JOURNAL OF THE SCIENTIFIC AGRICULTURAL SOCIETY OF FINLAND
Maataloustieteellinen Aikakauskirja
Vol. 355–362, 1983

Effect of liming on phosphorus in two soils of different organic matter content

II Changes in the availability of phosphorus to turnip rape (*Brassica campestris*)

HELINÄ HARTIKAINEN

Department of Agricultural Chemistry, University of Helsinki, 00710 Helsinki 71

Abstract. The effect of calcitic limestone treatments on the availability of P to turnip rape was studied with two acid mineral soils of pH 4.8 ($CaCl_2$) in a pot experiment during two growing seasons. The soil reactions of a connected incubation test served to interpret the results obtained in the pot experiment.

The experimental soils represented soil types of dissimilar responses to liming in regard to P availability. In the muddy fine sand (3 % of org. C), initially poor in easily soluble P, liming enhanced plant growth as well as P uptake in the second year. However, in spite of intensified P removal, the final content of water- soluble P in the limed soils was not lower than in the unlimed ones. This was assumed to demonstrate an augmented availability of P.

Also in the fine sand soil (6.4 % of org. C), rich in water-soluble P, liming slightly improved growth of the second harvest in the pots not treated with P, but it did not affect P removal. In the pots amended with P, on the contrary, liming had no effect on the dry matter yields, but it tended to depress P withdrawal. Nevertheless, all the limed soils contained finally less water-soluble P than the unlimed ones, which suggests a diminished availability.

The results of the pot experiment demonstrate that a relatively low soil pH does not necessarily limit growth of turnip rape, provided no nutrient deficiency or metal toxicity occurs.

Introduction

The role and importance of pH control in plant production have been largely discussed and contested during the last few decades. Liming is conventionally used to reduce soil acidity and to improve growth conditions as well as the availability of some nutrients, e.g. phosphorus. The profitable effect on P uptake is attributed to many factors, e.g. an intensified mineralization of organic P compounds (SALONEN 1946, DORPH-PETERSEN 1953) or an increased solubility of secondary inorganic phosphate compounds (GHANI and ALEEM 1942). Since the introduction of the concept of ligand exchange, the action of lime is rather attributed to the competition between hydroxyl and phosphate ions for sorption sites.

In Finland, incubation experiments have shown the application of base to cause some redistribution of native P between various fractions assumed to represent different P compounds (KAILA 1961 and 1965, HARTIKAINEN 1981). These reactions are considered responsible for the increased solubility of P in water (HARTIKAINEN 1981), but there is no evidence of the relationship between them and the availability of P to plants.

In an incubation experiment with two soil samples carried out by HARTIKAINEN (1983), liming tended to enhance the solubility of P in one of the samples and to depress it in the other. The detrimental effect was observed in the soil rich in organic matter and seemed to be associated with the simultaneous reactions of soil Al. The purpose of the present study was to investigate the relevancy of the incubation test data by comparing them with the results of a connected pot experiment.

Materials and methods

The pot experiment was carried out in 1980 and 1981 with two mineral soil samples the characteristics of which are reported in a previous paper (HARTIKAINEN 1983). Mitscherlich pots were filled with 4.5 kg of moist soil corresponding to 3.9 kg of air-dried muddy fine sand and 3.6 kg of air-dried fine sand. The soils were treated with 0, 6, 12 or 24 g of $CaCO_3$ and plant nutrients were added as follows: 1000 mg N as NH_4NO_3, 200 mg Mg as $MgCl_2 \cdot 6H_2O$, 10 mg B as H_3BO_3, 15 mg Cu as $CuSO_4 \cdot 5H_2O$, 10 mg Mn as $MnSO_4 \cdot H_2O$, 10 mg Zn as $ZnSO_4 \cdot 7H_2O$, 5 mg Mo as $NaMoO_4 \cdot H_2O$. Half of the pots were amended with 400 mg of P, added as K_2HPO_4, corresponding to 104 mg and 114 mg per kg of the muddy fine sand and fine sand soil, respectively. The control pots received a corresponding quantity of K (1000 mg) as KCl. Liming as well as Mg and P treatments were performed only in the beginning of the experiment, but the other nutrients were added also in the second spring before sowing.

After nutrient treatment and liming, 20 seeds of turnip rape (*Brassica campestris* v. oleifera f. annua) were sown per pot. The experiment was carried out with four replicates. It has been described in more detail by JOKINEN (1982).

Plant analyses. The plant material, first dried at 60 °C and thereafter heated at 105 °C for two hours, was ground and digested with the acid mixture of $HClO_4$: H_2SO_4: HNO_3 in the ratio of 1: 2.5: 10 (SCHARRER and MUNK 1956). The P content in the filtered extract was determined by an ammonium vanadate method (JACKSON 1958).

Soil analyses. After cultivation, the content of soluble salts in soil solution was estimated by measuring the electrical conductivity of the clear supernatant solution from a water-soil suspension. Soil pH was measured in 0.01 M $CaCl_2$ solution. Water-soluble P was extracted by a slightly modified van der PAAUW (1971) and SISSINGH (1971) method and various P forms by a modified CHANG and JACKSON (1957) fractionation method.

Results

a) Dry matter yields

The dry matter yields in grams per kg of air-dried soil are given in Table 1. The data of both soils and years are tested separately. Without liming and

Table 1. Dry matter yields (g/kg of soil).

Lime added g/pot	Year 1980 –	Year 1980 P applied	Year 1981 –	Year 1981 P applied	Total –	Total P applied
			Muddy fine sand			
0	5.3^{a}	9.2^{bc}	1.3^{a}	4.4^{b}	6.6^{a}	13.6^{c}
6	6.1^{a}	10.0^{c}	3.4^{b}	6.5^{c}	9.5^{b}	16.5^{d}
12	6.0^{a}	11.3^{c}	3.4^{b}	6.7^{c}	9.4^{b}	18.0^{d}
24	6.5^{ab}	10.9^{c}	3.8^{b}	6.4^{c}	10.3^{b}	17.3^{d}
			Fine sand			
0	8.4^{ab}	10.1^{ab}	5.7^{a}	7.8^{cd}	14.1^{a}	17.9^{bc}
6	8.3^{ab}	10.7^{ab}	7.2^{bc}	8.7^{d}	15.5^{ab}	19.4^{d}
12	9.6^{ab}	11.0^{b}	6.4^{b}	8.3^{cd}	16.0^{abc}	19.3^{cd}
24	8.1^{a}	10.6^{ab}	6.4^{b}	8.9^{d}	14.5^{a}	19.5^{d}

P fertilization, the total yield of the fine sand soil sample was about twice that of the muddy fine sand sample.

The experimental soils differed in their responses to P treatment and liming. In the first year, P addition improved the growth of turnip rape in the muddy fine sand, but not in the fine sand soil of higher initial content of water-soluble P. A positive residual effect of P fertilization appeared in both soils, though, more markedly in the muddy fine sand sample.

The influence of $CaCO_3$ treatment on the dry matter yields could be verified only in the second year. In all the soils not receiving P, liming promoted plant growth but remained ineffective in the fine sand soils amended with K_2HPO_4 and had no influence on the total shoot yields of this sample.

The P content was lower in the shoots harvested from the muddy fine sand soil than in those harvested from the fine sand soil: without P addition, it ranged in the first yield 3.76–4.01 ‰ and 4.04–4.68 ‰, and in the second one 1.91–2.69 ‰ and 2.61–3.46 ‰, respectively. It was interesting to notice that in the fine sand soil the highest dosages of lime tended to diminish the P

Table 2. Amounts of P (mg/kg of soil) taken up by yields.

Lime added g/pot	Year 1980 –	Year 1980 P added	Year 1981 –	Year 1981 P added	Total –	Total P added
			Muddy fine sand			
0	19.4^{a}	41.7^{b}	3.4^{a}	16.1^{c}	22.8^{a}	57.8^{c}
6	24.7^{a}	42.3^{b}	8.4^{b}	20.2^{c}	33.1^{b}	62.5^{cd}
12	22.5^{a}	52.0^{b}	6.5^{ab}	19.1^{c}	29.0^{ab}	71.1^{d}
24	24.3^{a}	48.1^{b}	9.5^{b}	16.0^{c}	33.8^{b}	64.1^{cd}
			Fine sand			
0	38.5^{ab}	50.0^{bc}	20.1^{ab}	33.1^{e}	58.6^{a}	83.1^{c}
6	37.6^{ab}	53.5^{c}	23.0^{bc}	32.3^{de}	60.7^{ab}	85.8^{c}
12	39.7^{ab}	50.4^{bc}	17.4^{a}	29.1^{de}	57.0^{a}	79.5^{c}
24	33.0^{a}	45.5^{abc}	16.7^{a}	27.4^{cd}	49.7^{a}	72.9^{bc}

content. In the second year this depressive effect was reflected in the uptake of native P (Table 2) despite the slight improvement in the dry matter yields. However, partly because of a great variation between the replicates, the differences of the treatments often remained statistically insignificant. In the muddy fine sand soil, on the contrary, liming enhanced removal of native P along with increased dry matter harvests.

In most cases P fertilization raised P percentages only in the second harvests. As could be expected on the basis of dry matter yields, in the first year the P addition increased the P quantities taken up from the muddy fine sand sample, but did not affect equally significantly those removed from the fine sand soil. Nevertheless, the positive residual effect on the P uptake appeared distinctly also in the fine sand sample. The percentages of added P recovered in the shoots harvested were as follows:

$CaCO_3$ g	*Muddy fine sand*	*Fine sand*
0	*34*	*21*
6	*28*	*22*
12	*41*	*20*
24	*29*	*20*

The data suggest quite marked amounts of applied P to have been immobilized by root material or retained by various soil components. This surplus was greater in the fine sand soil in which liming did not affect the supply of added P to turnip rape. On the other hand, in the muddy fine sand sample the medium dosage of $CaCO_3$ (12 g/pot) seemed most favourably to promote utilization of this P source.

b) Soil analyses

For further information about the effect of liming, the soil samples were analyzed for inorganic P. In addition, some other indicative analyses were performed. In the pot experiment, $CaCO_3$ neutralized the soil acidity to the same rate as in the incubation test described earlier (HARTIKAINEN 1983), but cultivation tended further to raise pH by 0–0.2 and 0.2–0.4 pH units in the muddy fine sand and fine sand, respectively. This was probably due to a marked decrease in salt concentration of the soil solution, indicated by a lowered electrical conductivity (about 31–91 %). The decrease seemed to be more considerable in the limed soils.

The lime-induced reduction in soil acidity hardly increased the final P intensity, as determined by water extraction. The results reported in Table 3 show the water-soluble P in the fine sand soil to have been even lowered. This is unexpected, because in this soil the P uptake by the turnip rape was not enhanced: it rather tended to be reduced as liming was intensified. Further, as stated above, the salt concentration in the soil solution decreased simultaneously, which in most soils is known to enhance the extractability of soil P into water. On the other hand, in the muddy fine sand soil, liming did not decrease the final water-soluble P, even if the uptake of this nutrient was significantly augmented.

Table 3. Water-soluble P (mg/kg) in soils after cultivation.

Lime added	Muddy fine sand		Fine sand	
g/pot	–	P applied	–	P applied
0	5.9[a]	11.7[c]	27.5[c]	38.1[g]
6	5.1[a]	11.4[bc]	24.1[b]	35.6[f]
12	5.6[a]	10.5[b]	23.1[b]	32.8[e]
24	5.9[a]	12.1[c]	20.5[a]	29.6[d]

Changes in native P during the cultivation were investigated by the CHANG and JACKSON fractionation method, comparing the differences between a given fraction in the cultivated and uncultivated samples (Table 4). The differences between the P fractions in the samples treated and those not treated with K_2HPO_4 were assumed to represent the accumulation of residual applied P. It can be concluded from the data in Tables 2 and 4 that the quantities removed by shoot harvests are generally lower than the total depletion in the fractions. This is partly attributable to the immobilization of P in the root material.

Table 4. Changes caused by cultivation in native P fractions (a) and recovery of residual added P in various forms (b) as mg/kg.

Lime added		P extracted sequentially by				
g/pot		NH_4Cl	NH_4F	NaOH	H_2SO_4	$\sum$
			Muddy fine sand			
0	a	0	–9	–5	–9	–23
	b	1	24**	29**	5	59
6	a	–1***	–19*	–22**	0	–42
	b	1***	24***	21**	2	48
12	a	–2***	–19*	–32**	–4	–57
	b	0	15*	22*	5	42
24	a	–1***	–15*	–33**	10	–39
	b	2***	26***	13*	2	43
			Fine sand			
0	a	–1*	–37***	–5	–11*	–54
	b	1*	33**	29*	14	77
6	a	–3**	–53***	–7	–1	–64
	b	2*	53***	21*	–8	68
12	a	–4***	–41***	–16**	–6	–67
	b	3***	51***	30***	7	91
24	a	–3***	–29***	–36***	4	–64
	b	3***	49**	30***	–1	81

The results in Table 4 imply that intensified liming decreased native NaOH-P more and NH_4F-P less in the muddy fine sand than in the fine sand. It is noteworthy that in all the limed fine sand soils the total depletion was of about the same magnitude, which is contradictory to what could be expected on the basis of the final water-soluble P.

The recovery of applied P in the shoots and soil P fractions amounted to 71–90 % and 82–99 % in the muddy fine sand and fine sand soil, respectively. As expected, greater amounts of residual added P were extracted from the fine sand soil in general than from the muddy fine sand. Table 4 shows liming to increase the enrichment of applied P in the former soil sample and to decrease it in the latter. These results seemed to be attributed to an enhanced accumulation in the NH_4F soluble fraction in the fine sand and to a reduced accumulation in the NaOH soluble one in the muddy fine sand. In the unlimed fine sand soils, also H_2SO_4-P seemed somewhat to increase.

Discussion

Phosphorus seemed to be a growth-limiting factor in the muddy fine sand soil. In the fine sand soil, on the contrary, the P reserves accumulated during the intensive sugar beet cultivation were nearly sufficient to satisfy the requirements of the first turnip rape harvest. The positive residual effect of applied P also in this sample suggests, however, P uptake later to have reduced the P supplying power.

In spite of increased harvests and P uptake, the final intensity of native P in the limed muddy fine sand soils was not lower than in the unlimed ones, which suggests liming to have rendered native soil P better available to turnip rape. This is in accordance with the increase in the water-extractable P in the coexistent incubation test (HARTIKAINEN 1983). The result gives, in turn, reason to infer that in the P deficient muddy fine sand the improved availability of soil P reserves was responsible for the more abundant shoot yields in the limed pots. The retarded effect of liming is due to the slow solubility of $CaCO_3$. It can be ascribed also to the fact that a raised pH affects the P solubility the more favourably the poorer the soil is in this nutrient (HARTIKAINEN 1981). The conditions prevailing in the second growth period better complied with this qualification.

In the muddy fine sand pots amended with P, the $CaCO_3$ treatment seemed to ameliorate growth conditions other than P supply. However, the medium lime dosage appeared somewhat to advance the total withdrawal of applied P. The remaining water-soluble P being a little lower in this treatment is in agreement with the effective P utilization by plants. Evidently, the moderate liming was sufficient to promote P uptake but not too heavy to cause some disbalance between the different nutrients.

On the other hand, in the fine sand soils not treated with P, liming improved plant growth without affecting P removal. In the soils amended with P, the highest dosage of $CaCO_3$ even markedly reduced the P uptake. Nevertheless, the final water-soluble P was significantly reduced in all the limed treatments, indicating a diminished availability. The indicative incubation test (HARTIKAINEN 1983) showed a similar decrease in the P solubility in the limed soils. These results lead to conclude that also in the fine sand soil not treated with P liming improved other factors than P supplying power.

Nowadays, Al toxicity is considered an important factor contributing to the infertility of acid soils (e.g. EVANS and KAMPRATH 1970). The lime-induced drop in the exchangeable Al found in the connected incubation experiment (HARTIKAINEN 1983) may have some profitable effect on the growth of turnip rape. The improved growth appeared, however, only in the second growth period, even though plenty of exchangeable Al was neutralized already during the first season. The retarded effect suggests that the impoverishment in P status owing to plant uptake reinforced the influence of Al stress. Further, the incubation test showed the application of basic K_2HPO_4 to have lowered the level of exchangeable Al in both experimental soils. Hence, the P treatment may have substituted or masked the influence of liming on the growth of turnip rape.

The fractionation analysis data agreed with those of plant analyses and the incubation test (HARTIKAINEN 1983). In the muddy fine sand, liming tended to increase the exhaustion of native P, especially NaOH-P, and to decrease the accumulation of applied P. In the fine sand, on the contrary, it promoted the enrichment of added P, but less in the H_2SO_4 fraction than in the incubation experiment.

According to general knowledge, liming augments P uptake from soil. However, a soil type of dissimilar response, e.g. the fine sand in the present study, is not necessarily very exceptional. As concluded in earlier studies (HARTIKAINEN 1981 and 1983), the changes in P solubility due to increasing pH are a net result of processes enhancing desorption and of those promoting sorption. Yet, it is possible that under field conditions the difference between the experimental soils would not have been as distinct. For instance, in the field trials of JAAKKOLA et al. (1977), it was difficult to determine with certainty the effect of liming on P fertilization requirement. The basal dressing of fertilizers raises the utilization degree and may partly impair the efficiency of lime. On the other hand, the results of the present study and the experience obtained in the sugar beet cultivation on the fine sand block (see HARTIKAINEN 1983) demonstrate that a relative low soil pH does not necessarily limit the growth of even pretentious plant species, provided no nutrient deficiency or metal toxicity occurs.

References

CHANG, S. C. & JACKSON, M. L. 1957. Fractionation of phosphorus. Soil Sci. 84: 133–144.

DORPH-PETERSEN, K. 1953. Kalkningens virkning på sure jorders fosfattilstand. Tidssk. f. Planteavl. 50: 653–675.

EVANS, C. E. & KAMPRATH, E. J. 1970. Lime response as related to percent Al saturation, solution Al, and organic matter content. Soil Sci. Soc. Amer. Proc. 34: 893–896.

GHANI, M. O. & ALEEM, S. A. 1942. Effect of liming on the transformation of phosphorus in acid soils. Indian J. Agric. Sci. 12: 873–882.

HARTIKAINEN, H. 1981. Effect of decreasing acidity on the extractability of inorganic soil phosphorus. J. Scient. Agric. Soc. Finl. 53: 16–26.
— 1983. Effect of liming on phosphorus in two soils of different organic matter content. I Changes of native and applied phosphorus in incubation experiment. J. Scient. Agric. Soc. Finl. 55: 345–354.
JAAKKOLA, A., HAKKOLA, H., KÖYLIJÄRVI, J. & SIMOJOKI, P. 1977. Effect of liming on phosphorus fertilizer requirement in cereals and ley. Ann. Agric. Fenn. 16: 207–219.
JACKSON, M. L. 1958. Soil chemical analysis. 498 p. London.
JOKINEN, R. 1982. The efficiency of dolomitic limestone, basic slag and peat ash as liming agents, and as calcium and magnesium sources for turnip rape. J. Scient. Agric. soc. Finl. 54: 371–383.
KAILA, A. 1961. Effect of incubation and liming on the phosphorus fractions in soil. J. Scient. Agric. Soc. Finl. 33: 185–193.
— 1965. Some phosphorus test values and fractions of inorganic phosphorus in soils. J. Scient. Agric. Soc. Finl. 37: 175–185.
PAAUW, F. van der, 1971. An effective water extraction method for the determination of plant-available soil phosphorus. Plant and Soil 34: 467–481.
SALONEN, M. 1946. Kalkituksen vaikutuksista maaperän orgaaniseen ja helppoliukoiseen fosforiin. J. Scient. Agric. Soc. Finl. 18: 1–10.
SCHARRER, K. & MUNK, H. 1956. Zur Methodik der nassen Veraschung in der agrikulturchemischen Analyse. Agrochimica 1: 44–55.
SISSINGH, H. A. 1971. Analytical technique of Pw method, used for the assesment of the phosphate status of arable soils in the Netherlands. Plant and Soil 34: 483–486.

Ms received May 6, 1983

SELOSTUS

Kalkituksen vaikutus fosforiin kahdessa erityyppisessä hietamaassa

II Muutokset fosforin käyttökelpoisuudessa rypsille (*Brassica campestris*)

Helinä Hartikainen
Helsingin yliopiston maanviljelyskemian laitos, 00710 Helsinki 71

Kaksi kasvukautta kestäneessä astiakokeessa selvitettiin kalsiittikalkin vaikutusta fosforin käyttökelpoisuuteen kahdessa happamassa maanäytteessä (pH $_{CaCl_2}$ 4.8). Rypsillä tehdyn kasvatuskokeen tuloksia vertailtiin vastaavanlaisessa muhituskokeessa saatuihin.

Kalkitus vaikutti eri tavalla koemaiden fosforin käyttökelpoisuuteen, mutta vasta toisena kasvukautena. Vähän helppoliukoista fosforia sisältäneessä liejuisessa hiedassa kalkitus edisti rypsin kasvua sekä fosforin ottoa. Huolimatta tehostuneesta fosforin otosta kalkitut maat sisälsivät kokeen lopussa yhtä paljon vesiliukoista fosforia kuin kalkitsemattomat maat, minkä katsottiin osoittavan, että kalkitus paransi fosforin käyttökelpoisuutta.

Runsaasti vesiliukoista fosforia sisältäneessä karkeassa hiedassa kalkitus nosti jonkin verran satoja, mutta ei niiden ottamia fosforin määriä koejäsenissä, joita ei lannoitettu fosforilla. Sitä vastoin fosforilla lannoitetuissa koejäsenissä kalkitus ei vaikuttanut kuiva-ainesatoihin, mutta pyrki alentamaan fosforin hyväksikäyttöä. Koska kaikki kalkitut maat sisälsivät kuitenkin kokeen lopussa vähemmän vesiliukoista fosforia kuin kalkitsemattomat, tulos viittaa alentuneeseen fosforin käyttökelpoisuuteen.

Muhituskokeen tuloksia, jotka olivat samansuuntaisia kasvatuskokeessa saatujen kanssa, käytettiin hyväksi kalkituksen vaikutusmekanismin tulkinnassa.