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Phosphorus Requirement of Maize in Relation to Soil Characteristics

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ABSTRACT

Phosphorus fertilizer requirement for maize in six soil series of the Punjab were determined by using P sorption isotherms. Quantities of fertilizer P (mg P kg^{-1} soil) required to adjust the standard soil solution P concentration (0.2 mg L^{-1}) were: the Missa, 67; the Rajar, 58; the Faisalabad, 54; the Kotli, 46; the Shahdara, 40; and the Hafizabad, 22. The Freundlich model conformed slightly better with the adsorption data than the Langmuir model and indicated that the order of maximum adsorption capacity (bk) was, the Missa> the Faisalabad> the Rajar> the Kotli> the Shahdara> the Hafizabad. Phosphorus sorption curves were used to develop the soil solution P concentration in all six soil series varying from native to 0.5 mg P L^{-1}. Soil solution P requirement of maize for maximum dry matter yield (95%) ranged from 0.15 for the Hafizabad to 0.32 mg P L^{-1} for the Missa soil series. The internal P requirement in the whole shoot of maize ranged from 0.178 for the Hafizabad to 0.295% for the Missa soil series.

Key Words: Phosphorus; Langmuir; Freundlich; Adsorption; Soil series; Internal P; External P

INTRODUCTION

Fertilizers P applied to the soils under goes transformations in soil- plant system. After P application to soil, it reacts immediately with soil particles and calcium compounds, and converts to less available form by the processes of adsorption and precipitation. As a result the mobility of P is restricted from the site of its application, and a complex situation is created as compared to a mobile nutrient such as nitrate.

Phosphorus fertilizer is an expensive input and its use efficiency by crops may range from 10-25% (Bahl & Singh, 1986). An effective soil test can help to predict the fertilizer requirement of crops. However, conventional soil tests provide information only about plant available P (Fixen & Grove, 1990) and do not estimate the amount of fertilizers P needed unless calibrated for the particular soil under test (Fox & Kamprath, 1970). Further more these tests do not correctly predict the fertilizer-P requirement for a particular soil – crop system (Rashid & Hussain, 1988). Consequently, P sorption isotherms, which relate P concentration in soil solution with P sorbed by the soil, have been used to predict the fertilizer-P requirement of crops (Beckwith, 1965; Fox & Kamprath, 1970; Ahmed, 1982). Soil solution P is immediate P source for the plant (Holford, 1989), and the standard solution P concentration (0.2 mg P L^{-1}) provides P adequately for many crops if it continuously maintained in the growing medium (Beckwith, 1965).

The soil parameters which play a major role in P flux to plant roots include: (i) the intensity (I), (ii) quantity (Q), (iii) capacity ($\Delta Q / \Delta I$) and (iv) mobility factors (Dalal & Hallsworth, 1976). The quantitative description of the Q / I relationship is important for predicting the fertilizers-P requirements for the soil (Fox & Kamprath, 1970). Such relationships for P in the soil system can be obtained by fitting suitable equations, such as the Langmuir or Freundlich (Holford, 1989).

Until very recently, use of P sorption isotherms for determining the fertilizer-P requirement has primarily been confined to acid soils of tropical regions but very little information is available on the use of the technique for the alkaline soils. This paper addresses some aspects of P research that deal with the suitability of P sorption isotherms for determining external and internal P requirement of maize grown on selected soil series of the Punjab.

MATERIALS AND METHODS

Bulk surface soil samples representing six series i.e. the Missa, the Rajar, the Faislabad, the Kotli, the Shahdara and the Hafizabad were used in the experiment. All the samples were air-dried, passed through a 2mm sieve and used triplicate for this study. Organic matter (%) was determined by method as described by Walkely and Black (1934). Clay contents were ascertained by Bouyoucos hydrometer method (Moodie *et al.,* 1959). The pH of the saturated soil paste and EC of the saturation extract was measured according to the method described by U. S. Salinity Lab. Staff (1954). The samples were extracted with 0.5 M $NaHCO_3$ and P was determined by employing the method of Watanabe and Olsen (1965) using ascorbic acid as the reducing agent. The physio-chemical properties of these soils are given in Table I.

Table I. Characteristics of the soil used

Soil series	Soil order	$NaHCO_3$ Ext. P ($mgkg^{-1}$)	PHs	E C e (dSm^{-1})	$CaCO_3$ (%)	O. M. (%)	Clay (%)	Silt (%)
Missa	Inceptisol	2.6	8.15	1.95	13.47	0.72	19	57
Rajar	Entisol	3.7	7.57	1.86	10.50	0.32	16	53
Shahdara	//	4.7	7.87	2.44	11.14	0.21	10	36
Faisalabad	Aridisol	3.9	7.43	0.84	2.34	0.63	17	51
Hafizabad	//	4.5	7.95	1.62	2.10	0.54	15	51
Kotli	Vertisol	10.5	7.48	1.54	2.90	1.35	48	44

Phosphorus sorption. Phosphorus sorption isotherms were constructed by equilibrating 3 g soils with 30 mL 0.01 M $CaCl_2$ solution containing different concentrations of P (0, 20, 40, 60, 80, 100, 120, 140 and 160 mg P L^{-1}) for six days at 25 ± 2°C by shaking for 30 min each twice a day (Fox & Kamprath, 1970). After centrifugation, the P contents of the supernatant were determined by using the ascorbic acid molybdenum – blue color method (Watanabe & Olsen, 1965). The differences between the amounts of P in solution before and after equilibrium were taken as the amount of P sorbed. Sorption data were fitted to the linear forms of the Langmuir and Freundlich models as described below.

Langmuir model. The Langmuir equation may be written as

$$X= k\,b\,C / I + kC \quad [1]$$

Where

X = Amount of P sorbed per gram soil (mg P kg^{-1})

C =equilibrium solution concentration of (mg P L^{-1})

k =Affinity coefficient between phosphate ions and the surface of soil particles (L mg^{-1} P).

b = maximum adsorption (mg P kg^{-1} soil).

In a linear form the equation [1] can be written as:

$C/X = 1/ kb + C/b$ [2]

The parameters of equation [2] (1/k and b) were calculated using linear regression equations fitted to the original data. The 1/k was constant and b was inverse of slope of the regression equation.

Freundlich model. The empirical derived Freundlich equation is:

$$X= a\,C^{n} \quad [3]$$

Where

"a" and "n" are sorption constants and X and C have the usual meaning. A linear version of equation [3] is

$\text{Log } X = \log a + n \log C$ [4]

Again, the parameters "a" and "n" were calculated from linear regression equation by plotting log X vs log C in which "a" was constant and "n" was slope.

Phosphorus requirement for plants. Nine kg of each soil was placed in polythene-lined pots. Six soil solution P levels; 0.025 0.05, 0.10, 0.25, 0.375 and 0.50 mg P L^{-1} in addition to original solution P levels (Table I) were developed on the basis of the sorption studies. Control treatment was also included in this experiment. All the treatments were replicated three times. Adequate levels of other plant nutrients i.e. 150 mg N kg^{-1} as urea, 150 mg K kg^{-1} as potassium sulphate (K_2SO_4), 10 mg Zn kg^{-1} as zinc sulphate ($ZnSO_4$) and 1 mg B kg^{-1} as boric acid were applied as a basal dose. Soil moisture was brought to near field capacity by daily addition of tap water. Four maize (*Zea mays*) seeds were planted in each pot. Plants were thinned to two per pot after emergence and harvested after six weeks from germination. Dry matter yield was recorded for each pot. The Plant material, after dry ashing (Jones & Case, 1990) was analyzed for P contents by the vanadomolybdo-phosphoric acid color method (Jackson, 1979).

RESULTS AND DISCUSSION

The soils with respect to their P sorption behavior varied considerably (Fig. 1). The Missa and the Rajar soils adsorbed most of the added P whereas the difference between applied and adsorbed P was wide for the Hafizabad soil. The higher amount of $CaCO_3$ and clay in the Missa and the Rajar soils as compared to other soil series might have contributed to their high P sorption capacity (Holford, 1989). Generally, P sorption increased with increase in equilibrium P concentration. The sorption capacity of the Hafizabad soil was almost saturated at low P fertilizer rate but the same did not happen in the other soils as indicated by the slope of the isotherms, it appeared that high affinity sites were satisfied when 20 mg P kg^{-1} soil was applied. At lower fertilizer rate, the increase in P sorption was very high as compared to higher rates (60 to 160 mg kg^{-1}).

The order of rise in solution P with incremental doses of P was: the Missa > the Rajar > the Faisalabad > the Kotli > the Shahdara > the Hafizabad (Fig. 2). Fertilizer required to attain a standard solution P concentration of 0.2 mg P L^{-1} varied greatly and it ranged from 22 mg P kg^{-1} for Hafizabad soil to 67 mg P kg^{-1} for Missa soil. In previous investigations, the magnitude of fertilizer requirement for most Pakistani soils varied from 50 to 100 kg P_2O_5 ha^{-1} for optimum crop yield (Memon *et al*., 1991). Memon (1986) reported that the soils of Pakistan have low P sorption capacity as are less weathered, alkaline in reaction and generally calcareous in nature.

The Langmuir and the Freundlich models were used to derive the P sorption parameters of the soils. The order of maximum P sorption by both the models was the Missa > the Rajar > the Faisalabad > the Kotli > the Shahdara > the Hafizabad (Table. II). The Missa soil had the highest Langmuir maximum adsorption capacity (bk) as well as the Freundlich P sorption capacity (a). High P fixation in the Missa and the Rajar soils indicated the presence of more

Fig. 1. Sorption isotherm indicating dynamics of solution P in soil with imcemental addition of P (6 days contact time)

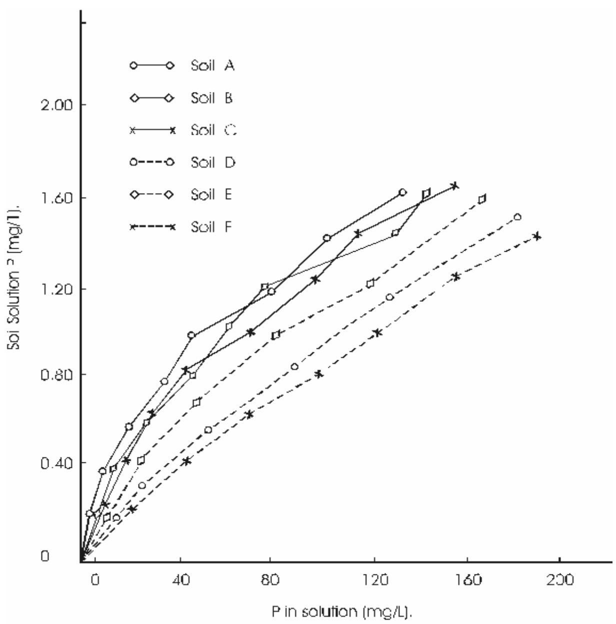


Fig. 2. Equilibrium isotherm indicating P sorbed in relation to P in solution in the soil (6 days contact time)

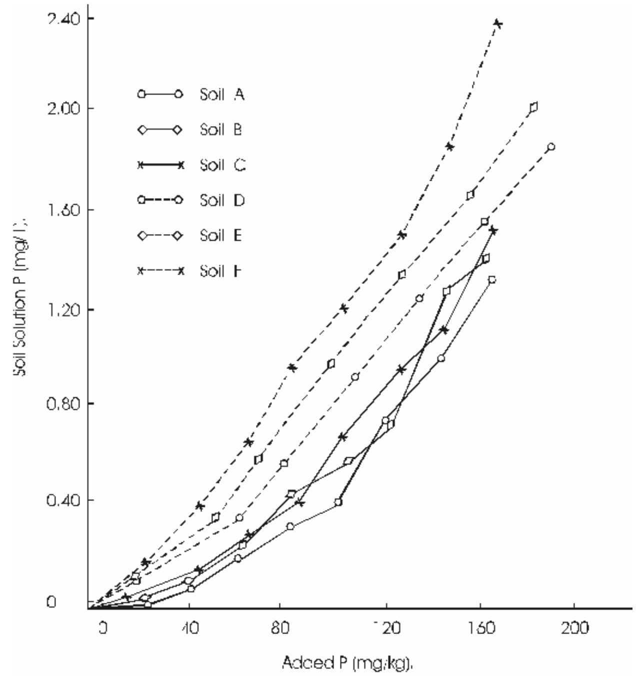


Fig. 3. Internal P requirement or critical P concentration of whole shoot associate with 95% relative dry matter yield of maize

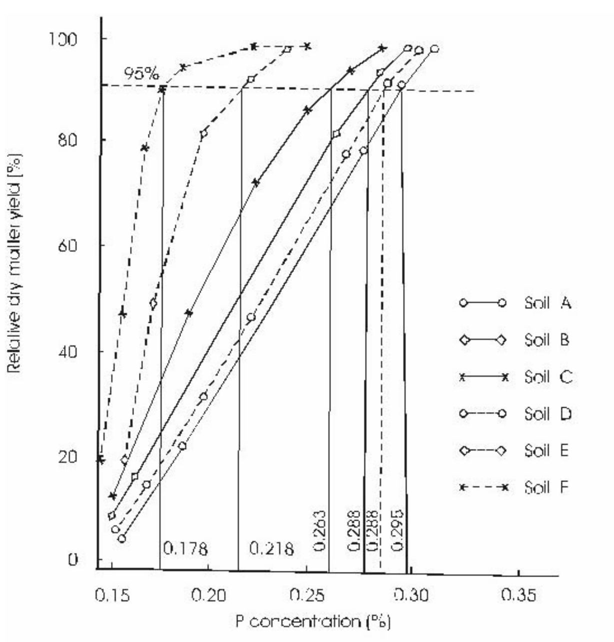
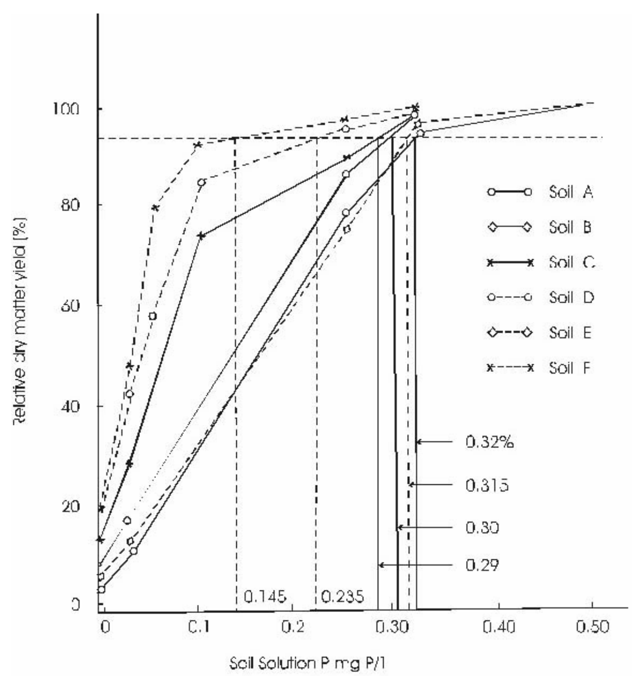


Fig. 4. External P requirement or critical p solution concentration associated with 95% relative dry matter yield of maize



active sites for P sorption, which may be attributed to its high $CaCO_3$ contents (Table I). Holford (1989) Postulated that in alkaline soils, P may be fixed on the surface of Ca / Mg carbonates as well as in the Ca / Mg phosphate compounds.

Buffering capacity, known as maximum buffering capacity (MBC), the kb in the Langmuir equation measures the ability of the soil to replenish phosphate ions when depleted by plant uptake. The data in Table II revealed that the Missa soil had the highest MBC followed by the Rajar soil, whereas the Hafizabad soil had the lowest one.

Phosphorus requirement of maize. The P requirement can be expressed as the "internal P requirement" or the "critical P concentration in plant tissue" and the "external P requirement". The term, "internal P requirement" refers to the concentration of P in the plant associated with near maximum yield, and the "external P requirement" is the P concentration in soil solution associated with adequate nutrition (Fox, 1981).

Dry matter yield, P content in the whole plant shoot and P uptake by maize are given in Table III. The internal P requirements of whole shoot, associated with 95% of biomass production, ranged from 0.178% for the Hafizabad soil to 0.295% for the Missa soil (Fig. 3). Bughio and Rashid (1992) listed 0.24% P as the internal P requirement for corn. However, Hassan *et al.* (1993) found almost the same value of 0.29% for corn in the Missa soil series.

Typical symptoms of P deficiency in corn, viz. purple

Table II. Phosphorus sorption parameters of the Langmuir and Freundlich Models

Soil series	Maximum buffering Capacity (bk) Mg kg^{-1}	Maximum adsorption (b) L kg^{-1}	Affinity coefficients (k) L kg^{-1}	Free energy (-ΔG) kj $mole^{-1}$	Correlation coefficient (r^2)
			Langmuir model		
Missa	617	185	3.34	-1.29	0.979
Rajar	457	207	2.21	-0.794	0.933
Shahdara	314	204	1.54	0.185	0.950
Faisalabad	502	184	2.73	-0.947	0.965
Hafizabad	132	160	0.827	0.205	0.955
Kotli	419	214	1.96	-0.492	0.932
Mean	407	192	2.10	-0.522	0.952

	Freundlich model		
Soils	**Sorption Capacity (a) mg kg^{-1}**	**P sorption energy (1/n) L kg^{-1}**	**Correlation coefficient (r^2)**
Missa	164	0.560	0.975
Rajar	140	0.696	0.980
Shahdara	116	0.603	0.994
Faisalabad	147	0.612	0.981
Hafizabad	55	0.484	0.998
Kotli	134	0.526	0.993
Mean	126	0.580	0.987

Table III. Dry matter yield, while shoot P content, and P uptake by maize

Soil sol. P (mg /L)	Missa			Rajar			shahdara		
	D. M. Yield	P content	P uptake	D. M. Yield	P content	P uptake	D. M. Yield	P content	P uptake
NK	0.19 f	0.160 d	0.304 g	0.42 g	0.155 e	0.650 g	0.78 c	0.160 f	1.25 g
0.025	0.54 e	0.180 d	0.970 f	0.76 f	0.165 de	1.250 f	1.67 b	0.175 e	2.92 f
0.05	0.93 d	0.190 d	1.770 e	1.69 e	0.190 d	3.210 e	2.32 b	0.180 e	4.180 e
0.10	2.02 c	0.240 c	4.850 d	2.45 d	230 c	5.640 d	3.34 a	0.200 d	6.680 d
0.25	3.11 b	0.275 b	8.550 c	3.55 c	0.265 b	9.410 c	3.72 a	0.220 c	8.180 c
0.375	3.73 a	0.295 a b	11.00 b	4.14 b	0.285 ab	11.80 b	3.87 a	0.240 b	9.290 b
0.50	3.89 a	0.310 a	12.06 a	4.23 a	0.300 a	12.69 a	3.88 a	0.250 a	9.700 a
R^2	0.951			0.928			0.830		
		Faisalabad			*Hafizabad*			*Kotli*	
NK	0.43 d	0.155 d	0.67	1.30 c	0.150 c	1.95 f	0.26 g	0.160 f	0.420 g
0.025	0.93 d	0.165 cd	1.53	3.25 b	0.160 c	5.200 e	0.46 f	0.170 f	0.780 f
0.05	1.55 c	0.190 c	2.95	5.20 a	0.170 c	8.840 d	1.07 e	0.200 e	2.140 e
0.10	2.36 b	0.225 b	5.31	6.11 a	0.175 b	10.69 cd	1.59 d	0.230 d	3.660 d
0.25	2.79 ab	0.250 b	6.98	6.37 a	0.190 b	12.10 bc	2.60 c	0.265 c	6.890 c
0.375	3.07 a	0.270 a	8.29	6.48 a	0.225 ab	14.58 ab	3.23 b	0.290 b	9.370 b
0.50	3.10 a	0.285 a	8.84	6.50 a	0.250 a	16.25 a	3.33 a	0.305 a	10.160 a
.r^2	0.876			0.721			0.959		

coloration on midrib and on leaf lamina, were observed at the lower solution P concentration up to 0.1mg P L^{-1} in the Missa soil and 0.05mg P L^{-1} in the Hafizabad soil. The symptoms were not observed at higher solution P concentration.

The external P requirements associated with 95% of maximum yield ranged from 0.145 mg L^{-1} for the Hafizabad soil to 0.32 mg P L^{-1} for the Missa soil (Fig. 4). Hassan *et al.* (1993) reported 0.32 mg P L^{-1} as the critical solution P concentration for maize in the Missa soil.

From this study it was concluded that soils varied in P sorption capacity. Increased P sorption capacity was associated with increasing clay and $CaCO_3$ content rather initial soil P content. The internal P requirement was greater for the Missa soil and lower for the Hafizabad soil series. The external P requirement also followed the same trend as it was observed in internal P requirement for attaining near maximum yield for maize.

REFERENCES

Ahmad, A.R., 1982. Phosphate adsorption characteristics of some Malaysian soils. 1Conformity with adsorption model. *MARDI Res. Bull,* 1: 52–64

Bhal, G.S. and N.T. Singh, 1986. Phosphorus diffusion in soils in relation to some edaphic factors and its influence on P uptake by maize and wheat. *J Agri. Sci. Camb*., 107: 335–41

Beckwith, R.S., 1965. Sorbed phosphate at standard supernatant concentration as an estimate of the phosphate needs of soils, *Australian J. Exp. Agri. An. Husb*., 5: 52–8

Bugio. N. and A. Rashid, 1992. Plant analysis and soil testing diagnostic indices for phosphorus nutrition of some kharif crops. *In. Proc. 4th National Cong. Soil Sci.* May 24–26 Islamabad, Pakistan

Dalal, R.C. and E.G. Hallsworth, 1976. Evaluation of the parameters of soil phosphorus availability factors in predicting yield response and phosphorus uptake. *Soil Sci. Soc. Am. J.,* 40: 541–5

Fixen P. E. and J. H. Grove, 1990. Testing soil for phosphorus, pp. 141–80. *In:* R.L. Westerman (ed.), *Soil Testing and Plant Analysis,* 3rd Ed. *Soil Sci. Soc. Am. Madison,* WI

Fox, R.L., 1981. External phosphorus requirement of crops. pp. 223– 39. *In:* M. Stelly *et al.* (ed.), *Chemistry in the Soil Environment. Am. Soc. Agron. Madison,* Wisconsin, USA

Fox, R.L. and E.J. Kamprath, 1970. Phosphate sorption isotherm for evaluating the phosphate requirement of soils. *Soil Sci. Soc. Am. Proc.* 34: 902– 7

Holford, I., 1989. Phosphorous behavior in soils. *Agric. Sci.,* 12: 15– 20.

Jackson, M.L., 1979. *Soil Chemical Analysis–Advanced Course,* Madison, WI

Jones, Jr. J.B. and V.W. Case, 1990. Sampling, handling and analyzing Plant tissue samples, pp.389–429. *In:* R.L. Westerman (ed.), *Soil Testing and Plant Analysis,* 3rd Edition. *Soil Sci. Soc. Am.* Madison, WI

Hassan, M.M., A. Rashid and M.S. Akhtar, 1993. Phosphorus requirement of corn and sunflower grown on calcareous soils of Pakistan. *Commun. Soil Sci. Plant Anal.*, 24: 1529– 41

Malik, D.M., B. Ahmed and M. Ahmed, 1984. Survey of soil fertility status and quality of ground waters. *Punjab Digest 1981– 84. Department of Agriculture* (Lahore) Punjab, Pakistan

Memon, K.S., 1986. Phosphorus requirements of Pakistan soils. In Proc. XII *Int. Forum on Texonomy and Agro– Technology Transfer* II: 105– 12 Lahore, Pakistan.

Memon, K.S., H.K. Puno and R.L. Fox, 1991. Phosphate sorption approach for determining phosphorus requirements of wheat in calcareous soils. *Fert. Res.,* 28: 67– 2

Moodie, C.D., H.W. Smith and R.A. Mcreery, 1959. *Laboratory Manual for Soil Fertility,* Pp: 31–9. State college of Washington, Mimeoigraph, Pullman, Washington, D.C. USA

Rashid, A. and F. Hussain, 1988. Evaluation of universal soil tests for determining phosphorous fertility of soils, pp. 187–193.In: *Proc. 2nd National Cong. Soil Sci.* Faisalabad–Pakistan

U. S. Salinity Laboratory Staff, 1954. Diagnosis and improvement of saline and alkali soils. *USDA Handbook 60*. Department of Agriculture, Washington, D.C.

Walkley, A. and C.A. Black, 1934. An examination of the method for determining soils organic matter and a proposed modification of the chromic acid titration method. *Soil Sci*., 37: 29– 38

Watanabe, F.S. and S.R. Olsen, 1965. Tests of an Ascarbic acid method for determining phosphorus in water and $NaHCO_3$ Extracts from soil. *Soil Sci. Soc. Am. Proc.,* 29: 677– 8

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