RESIDUAL EFFECT OF ROCK PHOSPHATE AND SUPERPHOSPHATE

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In 1954 two field trials were started in Central Finland by the head at that time of the local agricultural experiment station, the late Dr. Pentti Hänninen, to compare the response of cereals and ley plants to finely ground North African rock phosphate (Hyperphosphate) and superphosphate. In Finland, usually, about twice as much phosphorus as hyperphosphate than as superphosphate is needed for the production of equal increases in dry matter yields. In these trials, however, from the third to the sixth test crops, repeated application of equal amounts of phosphorus either as rock phosphate or as superphosphate gave the same response in the dry matter yields, but, at least in the red clover-timothy ley of 1959, the phosphorus content of the hay from the rock phosphate plots was distinctly lower than that from the superphosphate plots, mainly because of the poor uptake of apatite phosphorus by grasses (Kaila and Hänninen 1960). When the trials were continued with winter rye as the test crop, the superiority of superphosphate to rock phosphate was significant also in the grain and straw production, and this could be mainly attributed to the better overwintering of sprouts feeding on superphosphate (Kaila and Hänninen 1961).

The total amount of phosphorus applied during the seven experimental years was 166 kg/ha as superphosphate or rock phosphate. The residual effect of these treatments was studied by growing test crops for three years without any phosphorus application. The results of these studies are reported in the present paper. The primary yield results and the samples were provided by Dr. Hänninen; the analytical work has been done by the author.

Field trials

Trial K 104 was on a fine sand soil containing about 3.5 % organic C. Trial K 105 was on a humus soil with about 12 % organic C. In 1960 the pH values measured in 0.01 M $CaCl_2$ suspension were 4.8 and 5.2, respectively.

The total area of an experimental plot was 50 m², and the treatments were in randomized blocks replicated four times. Basal dressings of nitrogen and potassium fertilizers were applied annually, with a few exceptions. The application of phosphorus fertilizers was the following:

1. No phosphate
2. Rock phosphate 125 kg/ha in 1954 and 1955, 500 kg/ha in 1956 as a store dressing to the nurse crop for the three ley-years, and 460 kg/ha to winter rye in the autumn 1959.
3. Superphosphate 200 kg/ha annually from 1954 to 1959, and 800 kg/ha to winter rye in the autumn 1959.

In both trials oats was grown in 1961. In 1962 and 1963 the test crops were red clover-timothy ley in trial K 104, and oats in trial K 105.

Soil samples were collected from the plough layer of every plot after the harvest of rye in the autumn 1960. They were analysed for phosphorus by several methods to get an idea of the accumulation of the fertilizer phosphorus applied.

The results were treated by DUNCAN's new multiple range test (DUNCAN 1955). Within trials means in each column not followed by the same letter differ at $P = 0.05$.

Results

According to various phosphorus tests performed, the phosphorus condition in the soil treated with superphosphate was significantly better than in that treated with rock phosphate. This was true particularly in trial K 105 where the test values of the rock phosphate plots did not markedly differ from those of untreated soil (cf. KAILA and HÄNNINEN 1961). Accumulation of fertilizer phosphorus may be detected in the first three fractions of the CHANG and JACKSON procedure (1957), as shown by the data in Table 1 which reports the amounts of inorganic phosphorus successively extracted by fluoride, alkali and acid. The values are expressed as P kg/ha in a layer of 20 cm.

The ammonium fluoride soluble fraction is supposed to be mainly aluminium bound phosphate, or in recently fertilized soils partly even dicalcium phosphate (KAILA 1961), and, usually it is considered to be the most available of these three fractions. It was markedly

Table 1. Some fractions of inorganic P in the soil in autumn 1960.

	Treatment before 1960	Inorganic P kg/ha extracted by NH_4F	$NaOH$	H_2SO_4
Trial K 104				
	No phosphate	40^{a}	240^{a}	550^{a}
	Rock phosphate	60^{b}	260^{a}	650^{b}
	Superphosphate	100^{c}	300^{b}	560^{a}
Trial K 105				
	No phosphate	20^{a}	90^{a}	570^{a}
	Rock phosphate	30^{a}	100^{a}	670^{b}
	Superphosphate	70^{b}	150^{b}	610^{a}

increased by the superphosphate dressings, but, only in trial K 104, it is in the rock phosphate plots significantly higher than in the untreated soil. The accumulation of superphosphate phosphorus as the alkali-soluble, or mainly iron bound form, is also marked in both trials. Most of the rock phosphate seems to be found in the acid-soluble fraction where it probably exists largely as unweathered apatite (cf. MOSCHLER et al. 1957, DOLL et al. 1960 etc.).

In trial K 104, there appears to be in the rock phosphate plots about 140 kg/ha and in the superphosphate plots about 150 kg/ha more phosphorus than in the untreated plots, if the total amounts of these three fractions of inorganic phosphorus are compared. In trial K 105, the corresponding differences are 120 kg/ha and 150 kg/ha, respectively. These figures cannot, however, be used to estimate the uptake of phosphorus by the crops from the fertilizers because of the many sources of error involved. These figures only indicate that a large part of the fertilizer phosphorus was left in the soil, when the studies on the proper residual effect were started.

Table 2. Residual effect of rock phosphate and superphosphate on oats in 1961.

	Treatment in 1954—59	Grain kg/ha	Straw kg/ha	P g/kg in grain	P g/kg in straw	P in yield kg/ha
Trial K 104						
	No phosphate	2060[a]	3310[a]	3.52[a]	1.06[a]	10.8[a]
	Rock phosphate	2210[b]	3580[ab]	4.01[b]	1.37[b]	13.8[b]
	Superphosphate	2340[b]	3760[b]	3.86[b]	1.71[c]	15.5[c]
Trial K 105						
	No phosphate	2140[a]	3750[a]	3.46[a]	1.30[a]	12.3[a]
	Rock phosphate	2210[a]	3630[a]	3.76[a]	1.32[a]	13.1[a]
	Superphosphate	2150[a]	3430[a]	3.65[a]	1.37[a]	12.5[a]

The dry matter yields and the phosphorus content of grain and straw of oats grown in 1961 without any application of phosphorus fertilizers are recorded in Table 2. In trial K 104, the residual effect of rock phosphate on the grain yield and its phosphorus content is statistically significant and equal to that of superphosphate. In the superphosphate plots the straw yield is significantly higher than that of the untreated plots, but it does not differ from the yield of the rock phosphate plot. The lower phosphorus content of the straw from the latter plots indicates that there was less phosphorus available in the residues of rock phosphate than in those of superphosphate. This is in accordance with the soil analyses. Thus, the total amount of phosphorus in the crop harvested from the rock phosphate plots remains lower than that from the superphosphate plots, but it is significantly higher than the quantity of phosphorus taken up from the untreated plots.

In spite of the fact that the untreated plots did not get any phosphorus for seven years, the yields they produced are fairly high in both trials. In trial K 105, no significant residual effect of either phosphorus fertilizer on the oat yield may be found.

In trial K 104, oats was followed by red clover-timothy ley in 1962 and 1963. The results in Table 2 show that the level of the dry matter yield was low in the first year and

Table 3. Hay yield in trial K 104 in 1962 and 1963.

	Treatment in 1954—1959	Dry matter kg/ha	P g/kg in clover	P g/kg in grasses	P g/kg in hay	P in yield kg/ha
In 1962						
	No phosphate	2780[a]	2.06[c]	1.85[c]	1.91[c]	5.3[a]
	Rock phosphate	3540[b]	2.34[d]	2.10[d]	2.14[d]	7.6[b]
	Superphosphate	3760[b]	2.37[d]	2.36[e]	2.36[e]	8.9[c]
In 1963						
	No phosphate	4720[c]	1.15[a]	0.93[a]	0.97[a]	4.6[a]
	Rock phosphate	5830[d]	1.52[b]	1.18[b]	1.24[b]	7.2[b]
	Superphosphate	6060[d]	1.59[b]	1.25[b]	1.30[b]	7.9[b]

fairly high in the second year, while the phosphorus content of hay was satisfactory in the first year and very low in the second one. Yet, in both years there were distinct and respectively equal residual effects of both phosphorus fertilizers on the dry matter yield, and also on the phosphorus content of clover. In the younger ley, grasses were not able to utilize the residues of rock phosphate as well as those of superphosphate. Therefore, the phosphorus content of hay from the rock phosphate plots is somewhat lower than that from the superphosphate plots, and also the total amount of phosphorus in the hay yield is highest in the superphosphate plots. In the second year, there is no more any significant difference in the phosphorus content of grasses from the plots treated with phosphorus fertilizers, and also the amounts taken up by the hay crop are equal.

Table 4. Oats yield in trial K 105 in 1962 and 1963.

	Treatment in 1954—59	Grain kg/ha	Straw kg/ha	P g/kg in grain	P g/kg in straw	P in yield kg/ha
In 1962						
	No phosphate	950[a]	3870[b]	3.26[a]	1.44[ab]	8.7[a]
	Rock phosphate	1000[a]	4000[b]	3.33[a]	1.40[a]	8.9[a]
	Superphosphate	1230[b]	3800[b]	3.46[a]	1.53[ab]	10.1[b]
In 1963						
	No phosphate	2270[c]	2880[a]	3.69[a]	1.23[a]	11.9[c]
	Rock phosphate	2250[c]	2820[a]	3.81[a]	1.54[ab]	12.9[c]
	Superphosphate	2090[c]	2560[a]	3.72[a]	1.97[b]	12.8[c]

In trial K 105 where oats was grown as the second and third test crops (Table 4), the yield was very poor in 1962 but fairly satisfactory in the following year. There was no significant difference between the straw yields from the various treatments in either year, but in 1962 the low amount of grain harvested from the superphosphate plots was somewhat higher than those from the other plots. This also resulted in a higher quantity of phosphorus taken up from this treatment. In 1963 the straw from the superphosphate plots is richer in phosphorus than that from the untreated soil, but because of the large variation, typical of this trial, its phosphorus content is not significantly higher than that of the rock phosphate straw. Thus, there is almost no residual effect of phosphate fertilizers in trial K105 during the three experimental years.

Discussion

The initial response of crops to apatite of rock phosphate is in most cases lower than that to the readily soluble monocalciumphosphate of superphosphate, but the gradual release of phosphorus from the former, and the immobilization of the latter will often result in an equal residual effect of these fertilizers. This kind of observations have been reported by several authors (e.g. Moschler et al. 1957, Tainio 1958, McLachlen 1960, Mattingly 1963), and also the results of trial K 104 are in accordance with this view, if only the dry matter yields are compared. In the first two experimental years, 1954 and 1955, there was a significant response of cereals to superphosphate but not to rock phosphate. Yet, since the third year's nurse crop and the following ley rock phosphate produced yield increases equal to those by superphosphate. The only exception was the winter rye crop in 1960, when low temperature parasitic fungi caused larger devastation in the sprouts feeding on rock phosphate. On the other hand, there was no indication of a better residual effect of rock phosphate than of superphosphate during the three years discussed in this paper. Apparently, this may only occur, when phosphorus is applied as rock phosphate at higher rates than as superphosphate (Weeks and Miller 1948, Doll et al. 1960).

Even in trial K 105 the response of crops to these two fertilizers did not markedly differ, though the increase in yield were in many years rather low because of the high productivity of this soil. Yet, if the effect of these fertilizers is compared on the basis of the uptake of phosphorus by the crops, the superiority of superphosphate is usually quite distinct. In 1959 and 1960, when both the initial and the residual effects of the phosphorus treatments were measured, the total amount of phosphorus in the crops harvested were the following (Kaila and Hänninen 1960, 1961):

	No phosphate	Rock phosphate	Superphosphate
Trial K 104	8.0 kg/ha	12.4 kg/ha	15.9 kg/ha
Trial K 105	16.6 »	18.5 »	23.9 »

In trial K 104 the increase in the phosphorus yield by rock phosphate appears to be only about 60 per cent of that by superphosphate. In trial K 105 the amount of phosphorus harvested from the rock phosphate plots is hardly higher than that from the untreated soil, while superphosphate has increased the phosphorus yield almost as much as in trial K 104.

In the three years without any phosphate dressing the total uptake of phosphorus in these trials were the following:

	No phosphate	Rock phosphate	Superphosphate
Trial K 104	20.7 kg/ha	28.6 kg/ha	32.3 kg/ha
Trial K 105	32.9 »	34.9 »	35.4 »

In trial K 104 the apparent recovery of superphosphate phosphorus decreased from 4.7 kg/ha in the first year to 3.3 kg/ha in the third year. The apparent recovery of rock phosphate phosphorus was lower than that of superphosphate in the first and the second year, but in the third year it did no more differ from the latter. In total, the crops took up from the rock phosphate residues about two thirds of the amount they obtained from the superphosphate residues. In trial K 105 no significant difference may be found between the total uptake of phosphorus from the variously treated plots.

A comparison of rock phosphate and superphosphate as annual applications, even if repeated during a longer period, is of no practical importance in Finland where rock phosphate is recommended only for store dressing. However, it was of interest to find in these trials that crops, even those of graminaceous plants, feeding on rock phosphate or its residues in the soil may produce dry matter yields not significantly lower than those obtained when superphosphate had been applied. The phosphorus content of the plants showed that only red clover had been able to take up phosphorus from the rock phosphate plots as readily as from the superphosphate plots. Attention has been paid to the good capacity of clovers to use rock phosphate (e.g. Drake and Steckel 1955, Murdock and Seay 1955), and it has been even observed that a spectacular increase of clover may often follow the application of rock phosphate to old pastures (Neenan 1959). In these trials no significant difference in the clover content could be detected between the two fertilizer treatments, but it would be of interest to study whether a large store dressing with rock phosphate could help clovers in the competition with grasses in mixed leys.

Summary

Results are reported of the residual effect of North African finely ground rock phosphate and superphosphate in two field trials on acid fine sand and humus soils. During the first seven years of these trials 166 kg P/ha was applied either as rock phosphate or as superphosphate to cereals and mixed leys. Then crops were grown for three years without any application of phosphorus fertilizers.

The phosphorus analyses of the soil at the end of the seventh experimental year proved that the largest part of rock phosphate occurred in the acid soluble fraction, probably mainly as unweathered apatite. The superphosphate phosphorus seemed to be accumulated as fluoride-soluble and alkali-soluble forms.

In the trial on the humus soil of a fairly high productivity, the residual effect of both fertilizers on three oat crops was insignificant. In the trial on the poorer fine sand soil, the residues of both fertilizers produced significant and mutually equal increases in the dry matter yields of the oat crop in the first year and of the hay crops in the second and third years. The tendency to a higher phosphorus content in the graminaceous plants from the superphosphate plots resulted in a higher uptake of phosphorus from these plots as compared with the phosphorus yield from the rock phosphate plots; only in the third year the difference was no more significant.

Attention was paid to the good capacity of red clover to use phosphorus of rock phosphate.

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SELOSTUS

HIENOFOSFAATIN JA SUPERFOSFAATIN JÄLKIVAIKUTUKSESTA

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Yliopiston maanviljelyskemian laitos, Viikki

Tutkimuksessa käsitellään kolmen varsinaisen jälkivaikutusvuoden tuloksia kahdesta Keski-Suomen koeaseman edesmenneen johtajan tohtori Pentti Hännisen kanssa aloitetusta kenttäkokeesta. Kokeissa verrattiin yhtä suurien hienofosfaattina tai superfosfaattina annettujen fosforimäärien vaikutusta vilja- ja nurmikasvien satoihin kaikkiaan kymmenen koevuoden aikana. Vuosien 1954—60 tulokset on julkaistu aikaisemmin (Kaila ja Hänninen 1960 ja 1961).

Hyvässä kasvukunnossa olevalla multamaalla ei voitu todeta kummallakaan lannoitteella olleen mainittavaa jälkivaikutusta kolmeen kaurasatoon. Happamalla hietamaalla molempien fosfaattia saaneiden koejäsenten kuiva-ainesadon lisäykset sen sijaan olivat merkitsevät ja kulloinkin yhtä suuret sekä ensimmäisen vuoden kaurasadossa että toisen ja kolmannen vuoden nurmen heinäsadossa. Hienofosfaattia saaneen koejäsenen kauran olkien ja nurmiheinien matalampi fosforin pitoisuus johti kuitenkin merkitsevästi matalampiin fosforisatoihin verrattuna superfosfaatin tuottamiin, paitsi kolmantena vuonna, jolloin ero ei enää ollut tilastollisesti merkitsevä.

Tulosten tarkastelussa kiinnitettiin huomiota mm. apilan hyvään hienofosfaatin käyttökykyyn.