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THE ROLE OF ROOT PROPERTIES AND ORGANIC MATTER ON MOBILIZATION OF SOIL P AND ROCK PHOSPHATES

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ABSTRACT

Amberger, A., 1991. The role of root properties and organic matter on mobilization of soil P and rock phosphates.

Root properties have a high influence on mobilization of rock phosphates. These are root surface and density, symbiosis with mycorrhiza, exudation of exoenzymes, chelating and reducing substances and high Ca demand. However the most effective property is the acidification of rhizosphere by excretion of protons. This is very known for legumes but can also be achieved by mineral NH_4^+ nutrition.

There is also an indirect but much less effect of soil organic matter or organic fertilizers, which acts principally in the same way.

Another possibility is to compost rock phosphates with organic waste material like straw or molasses.

INTRODUCTION

Rock phosphates (RPs) consist of different types of apatite. As higher the rate of hydroxyl and carbonate apatite and therefore the "activity" (determined in 2% citric or formic acid) is ("soft" rock phosphates) as more these phosphates are suitable for direct application without chemical process presumably on more or less acid soils. The pH-influence on the solubility of phosphates corresponds theoretically with the formula:

$$Ca_{10}(PO_4)_6F_2(2\ OH^-,\ CO_3^{2-}) + 12\ H^+ \longrightarrow 10\ Ca^{2+} + 6\ H_2PO_4^{2-} \quad (1)$$
$$+\ 2\ F^-(2\ OH^-,\ CO_3^-)$$

From this equation follows, that the dissolution rate depends on the concentration of protons (H^+) and the reaction products Ca^{2+} and $H_2PO_4^-$ in soil solution closely around the phosphate particles. Among the various factors pH has the greatest effect on RPs dissolution.

1 ROOT PROPERTIES AND ROCK PHOSPHATE MOBILIZATION

Plants themselves are able to mobilize soil P and "soft" RPs in the rhizosphere directly via specific root properties (Curl et Truelove, 1968).

1.1 As the magnitude of P release depends on the diffusion process, with increasing surface and density of root hairs the distance between root surface and phosphate particles in the rhizospere decreases and the direct contact increases. There are great differences among the plants in phosphate efficiency (Amann et Amberger, 1989; Claassen, 1990). The "active root surface", which is responsible for the uptake of nutrients, is defined by the root plasmalemma. Among other methods it can be determined by eosin-5-maleinimide as a colouring substance (Bauschmid, 1990). Fig. 1 demonstrates, that on the basis of root fresh weight the active root surface of wheat is nearly double of maize which is in accordance with a much higher ability to utilize RPs.

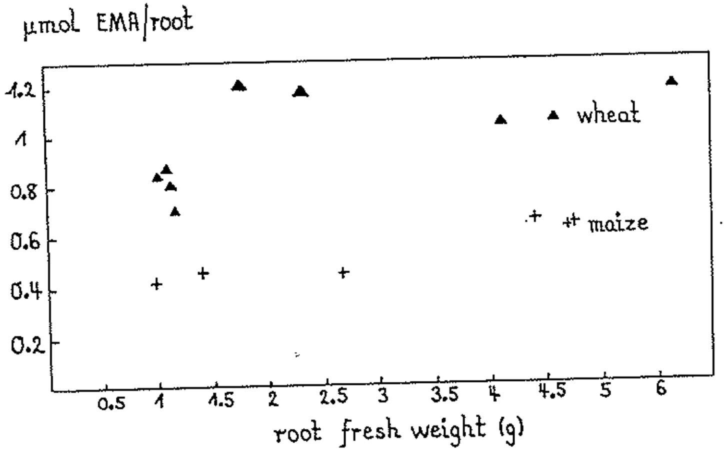


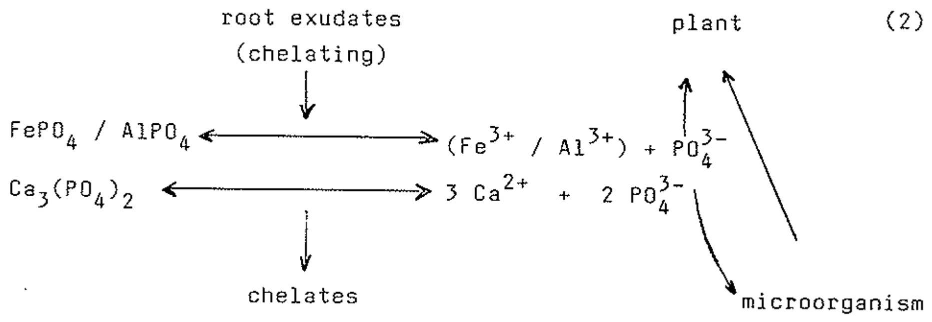
Fig. 1. Eosin-5-maleinimide labelled active maize and wheat roots (Bauschmid)

Some plant families (proteaceae and fabaceae) produce, especially under P-stress, characteristic forms of root hairs (dense bunches), so called root proteids (Purnell, 1960), by which the active root surface will also be markebly increased.

1.2 Another possibility is the symbiosis of roots with mycorrhiza (Crul and Truelove, 1986), which again means an increase of active root surface. This phenomenon can be very effective especially with subtropical shrubs or trees.

1.3 Root hairs and proteids are known to exudate enzymes (phosphatase etc.) (Amann et Amberger, 1989; Helal et Saurbeck, 1984; Helal et Sauerbeck, 1988; Helal et Dressler, 1989) especially under P deficiency stress as a consequence of increased membrane permeability along with a decreased activity of membrane protecting enzymes like superoxidedismutase.

1.4 Roots can exudate also chelating substances (Amann et Amberger, 1989) like citrate, malate or amino acids, which are able to build up Fe or Ca complexes resulting in a deliberation of phosphate ions.



(2)

The stability of such chelating substances is different: citrate > tartrate > malate.

Also reducing substances f.i. sugars or the microbially very stable phenols chlorogenic and caffeic acids are mainly produced under P stress (Hengeler, 1990) and act in the same way (Fig. 2).

1.5 Some plants have a high demand of calcium f.i. rape which can be satisfied from Ca^{2+} as reaction products of rock phosphates along with proton excretion, which improves the dissolution of apatites (Bekele et al., 1983; Hoffland et al., 1989).

1.6 However the most important and effective property of roots on mobilization of rock phosphates is to acidify the rhizosphere by the excretion of protons. This mechanism is very known for legumes (Mengel et Steffens, 1982) in exchange of NH_4^+-uptake produced by microbial N fixation (Fig. 3).

After seven cuts of clover the original soil pH dropped from 7.0 to 4.3 whereas ryegrass did not influence the pH.

In Mitscherlich experiments we proved the effect of increased proton release on RP mobilization with red clover (Table 1).

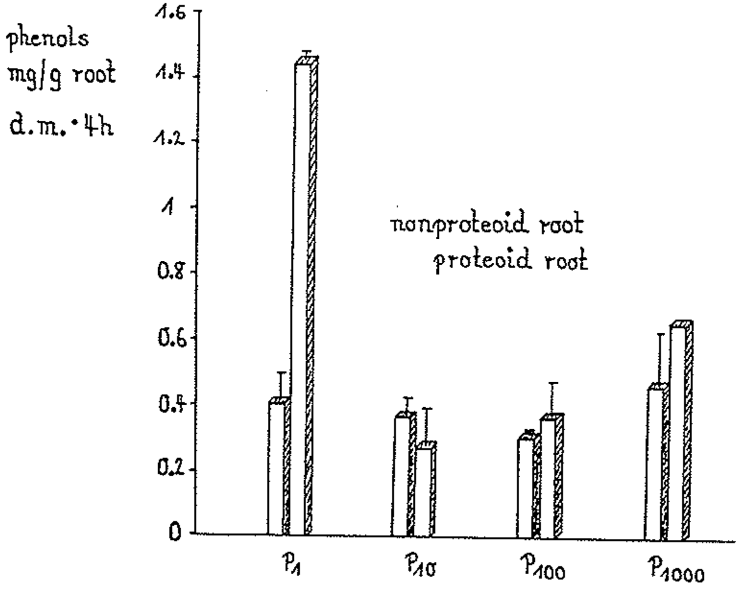


Fig. 2. Phenol release into 0.1 mM $CaSO_4$-solution from isolated proteoid and nonproteoid roots of lupinus albus (24 d old) (Hengeler)

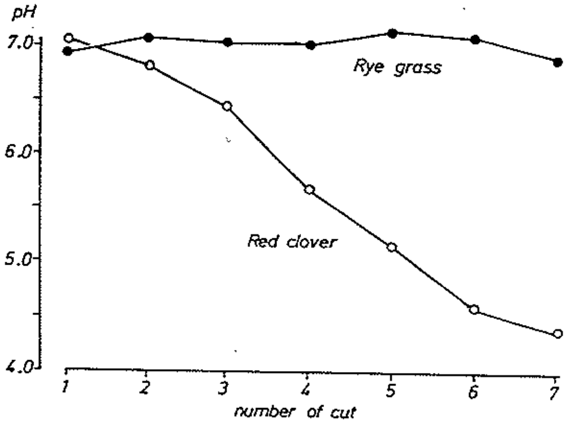


Fig. 3. Soil pH under red clover and rye grass during the experimental period (Mengel and Steffens)

TABLE 1

Total P uptake (5 cuts) of red clover and pH values (in soil) at the end of the experiment (Bauschmid)

fertilisation	P uptake (mg P/pot)	Ca uptake (mg Ca/pot)	pH values
hyperphos	399	2197	4.6
basic slag	395	2396	4.8
superphosphate	356	2138	4.4
$LSD_{5\%}$	24	164	orig. 6.0

After five cuts the pH decreased from 6.0 by 1.5 units and total P uptake from hyperphos (a "soft" rock phosphate) was equal to basic slag.

Hyperphos mobilization could also be realized by mineral NH_4^+ nutrition (as $(NH_4)_2SO_4$) especially when intensified by the addition of the nitrification inhibitor dicyandiamide (DCD), which prolongs the NH_4^+ phase in the soil and therefore improves NH_4^+ uptake in exchange for proton release for charge equilibration in the roots (Fig. 4).

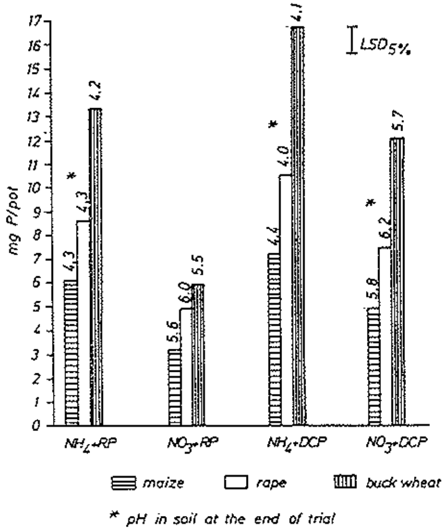


Fig. 4. P uptake by different crops with NH_4-resp. NO_3-nutrition
Soil: pH 5.4 Fertilisation: 30 mg P/pot (300 g soil)
(Bauschmid)

In a Neubauer experiment with $(NH_4)_2SO_4$ + DCD the pH was lowered from 5.4 to 4.3 P uptake of all crops was much higher compared with NO_3^- nutrition and came very near to dicalciumphosphate.

Similar results we got in a Mitscherlich experiment with wheat and maize (Table 2). NH_4^+ nutrition resulted again in much higher P uptake (without any difference between hyperphos and basic slag) and lower pH compared with NO_3^- nutrition and pH increase.

TABLE 2

Total P uptake and pH values in rhizosphere soil of wheat and maize (Bauschmid)

fertil.	P uptake (mg P/pot)		pH values wheat		pH values maize	
	$Ca(NO_3)_2$	$(NH_4)_2SO_4$ + DCD	$Ca(NO_3)_2$	$(NH_4)_2SO_4$ + DCD	$Ca(NO_3)_2$	$(NH_4)_2SO_4$ + DCD
hyperphos.	193	317	6.4	4.5	7.0	4.2
basic slag	264	305	6.6	4.6	7.3	4.4
superphosph.	259	271	6.5	4.3	7.0	4.0
$LSD_{5\%}$		12		original 6.0		

The acidifying effect of ammonium sulphate (AS) can be improved by cogranulation of RP and AS. In this experiment with mustard and ryegrass hyperphos achieved eaven a higher total P uptake than dicalciumphosphate (Table 3).

TABLE 3

P uptake of mustard and rye grass from hyperphos-$(NH_4)_2SO_4$ granulates. pH values in soil after the main crop (Bauschmid)

fertilisation	P uptake (mg P/pot) mustard	rye grass	Σ		pH values
$(NH_4)_2SO_4$ + hyperphos	110.1	60.4	170.5		5.03
dicalciumphosphate	88.4	67.4	155.8		5.65
control	58.5	47.9	106.4		5.33
$LSD_{5\%}$	11.2	4.1		orig.	6.00

All these possibilities demonstrate an active influence of plant roots on mobilization of RPs in the rhizosphere.

2 EFFECT OF ORGANIC MATTER ON PHOSPHATE MOBILIZATION

Compared with these strong direct effect of roots there is also a more indirect influence of soil organic matter or organic fertilizers which act principally in the same way but much less effectively.

2.1 Generally speaking a high biological activity in the upper zone of soil increases decomposition of organic material and produces organic acids, which can desorb phosphates from Fe/Al oxides/hydroxides, reducing and chelating substances and protons. Microorganisms release also exoenzymes (f.i. alkaline phosphatase) resulting in decomposition of organic phosphates. However microorganisms themselves compete also with roots on the released phosphates expecially from organic matter poor in P (f.i. straw).

2.2 However the concentration of reducing and chelating substances in the upper soil layer is much lower compared with the zone very close to the roots (rhizosphere) and therefore these substances will be decomposed much quicker. Similarly the effect of applied organic fertilizers is lower what the mobilization of RPs concerns. However the release of phosphate from added organic material itself (f.i. manure) will be definitely improved by an increased microbial phosphatase activity. These are finally the reasons why the positive effect of organic material on P mobilization is very often not so obvious (Amann et Amberger, 1984; Amann et Amberger, 1988).

3 PHOSPHATE MOBILIZATION BY COMPOSTING WITH ORGANIC MATERIAL

Composting organic material with rock phosphates is also a possibility for P mobilization. In pot experiments hyperphos composted with straw achieved highest dry matter production (v. Tucher, 1990) compared with only a mixture of hyperphos and straw (Table 4).

TABLE 4

Pot experiments with hyperphos-straw-compost (v. Tucher)
Soil: pH 5.4   4 cuts of ryegrass and oats
0.3 g P/pot as hyperphos resp. hyperphos-compost

	total d.m. (g/pot)
soil alone	78.7
soil + compost	98.1
soil + hyperphos	91.5
soil + hyperphos + compost	109.1
soil + hyperphos - compost	141.8

In another compost experiment (Singh et Amberger, 1990) the P retention in humic substances from rock phosphate straw compost was very much increased when molasses was added to the composting process (Table 5).

TABLE 5

Percent P in humic substance (humic and fulvic acids) produced from 1 g straw during composting

treatment	average P (ug/g)	increase over control (%)
wheat straw (control)	198	---
+ mussoorie phos	515	160
+ mussoorie + molasses	620	213
+ hyperphos	500	152
+ hyperphos + molasses	590	197

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