	8	55	32	5
	500	5.2	489	12	60	25	3
8. C 7	100	5.8	90	3	45	48	4
	200	5.8	189	4	40	43	13
	500	5.8	484	7	48	40	4
9. C 1	100	5.0	88	1	52	40	7
	200	5.0	192	3	61	31	5
	500	5.2	469	3	59	35	3
10. C 2	100	5.3	90	2	85	12	1
	200	5.3	179	3	88	8	1
	500	5.3	486	6	86	8	0
11. K 101	100	5.0	94	5	48	36	11
	200	5.1	192	7	53	34	6
	500	5.0	492	11	58	26	5
12. To 1b	100	6.5	93	6	47	36	11
	200	6.5	176	15	51	23	11
	500	6.3	487	22	54	17	7

latter fraction supposed to be bound by iron whereas the fine sand sample C 2 has accumulated 85 to 88 per cent of it in the former fraction which is assumed to be mainly connected with aluminium. In the other samples the applied phosphorus appears to have been divided more equally between these fractions. Usually, the fluoride-soluble part is larger, but in the samples 1, 2 and 4 the alkali-soluble fraction dominates.

The most interesting question of this experiment, the effect of the rate of the application on the distribution is answered by these results fairly distinctly. The larger the amount of phosphate applied, the higher part of it may be found in the fluoride soluble form and the less in the alkali-soluble form. Also the part which remains soluble in NH_4Cl increases with an increase in the application.

When the soil samples were submitted to the fractionation procedure immediately after the treatment with the phosphate solutions, results recorded in Table 3 were obtained. The part of applied phosphorus retained during the contact of two hours tends to decrease from the samples with a high value of k to those with a low k, although not quite regularly. It is of particular interest to note that the sample Vi 3a, with a value of $k = 1000$, is able to retain within two hours the lowest application of phosphate completely, and even about two thirds of the application of 500 ppm. The percentile retention decreases, of course, when the application is increased, but the absolute amounts increase. From the 10000 ppm soluble phosphorus added this sample sorbs 2200 ppm. Even in this case more than one half of the retained phosphorus is found in the alkali soluble fraction which fact indicates the dominance of iron in the pattern of phosphorus fixation in this soil. The samples K 5 and K 101, on the other hand have retained only 20 ppm P or less from the application of 100 ppm, and 16 or 15 per cent from the application of 500 ppm.

The figures in Table 3 showing the percentage of the recovered phosphorus in the various fractions differ surprisingly little from the corresponding values in Table 2 for the samples incubated for three months. The part which has been remained soluble in ammonium chloride is slightly higher in the samples analysed immediately after the application of phosphate, but this fraction, apparently, represents in this case only an indefinite portion of the phosphate not sorbed by the soil constituents during the two hours of contact. The percentage of recovered phosphorus in the fluoride-soluble fraction is higher and that in the alkali-soluble fraction correspondingly lower than in the incubated samples, but the differences may be rather small in some samples. Only in few cases, some of the applied phosphorus has been recovered in the acid-soluble form. In accordance with the results obtained for the incubated samples, the part of the applied phosphate found in the fluoride-soluble form tends to increase with an increase in the application whereas the contrary is true in regard to the alkali-soluble form.

The pattern of the retention appears to be characteristic of the soil from the period of contact of two hours to the period of three months. In the sample Vi 3a 79 to 82 per cent of the recovered phosphorus in the unincubated samples was in the alkali-soluble fraction, in the incubated samples the corresponding part was from 80 to 88 per cent. In the sample C 2, on the other hand, 70 to 80 per cent of the recovered phosphorus was sorbed in the fluoride-soluble form during the two

Table 3. Distribution of the applied P in various fractions in soil samples without incubation

Sample	P ppm applied	Per cent of P retained	Per cent of recovered P extracted by			
			NH_4Cl	NH_4F	NaOH	H_2SO_4
1. Vi 3a	100	100	2	16	82	0
	200	75	2	17	81	0
	500	67	2	19	79	0
	1000	61	1	22	73	4
	2000	47	2	26	70	3
	5000	31	3	31	64	2
	10000	22	5	35	55	5
2. VN 1	100	82	2	37	61	0
	200	69	2	38	60	0
	500	58	3	40	57	0
3. VN 2	100	80	3	46	51	0
	200	54	2	50	48	0
	500	45	3	55	42	0
4. Vi 2a	100	55	2	38	60	0
	200	48	3	38	59	0
	500	33	3	45	52	0
5. K 107	100	57	5	48	47	0
	200	39	6	53	41	0
	500	26	9	57	34	0
7. K 5	100	20	20	65	15	0
	200	18	11	64	25	0
	500	16	16	59	25	0
8. C 7	100	37	8	51	41	0
	200	29	8	54	38	0
	500	20	8	59	33	0
9. C 1	100	28	11	64	25	0
	200	25	6	67	27	0
	500	16	10	74	16	0
10. C 2	100	30	0	70	6	24
	200	26	2	77	6	15
	500	20	5	80	6	9
11. K 101	100	19	6	76	18	0
	200	19	7	70	23	0
	500	15	13	64	23	0
12. To 1b	100	29	4	48	24	24
	200	22	5	53	30	12
	500	13	12	49	21	18

Table 4. Ratio of the applied P in the fluoride-soluble fraction to that in the alkali-soluble fraction, and the absolute differences in these fractions in the unincubated (a) and incubated (b) samples

Sample	Al/Fe	»Al-P/Fe-P»	P ppm applied	Sorbed »Al-P/Fe-P»		b−a	
				a	b	»Al-P» ppm	»Fe-P» ppm
1. Vi 3a	0.7	0.05	100	0.2	0.1	−6	2
			200	0.2	0.2	2	33
			500	0.2	0.2	20	129
2. VN 1	0.8	0.16	100	0.6	0.4	−3	24
			200	0.7	0.5	12	52
			500	0.7	0.6	58	139
3. VN 2	0.8	0.31	100	0.9	0.8	10	56
			200	1.1	1.0	49	46
			500	1.3	1.2	131	126
4. Vi 2a	0.8	0.04	100	0.6	0.4	3	26
			200	0.6	0.6	22	57
			500	0.9	0.8	120	163
5. K 107	1.1	0.26	100	1.0	1.2	27	15
			200	1.3	1.7	64	30
			500	1.8	2.2	227	94
7. K 5	1.0	0.52	100	4.3	1.6	45	34
			200	2.6	1.7	89	56
			500	2.4	2.4	246	102
8. C 7	1.0	0.28	100	1.3	0.9	22	28
			200	1.5	0.9	45	59
			500	1.8	1.2	173	161
9. C 1	1.6	0.56	100	2.6	1.3	28	28
			200	2.4	2.0	83	46
			500	4.5	1.7	218	151
10. C 2	3.7	2.41	100	10.5	6.9	56	9
			200	13.3	11.3	118	11
			500	13.2	10.4	338	33
11. K 101	1.1	0.24	100	3.0	1.3	31	31
			200	3.0	1.5	75	56
			500	2.7	2.2	237	111
12. To 1b	1.4	0.27	100	2.0	1.3	30	26
			200	1.8	2.2	67	27
			500	2.3	3.1	230	69

hours of contact, whereas the values found for the incubated samples were 85 to 88 per cent. The patterns of the other soils are less distinct, but almost without an exception the samples which in the incubation experiment had accumulated more applied phosphorus in the alkali-soluble than in the fluoride-soluble form, or vice versa, did so also when the fractionation was performed after two hours of contact. This is particularly noteworthy, since in some soils the immediate retention has been only from 13 to 30 per cent of that in the incubation experiment.

Since in our soils the retention of soluble phosphorus seems to be almost completely depending on the factors determining its extractability by the fluoride or the alkali solutions of the fractionation procedure, a more detailed study of these fractions in the results of the present experiments may be illuminating. Table 4 contains data which show the ratio between the increases in the so-called »Al-P», or the fluoride-soluble fraction, and in the »Fe-P», or the alkali-soluble fraction both in the results obtained immediately and in those from the incubation experiment. Also the ratios of the acid oxalate soluble aluminium to iron (in moles) and the ratios of the fluoride-soluble and alkali-soluble phosphorus in the original samples are recorded. These data show that the distribution of the applied phosphorus in these two fractions in the incubated and unincubated soils is fairly similar in the first four samples. All of them are characterized by a higher increase in the alkali-soluble than in the fluoride-soluble form, at least in connection with the lowest application. This is in accordance with the molar ratio of oxalate-soluble aluminium to iron being less than 1 in these soils. In samples having a higher ratio of Al/Fe, the applied phosphorus has been accumulated in the fluoride-soluble form in larger amounts than in the alkali-soluble form. Although also in these samples the ratio between the sorbed amounts of »Al-P» and »Fe-P» tends to increase with the rate of application, this seems to be less regular than in the first samples. In these soils, also the ratios in the incubated samples partly appear to be higher than those in the unincubated ones.

It has been claimed (2) that while the newly retained phosphorus is mainly fixed as the aluminium bound form, the amount of the iron bound form will increase in time and usually surpass the other forms. The data in Table 4 showing the difference in the fluoride-soluble phosphorus and in the alkali-soluble phosphorus in the incubated and unincubated samples indicate that this is not always the case. In the iron dominated samples Vi 3a, VN 1, and Vi 2a the increase in the alkali-soluble fraction during the incubation has been markedly higher than that in the fluoride-soluble fraction. Yet, in most of the other soils the increase in the latter fraction has been equal to, or even significantly higher than that in the iron bound form. In all samples the relative increase in the fluoride-soluble fraction as compared to that in the alkali-soluble fraction tends to be the higher the higher the application of phosphate.

According to these laboratory experiments, the part of the applied phosphate sorbed as the fluoride-soluble form usually seems to be the higher and the part sorbed as the alkali-soluble form the lower the larger the amount of phosphate added. Under the field conditions this pattern may be less distinct, particularly on account of the effect of the uptake of phosphorus by plants, and also because of the less thorough mixing of the fertilizers with the soil.

In a field experiment on a silty clay soil with the pH 4.9, the annual applications of 400 or 800 kg of superphosphate (8.5 % P) per hectare for 12 years have increased the amount of the phosphorus in the various fractions as compared to the results obtained for the samples from the untreated plots with the following quantities:

Superphosphate	NH_4Cl-soluble P	NH_4-F-soluble P	NaOH-soluble P
400 kg/ha	2 ppm	32 ppm	43 ppm
800 »	6 »	92 »	109 »

No increase in the acid-soluble fraction could be detected. In this soil somewhat more of the applied fertilizer phosphorus appears to be accumulated in the alkali-soluble than in the fluoride-soluble fraction. Yet, the higher application has resulted in a relatively higher increase in the latter form. Also a slightly higher part of the applied phosphorus is remained soluble in ammonium chloride in the samples which got the heavier application.

In a field experiment on an acid peat soil (pH 4.2) reported in a previous paper (5), the annual applications of superphosphate during 34 years were 100, 200, and 300 kg/ha, respectively. The differences in the various phosphorus fractions between the samples from these treated plots and the untreated ones were the following:

Superphosphate	NH_4-F-soluble P	NaOH-solube P
100 kg/ha	4 ppm	16 ppm
200 »	20 »	54 »
300 »	66 »	148 »

In this soil rich in iron a far larger part of the applied phosphorus is found in the alkali-soluble than in the fluoride-soluble fraction. However, even in this case the ratio between these increases in the former and the latter fractions tends to be the higher the higher the application of super-phosphate. These ratios are 0.25, 0.37, and 0.45, for the 100, 200, and 300 kg of superphosphate, respectively. In this soil from 44 to 53 per cent of the increase in phosphorus content caused by the fertilization is found in the fraction of organic phosphorus. Also the acid-soluble fraction in the treated samples was larger than that in the untreated plots. This is likely to be partly connected with the possibility that in this soil, very poor in available phosphorus, the crops of the untreated plots have been compelled to utilize also the apatite-phosphorus in the mineral fraction of the clayed peat. In any case, in this old experiment other factors than the sorption of phosphate by the soil constituents have played their role.

Discussion

The results of the present study show that the soils tend to have a characteristic pattern of phosphate retention. In the extreme cases it means that in one soil the applied water-soluble phosphate is almost completely sorbed as the alkali-soluble form supposed to be bound by iron and its compounds, whereas in an other soil by far the largest part of the sorbed phosphorus is found in the fluoride soluble fraction which is assumed to be bound mainly by aluminium and its compounds. In such extreme cases the pattern appears to be distinct very soon after the phosphate has come into contact with the soil, and this pattern will in time grow more evident. In most of our soils, however, the distribution of the applied phosphate between the fractions supposed to be bound by aluminium or iron appears to be more equal. This could be proved in a previous work (9) on the basis of a larger material as to the newly retained phosphorus. The present results also indicate that these fractions tend to be of the same order, and usually the part of the fluoride-soluble forms is somewhat higher than that of the alkali-soluble forms. The retention of applied soluble phosphorus by calcium as an apatite-like compound seems to occur in our soils only seldom to any marked degree.

Another tendency revealed by the present results is the relative increase in the fluoride-soluble fraction as compared with the alkali-soluble fraction when the rate of the application of the soluble phosphate increases. This is apparent even in those samples in which the pattern of phosphate retention is dominated by iron. The few data from the field experiments are in accordance with the results of the laboratory studies.

It is likely that in the fractionation procedure used, the ammonium fluoride solution will extract not only aluminium bound phosphorus but also e.g. dicalcium-phosphate (5, 6, 10, etc.). The importance of this fraction as a source of phosphorus for plants has been emphasized (4, 11). In alkaline soils the uptake of phosphorus has been reported to be correlated with the iron bound form (1). There are no informations of the availability of phosphorus in the various fractions in our soils.

Probably, there are differences even within the same fraction in the intensity of the sorption. It is possible that e.g. the newly retained phosphorus in the fluoride-soluble or alkali-soluble fraction is more easily available for the plants than phosphorus in the same fractions in the samples incubated for three months. If fhe fluoride-soluble fraction would represent phosphorus which the plants are able to utilize more easily than the alkali-soluble phosphorus, the present results would, for their part, explain why a fairly large application of phosphate fertilizers is necessary to secure the phosphorus nutrition of the crops in most of our soils: the part of the applied phosphorus sorbed in the fluoride-soluble forms is the lower the lower the application of fertilizer phosphorus. Attention must be paid to the fact that the lowest amount of phosphorus added in the present laboratory experiments was 100 ppm which corresponds to about 2200 to 2800 kg superphosphate per hectare. From this addition a slightly higher part was sorbed as the fluoride-soluble form than as the alkali-soluble form. When only about 200 to 400 kg superphosphate is added per hectare, the part which will be retained as the fluoride-soluble fraction may be markedly lower than that retained in the alkali-soluble fraction.

Summary

The distribution of applied water-soluble phosphorus in the various fractions of soil inorganic phosphorus was studied in an incubation experiment under the laboratory conditions. Samples of twelve soils were incubated for three months

at room temperature with the applications of KH_2PO_4 in amounts corresponding to 100, 200, or 500 mg P/kg of soil. The results of the fractionation showed that in most samples the applied phosphorus could be found almost completely in the fluoride-soluble and alkali-soluble fractions, the part of the former being the higher and that of the latter the lower the higher the rate of the phosphate application. Similar results were obtained also when the fractionation was performed after the samples had been in contact with the phosphate solutions only for two hours. Analyses of samples from two field trials were in accordance with these results.

The soils tended to have a characteristic pattern of phosphate retention which in extreme cases means an almost complete sorption ot the applied phosphate either as the fluoride-soluble form or as the alkali-soluble form. In most soils, however, the distribution was more equal. Usually the fluoride-soluble part of the recovered phosphorus tended to be somewhat higher than the alkali-soluble part. This tendency was more distinct in regard to the newly retained phosphorus.

The effect of phosphate fertilizers in our soils is discussed on the basis of the results.

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SELOSTUS:

KIVENNÄISMAIHIN LISÄTYN VETEEN LIUKENEVAN FOSFORIN PIDÄTTYMISESTÄ

Armi Kaila

Yliopiston maanviljelyskemian laitos, Pihlajamäki

Kahdentoista kivennäismaan näytteisiin lisättiin 100, 200 tai 500 mg P/kg KH_2PO_4:na ja näytteitä muhitettiin kolme kuukautta huoneen lämpötilassa. Toinen näytesarja analysoitiin heti, kun niitä oli kahden tunnin ajan huiskutettu vastaavat fosforin määrät sisältävissä liuoksissa. Fraktioinnin tulokset osoittivat, että useimmissa maissa lisätty fosfori oli joutunut miltei kokonaan fluoridiin ja emäkseen liukeneviin fraktioihin. Edellisen osuus oli tavallisesti sitä suurempi ja jälkimmäisen sitä pienempi, mitä enemmän fosforia oli lisätty. Vastaavanlaisia tuloksia saatiin myös analysoimalla eräitten kenttäkokeitten maanäytteitä.

Maat näyttivät edustavan tiettyjä fosforin pidätyksen tyyppejä, joiden äärimmäisyyksinä olivat maat, jotka pidättivät lisätyn fosforin miltei kokonaan joko fluoridiin tai emäkseen liukenevaan muotoon. Useimmissa maissa lisätty fosfori jakautui tasaisemmin näiden fraktioiden kesken. Myös muhitetuissa näytteissä fluoridiin liukeneva osa oli tavallisesti hiukan suurempi kuin emäkseen liukeneva.

Todettiin, että mikäli emäkseen liukeneva fraktio todella edustaisi huomattavasti vaikeammin kasveille käyttökelpoista fosforia kuin fluoridiin liukeneva osa, olisi syytä käyttää etenkin runsaasti rautaa sisältävissä maissa voimakasta fosforilannoitusta satojen fosforin saannin turvaamiseksi.