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Factors affecting phosphate availability in soil

ABDULLAH M. AL-FALIH

Department of Science (Biology), Teachers College in Riyadh, P.O. Box 4341, Riyadh 11491, Saudi Arabia.

ABSTRACT

The influence of serial concentrations of salts (0.5, 1.0 and 1.5%), various amounts of calcium phosphate (0, 50, 100 and 200 mg P/kg soil), application of organic matter (0.5, 1.0 and 1.5% of wheat straw), varying soil moisture contents (25, 50, 75 and 100%) and different incubation temperatures (5, 15, 25, 35°C) on phosphate availability in a sandy clay soil was studied. Increased salinity reduced phosphate availability. Addition of phosphate fertilizer and organic matter enhanced phosphate solubilization processes. The amount of phosphate solubilized increased progressively with time at 75% water holding capacity (WHC). The optimum temperature for phosphate availability was 25°C.

INTRODUCTION

Phosphorus is second only to nitrogen as an inorganic nutrient required by plants and microorganisms, being important in the accumulation and release of energy during cell metabolism (Alexander 1977). Phosphorus transformations in soil are integral parts of the overall phosphorus cycle in nature. Phosphorus is an essential element in all living systems and often also a limiting mineral nutrient in plant nutrition and plant production. Microbial activity in the soil is important in the cycling of phosphorus and organic matter decomposition (Kucey *et al.* 1989).

A wide variety of heterotrophic fungi have been shown to be capable of solubilizing insoluble forms of organic and mineral phosphorus (Alexander 1977, Atlas & Bartha 1993, Killham 1994). Certain fungi and heterotrophic bacteria also have a role to play in phosphate solubilization. Microorganisms (fungi, yeast and bacteria) can solubilize insoluble phosphate. Phosphate solubilizing microorganisms (fungi, yeasts and bacteria) including species of *Pseudomonas*, *Mycobacterium*, *Micrococcus*, *Bacillus*, *Flavobacterium*, *Penicillium*, *Sclerotium*, *Fusarium*, *Aspergillus*, *Williopsis*, *Saccharomyces* and others are active in the conversion (Alexander 1977, Al-Falih & Wainwright 1995). These bacteria and fungi can grow in media with $Ca_3(PO_4)_2$, apatite, or similar slowly soluble materials as sole phosphate sources. This process appears to involve the production of organic acids and/or chelating agents (Wainwright 1981, Ali *et al.* 1986, Xie & Mackenzic 1988).

Soluble phosphates are present in most soils in only small concentrations, and thereby may limit plant growth. Microbial mobilization of phosphates therefore, is an important factor in plant nutrition. Because of the insolubility of the major phosphorus compounds, phosphorus is often the most important factor which limits plant productivity. Phosphorus transformations in soil are governed by various environmental factors, including moisture, salinity and organic matter (Ramirez-Martinez & McLaren 1966, Killham 1994, Al-Falih & Wainwright 1996).

The present investigation based on a laboratory experiment which extended to four months, was undertaken to study the biochemical transformation of soil phosphorus as influenced by moisture, salinity, incubation temperature, amount of phosphate fertilizer added and organic matter.

MATERIALS AND METHODS

Collection and analysis of soil samples

Samples of cultivated soil were collected in sterile polyethylene bags from the upper layer (0–20 cm) from Riyadh area, Saudi Arabia. Analyses of soil samples were carried out according to the methods given by Jackson (1962). A soil with a sandy clay texture containing 56.4% sand, 6.1% silt, 37.5% clay, 7.5% $CaCO_3$, 0.34% organic carbon, 0.045% total nitrogen, 17 μg/g nitrate-nitrogen, 27 μg/g ammonium-nitrogen, C/N ratio of 8.3, pH of 7.8 and total soluble salts (T.S.S.) 0.083% was used in this study.

Determination of phosphate availability

Soil samples were amended with either calcium phosphate, salts or wheat straw in order to determine the effect of amount of phosphate fertilizer, salinity, incubation temperature and organic matter on the process of phosphate solubilization in soil. Serial concentrations of salts (0.0, 0.5, 1.0 and 1.5%), various amount of calcium phosphate (0, 50, 100, 200 mg P/kg soil) and different rates of wheat straw (0.0, 0.5, 1.0 and 1.5%) were used. The soil moisture content was kept constant at 25, 50, 75 and 100% of the water holding capacity (WHC). The soil samples were incubated in polythene bags closed with a small hole to allow for gas exchange. The bags were set up in triplicate and incubated at 5, 15, 25 and 35°C for 4 months.

To study the effect of salinity, organic matter, soil moisture and incubation temperature on phosphate availability, 100 mg of calcium phosphate/kg soil was added to each soil sample.

Phosphate was extracted from soil using 0.5N $NaHCO_3$. The soil extractant ratio used was 1:10 and the slurry was shaken for 15 mins (100 throws min^{-1}). After being shaken, the soil slurries were filtered through Whatman No. 1 filter paper and the concentration of phosphate was determined colorimetrically according to Hesse (1971).

Population of phosphate-solubilizing bacteria

Populations of phosphate-solubilizing bacteria were counted on a standard medium containing 1.5% agar, 0.4% hydroxyapatite and 60 ppm cyclohexamide by a plate count method (Wollum 1982). The phosphate-solubilizing bacteria solubilized hydroxyapatite and made clear zones on the agar medium.

RESULTS AND DISCUSSION

Bashour *et al.* (1985) suggests that the factors which control the availability of phosphate can be summarised by organic matter, $CaCO_3$ content, soil pH, soil moisture content, clay content, salinity and microorganisms population. Phosphorus availability in calcareous soils is low despite frequent phosphate applications. A significant correlation between phosphorus availability and some properties of Saudi calcareous soils, such as soil pH and calcium carbonate, was reported recently (Al-Sewailem 1997).

Table 1 indicates the changes in phosphate-solubilizing bacteria counts as affected by salinity, phosphate fertilizer, wheat straw, moisture and temperature. The numbers of phosphate- solubilizing bacteria were decreased by increased salinity and were highly inhibited at 1.0% and 1.5% salinity. The impact of salt on phosphate-solubilizing bacteria was pronounced at levels of 1 % salt or greater, indicating that phosphate solubilizing bacteria are sensitive to high concentrations of salt. Similar results were reported earlier by Ramirez-Martinez & McLaren (1966) and Killham (1994).

As shown in Table 1, there were significant increases in phosphate-solubilizing bacterial counts following addition of increasing amounts of phosphate fertilizer and wheat straw. Similar trends were observed by other workers (Ali *et al.* 1986, Kucey *et al.* 1989, Kim *et al.* 1998).

The optimum moisture content for phosphate-solubilizing bacterial counts was found to be 75% WHC due to growth and proliferation of aerobic and facultatively anaerobic phosphate-solubilizing bacteria when adequate moisture and oxygen supply were present. Both the 25 and 50% WHC retarded growth of the bacterial

Table 1. Changes in phosphate-solubilizing bacterial counts ($\times 10^3$/g) as affected by salinity, calcium phosphate, wheat straw, moisture and temperature. (± Standard Deviation)

		Time in months			
Treatment		1	2	3	4
Salt (%)	0.0	21 ± 3.2	24 ± 2.5	25 ± 3.3	31 ± 1.5
	0.5	16 ± 1.9	19 ± 7.9	22 ± 4.1	26 ± 1.4
	1.0	9 ± 2.8	5 ± 2.3	7 ± 9.0	9 ± 2.0
	1.5	7 ± 3.6	5 ± 5.7	5 ± 4.8	8 ± 2.1
$Ca_3(PO_4)_2$ (mg/kg)	0	16 ± 2.3	23 ± 4.7	23 ± 1.3	25 ± 1.2
	50	21 ± 3.4	27 ± 5.8	39 ± 2.8	36 ± 1.9
	100	34 ± 5.6	38 ± 9.0	41 ± 6.0	49 ± 2.4
	200	42 ± 9.0	55 ± 4.1	57 ± 1.3	58 ± 3.6
Straw (%)	0.0	19 ± 3.2	24 ± 2.5	22 ± 3.8	30 ± 3.2
	0.5	76 ± 1.9	90 ± 7.9	92 ± 5.1	96 ± 1.0
	1.0	109 ± 1.1	125 ± 2.3	130 ± 2.0	139 ± 2.3
	1.5	138 ± 3.0	155 ± 5.7	185 ± 2.8	228 ± 4.1
Moisture (%)	25	6 ± 2.3	6 ± 4.7	4 ± 1.3	6 ± 3.4
	50	11 ± 3.4	17 ± 5.8	19 ± 5.8	16 ± 1.0
	75	24 ± 5.6	38 ± 9.0	41 ± 6.0	69 ± 2.8
	100	2 ± 9.0	5 ± 4.1	7 ± 1.3	8 ± 3.6
Temperature (°C)	5	6 ± 2.3	6 ± 4.7	5 ± 1.3	7 ± 2.2
	15	12 ± 3.4	12 ± 5.8	17 ± 5.8	18 ± 1.0
	25	14 ± 5.7	18 ± 9.0	21 ± 6.0	39 ± 2.8
	35	22 ± 9.0	35 ± 4.1	47 ± 1.3	64 ± 3.1

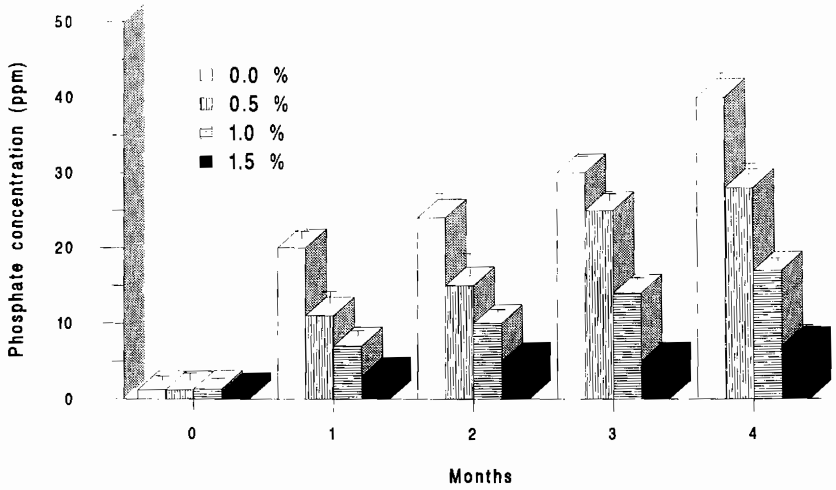

Fig. 1. Phosphate concentration (ppm) in soil amended with serial percentage of salts, all values are means of triplicates ±SD; $P < 0.05$. (100 mg Ca phosphate/kg soil was added.)

populations. The highest moisture content (100% WHC) limited oxygen diffusion in soil, and hence suppressed aerobic phosphate-solubilizing bacterial counts. This agrees with the findings of Ramirez-Martinez & McLaren (1966) and Atlas & Bartha (1993).

Available phosphate in soil as affected by serial concentrations of salts is shown in Fig. 1. The data show that solubilization of phosphorus was progressively decreased by increased salinity. Addition of P fertilizer to the control soil (no salinity) produced the maximum phosphate availability (42 ppm) at the end of incubation period. The phosphate solubilization rate progressively decreased from the lowest salt concentration of 0.5% to the highest concentration of 1.5% during the 4 months of incubation. The final phosphate concentrations of the soil samples were 28, 17 and 6.4 ppm after addition of 0.5, 1.0 and 1.5% salt, respectively. The decline in phosphate availability correlated with the marked inhibition of phosphate-solubilizing bacterial counts caused by salinity.

The effect of addition of various amounts of calcium phosphate on phosphate availability is given in Fig. 2. In all control samples the phosphate concentration ranged from 0.7 ppm to 3.0 ppm In the present study, soil samples amended with P fertilizer had a high concentrations of phosphate compared with unamended soils (control). However, phosphorus availability increased as the amount of calcium phosphate fertilizer increased. After four months of incubation the soil samples exhibited 28, 40 and 57 ppm of available phosphate following the supplementation of 50, 100 and 200 ppm of P fertilizer respectively. The maximum level of available phosphate occurred in soil amended with 200 ppm of calcium phosphate which also showed the highest population of phosphate-solubilizing bacteria. A similar relationship between phosphate-solubilizing bacterial counts and phosphate availability in the soil was reported by Kim *et al.* (1998).

Changes in the concentrations of phosphate as affected by organic matter (wheat straw) application are shown in Fig. 3. The addition of organic matter to soils

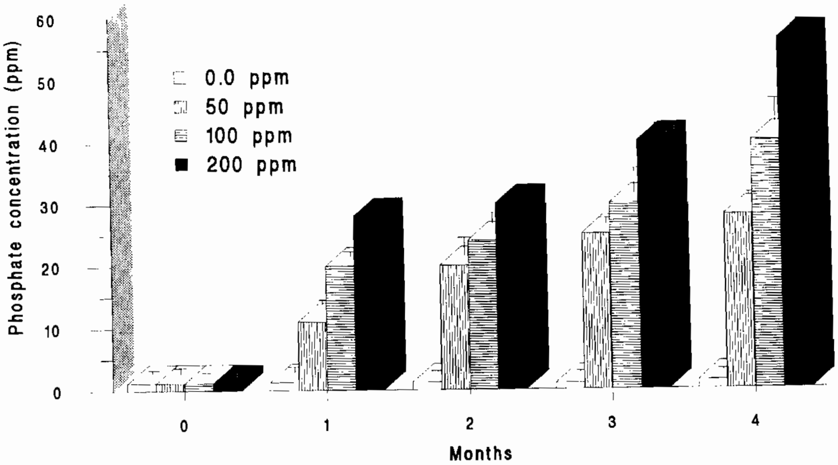

Fig. 2. Phosphate concentration (ppm) in soil amended with various amount of calcium phosphate, all values are means of triplicates ±SD; $P < 0.05$.

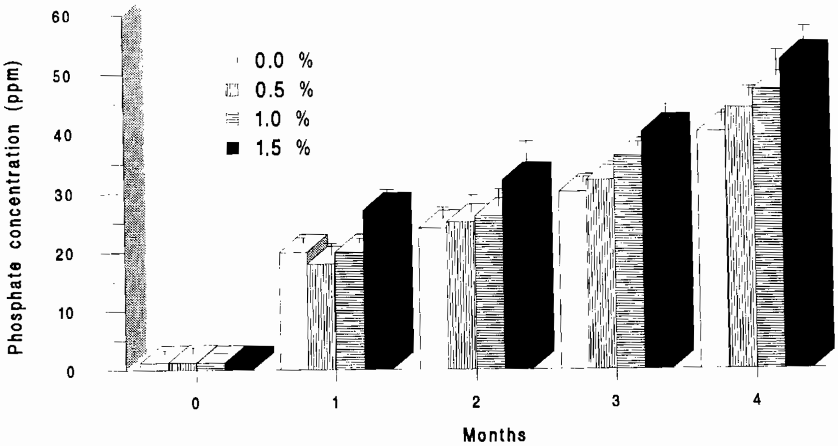

Fig. 3. Phosphate concentration (ppm) in soil amended with different amounts of wheat straw, all values are means of triplicates ±SD; $P < 0.05$. (100 mg Ca phosphate/kg soil was added.)

resulted in an increase in both phosphorus availability and numbers of phosphate-solubilizing bacteria. This suggests that organic matter amendments stimulate the solubilization. of calcium phosphate by phosphate-solubilizing bacteria. Stimulation of phosphate solubilization following organic matter amendment and the resultant increase in bacterial numbers is to be expected since these processes are mediated by heterotrophic microorganisms (Al-Falih & Wainwright 1996). The solubilization. of added phosphate fertilizer was greatly increased by increased organic matter percentage through the four month incubation period. The

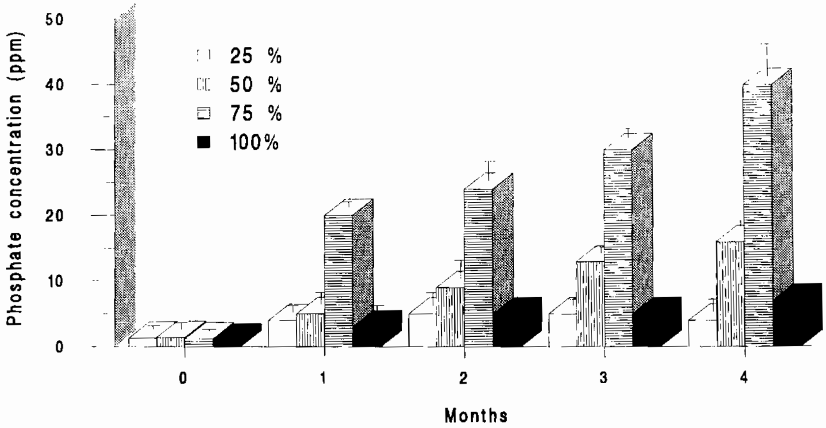

Fig. 4. Phosphate concentration (ppm) in soil at different percentage of moisture content, all values are means of triplicates ±SD; $P < 0.05$. (100 mg Ca phosphate/kg soil was added.)

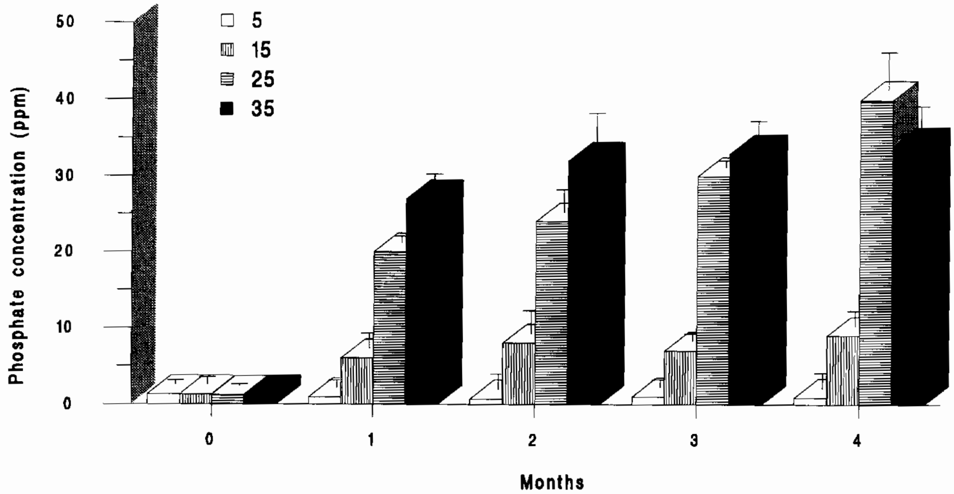

Fig. 5. Phosphate concentration (ppm) in soil at varying incubation temperatures, all values are means of triplicates ±SD; $P < 0.05$. (100 mg Ca phosphate/kg soil was added.)

maximum rate of phosphate availability (53 ppm) was observed at the highest level of organic matter amendment (1.5%).

Figure 4 illustrates changes in phosphate availability as affected by moisture levels. The highest available phosphate level (40 ppm) occurred at 75% moisture content, while at 25, 50 and 100% WHC the solubilization of added calcium phosphate fertilizer was significantly lower. At 50 % WHC, phosphate concentration slightly increased with time, reaching 17 ppm at the end of the incubation period. Both 25 and 100% WHC resulted in little solubilization of calcium phosphate.

Phosphorus availability increased as the incubation temperature increased following the supplementation of calcium phosphate fertilizer (100 mg P/kg soil) in all soil samples tested (Fig. 5). In fact, four months of incubation at 25°C yielded the most phosphate availability. As a result the optimum incubation temperature for phosphate availability and phosphate-solubilizing bacterial growth was found to be 25°C followed by 35°C. Both 5°C and 15°C incubation temperatures retarded bacterial growth, and subsequently the phosphate solubilization process (Table 1).

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تأثير بعض العوامل على جاهزية الفسفور في التربة

عبدالله مساعد خلف الفالح
قسم العلوم (الأحياء) – كلية المعلمين بالرياض
ص.ب: 4341 – الرياض 11491 – المملكة العربية السعودية

خلاصة

درس تأثير التركيزات المختلفة من الملوحة وإضافة كميات مختلفة من سماد الفوسفاتي والمادة العضوية والمحتويات الرطوبية والتحضين عند درجات حرارة مختلفة على جاهزية الفسفور في عينات رملية لومية جمعت من المملكة العربية السعودية.

وجد أن زيادة الملوحة أدت إلى تثبيط في جاهزية الفوسفور. بينما لوحظ أن إضافة السماد الفوسفاتي والمادة العضوية شجع كثيراً على عملية إذابة الفوسفور. ومن الملاحظ أيضاً أن عملية إذابة الفوسفور وصلت أعلى معدل لها عند رطوبة 75% من السعة المائية ، وتتناقص مع زيادة رطوبة التربة.

أوضحت نتائج الدراسة بأن درجة الحرارة 25 ° م هي درجة الحرارة المثلى لجاهزية فوسفور التربة.

وقد تمت مناقشة وعرض النتائج المتحصل عليها في الدراسة ومقارنتها مع الأبحاث الأخرى المنشورة في العالم.