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Comparison of Various Extractants for Evaluating Phosphorus Availability to Plants in Saudi Arabia Soils

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Abstract. Twenty two soil samples from important agricultural areas in the Kingdom, chiefly in the central region, were used in the present experiment. They show wide variability in chemical, physical as well as in extractable P. Distilled water, $NaHCO_3$, NH_4HCO_3–DTPA and NH_4F–HCl were used to determine extractable P in the soils. The P soil test values were then correlated with various yield and P uptake parameters obtained from a greenhouse pot experiment using corn as a test crop. With the exception of the NH_4F–HCl test, all the other tests yielded highly to very highly significant correlations, indicating that they were equally effective in evaluating the P status of the soils for plant growth. By relating the P test values to relative yields, useful impressions of critical levels for the soil tests used were obtained.

Introduction

Soil testing is becoming increasingly more important in modern agriculture for the purpose of controlling various cultural operations. Testing for rational fertilization primarily involves assessment of the status of plant nutrients in soils relative to established critical levels. Conventionally this is done by aid of chemical extractants found suitable for a given plant nutrient under specific soil conditions. The soil testing procedures, their calibrations and interpretations are well outlined in the literature [1-3].

Soil testing for plant-available phosphorus has received wide attention. In general, acid extractants e.g., Bray and Kurtz [4] are found to suit acidic soils most, whereas alkaline reagents e.g. Olsen *et al.* [5] show best suitability for neutral,

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alkaline and calcareous soils. Thus numerous extractants have been used in P soil tests. However, distilled water extraction (P-water) in use by European workers e.g., Paauw *et al.* [6] and AB-DTPA [7] appear particularly sound for developing countries because the former is simple and inexpensive while the latter has the advantage that it simultaneously extracts several plant nutrients. Since none of the two latter methods has been tested under Saudi Soil conditions, the present investigation aimed to compare distilled water and AB-DTPA together with $NaHCO_3$ and NH_4F–HCl for evaluating P availability to plants in Saudi soils.

Materials and Methods

Procedures adopted during the present investigation were basically those outlined by Hauser [1]. Twenty two soil samples were included as a result of screening a larger number of surface (0–20 cm) samples collected in bulk from important agricultural areas, chiefly in the central region of the Kingdom. The selected samples thus showed fair variability in chemical and physical properties (Table 1) as well as in extractable P.

The 22 bulk samples (about 50 kg soil each) were mixed well for homogenization. Three sub-samples, about one kilogram each, were then taken from each bulk sample. These were stored in clean bottles and later used for the various laboratory determinations. The major parts of the bulk samples were subsequently employed in a greenhouse pot experiment. Six, 10 kg-capacity, polythene pots were allocated to each sample (132 pots), and each carried 6 kg airdried soil after allowing for bottom drainage. The pots were sown to corn *Zea mays* L. in March 1986, ten seeds per pot, but the seedling stage only the five most vigorous plants were allowed to continue.

All pots received nitrogen, potassium and a trace element mixture, but only half of the pots pertaining to each of the experimental samples received phosphorus in addition. The pots receiving the P treatment were labelled "Fert" and those without it were given a "check" label. Urea was given at the rate of 350 kg N/ha in three split applications; 30% of this quantity before sowing then 50% and 20% afterwards at three and six weeks from germination respectively. Potassium was given as a single basal dose at 35 kg/ha. A trace element mixture (Product of Greezit) containing chelated Fe, Mn, Zn and Cu was applied to the soils two, four and six weeks after germination as 25 ml of a 0.05% solution per application. Phosphorus, where applied, was given in two equal applications as $NaH_2PO_42H_2O$, at sowing and four weeks later; total give as 70 kg P/ha.

Table 1. Some physical and chemical characteristics of the experimental soils

Soil No.	Texture*	Clay %	ECe mmhos/cm	CaCO %	OM %	pH (paste)
1	L	19.2	1.30	36.5	0.48	7.8
2	L	1.3	1.31	26.5	0.82	7.7
3	SL	16.0	2.25	32.8	0.56	8.0
4	SL	9.8	4.35	46.9	0.75	8.1
5	SL	11.0	5.25	6.9	0.58	7.8
6	SL	11.0	6.25	48.3	1.23	8.4
7	SL	9.8	2.25	35.1	1.15	8.0
8	SCL	26.0	3.15	34.9	1.30	8.1
9	L	16.0	2.40	39.8	1.05	7.9
10	LS	9.6	5.40	37.2	1.45	7.7
11	SCL	23.0	4.30	27.6	1.50	7.5
12	SCL	21.8	8.81	21.2	0.68	7.6
13	LS	8.6	2.75	37.8	0.85	8.3
14	CL	44.0	3.66	57.8	1.64	8.4
15	CL	46.0	4.65	40.1	1.90	7.9
16	SCL	24.0	1.60	37.4	1.50	7.8
17	SL	12.6	0.80	29.5	1.15	8.0
18	SCL	23.8	3.30	20.7	0.95	8.1
19	LS	10.0	1.25	28.5	1.05	7.6
20	LS	12.8	1.75	4.6	0.76	7.5
21	SCL	21.4	6.55	35.8	1.25	7.8
22	SCL	24.5	7.15	28.5	1.17	7.6

* L = Loamy. SL = Sandy loam. LS = Loamy sand. SCL = Sandy clay loam. CL = Clay loam.
OM = Organic matter. ECe = Electrical conductivity of the saturation extract.

The plants were grown for 8 weeks in a greenhouse, irrigatd as necessary with distilled water. At harvest, all of the above ground portions were removed. They harvest, all of the above ground portions were removed. They were then washed in tap and distilled water before drying at 70°C. The dry matter weights were recorded before grinding to a suitable mesh size. Phosphorus in plant material was determined by the ascorbic acid method [8] after wet ashing in a mixture of nitric and perchloric acids.

Determination of extractable (available) P in the sub-samples was done with distilled water, $NaHCO_3$, NH_4HCO_3 DTPA (AB–DTPA) and NH_4F–HCl. Extraction procedures are supplied in Table 2. Statistical correlations (total 30) were run between the amounts of P extracted by each of the test reagents and each of the following parameters:

a: check yield (DM yield of "check" in g/pot)
b: yield response (DM yield of "Fert" less "check" in g/pot)
c: P_0 uptake (P concentration X DM of "check" in mg/pot)
d: additional uptake (P concentration X DM of "Fert". less P_0 uptake (mg/pot)
e: % relative yield (DM yield of "check" × 100/DM yield of "Fert."

Table 2. Soil phosphorus tests and extraction procedures used

Extractant	Soil: solution	Shaking time	pH	Reference
Distilled water	1: 50	5 hr	7.0	[9]
Distilled water	1:100	16 hr	7.0	
0.5 M $NaHCO_3$	1: 20	20 min	8.5	[5]
0.5 M $NaHCO_3$	1:100	16 hr	8.5	[10]
NH_4HCO_3–DTPA	1: 10	20 min	7.3	[7]
0.03 M NH_4F^+ 0.025M HCl	1. 10	5 min	3.1	[4]

Results and Discussion

The P test values (maximum, minum, mean and % C.V.) for the 22 soil samples are given in Table 3 for the test methods used. Individual values varied considerably between the soils as well as between the extractants. For the latter, they were in the following descending order: NH_4F–HCl, $NaHCO_3$ (1:100), $NaHCO_3$ (1:20), AB-DTPA, H_2O (1:100) and H_2O (1:50). This variation is known to be due to the relative efficiency of each of the extractants to dissolve different forms of soil P [3,9,11-13]. Thus NH_4F–HCl resulted in the highest extractable P chiefly due to the dissolving of calcium-bound P by the acid in the mixture [12] and to displacement of phosphate in iron and aluminium phosphates by the fluoride ion [9]. Unbuffered distilled water, on the other hand, resulted in the lowest extraction (P intensity). However, the quantity of P extracted by a given chemical reagent bears little significance to its suitability as a soil test. This is normally derived from the ability of the extractant to predict plant responses i.e. to distinguish between soils that require fertilization from those that do not.

Table 3. Summary of extractable P by the different soil test methods and yeilds, and P uptake by corn

	Maximum	Minimum	Mean	% C.V.
Extractable-P (ppm)				
H_2O (1:50)	2.4	0.2	1.04	57.70
H_2O (1:100)	3.0	0.4	1.62	53.70
$NaHCO_3$ (1:20)	18.0	1.2	7.89	66.70
$NaHCO_3$ (1:100)	20.8	3.1	10.56	57.50
NH_4HCO_3-DTPA	5.5	0.8	3.01	49.83
NH_4F-HCl(P_1)	85.3	36.8	66.05	20.21
Yield and P uptake				
Check yield g/pot	19.2	1.6	11.55	45.50
Fert yield g/pot	36.20	8.2	20.69	29.90
Yield response g/pot	22.2	2.1	9.13	53.00
Relative yield %	87.8	19.5	54.19	47.10
Check P uptake mg/pot	6.4	0.7	3.98	47.99
Fert P uptake mg/pot	8.4	3.4	6.63	23.53
Additional P uptake mg/pot	4.7	0.5	2.64	49.51

Table 4 presents simple correlation coefficients (and their levels of statistical significance) between extractable P due to the various tests used and various yield and P uptake parameters. High correlation coefficients usually refer to high suitability of the soil test under the given soil conditions. These data suggest that with the exception of NH_4F–HCl (Bray P.) all the other tests employed appeared equally effective in evaluating the P status of the Saudi soils for plant growth, though the Bray P did occasionally give weak significant correlations. Sodium bicarbonate, whether employed in accordance with the procedure of Olsen *et al.* [5] or that of Colwell [10] has regularly proved suitable as a P soil test reagent for neutral, alkaline and calcareous soils [3,14] though the Colwell test proved more able to evaluate residual P in these soils in comparison with the Olsen test [15]. Thus present results emphasize more the value of $NaHCO_3$ for routine P soil test under the stated soil conditions.

Particular attention is directed to the distilled water and the AB-DTPA results in Table 4 since they both evaluated the P status of the Saudi soils extremely well, while neither has been tested before here. However, some data of Ayed and Chaudary (unpublished) have shown significant correlations between $NaHCO_3$ and AB–DTPA-extractable P in 54 Saudi soil samples. The AB–DTPA, originally recommended by Soltanpour and Schwab [7] has proved quite efficient as a soil P test [16]. Because it allows for simultaneous evaluation of other plant nutrients in soil, it is con-

Table 4. Simple correlation coefficient (r)* between different extractable P and yield and P uptake by corn

	H_2O 1:50	H_2O 1:100	$NaHCO_3$ 1:20	$NaHCO_3$ 1:100	NH_4HCO_3 DTPA	NH_4F HC1
Check yield g/pot	0.598**	0.577**	0.807***	0.786***	0.917***	0.464*
Relative yield %	0.716***	0.739***	0.832***	0.789***	0.868	0.452*
Response g/pot	-0.506*	-0.527*	-0.561**	-0.512*	-0.580**	n.s. -0.153
P uptake mg/pot	0.680***	0.738**	0.789***	0.744***	0.851***	0.420*
Additional uptake mg/pot	-0.567**	-0.616**	-0.712**	-0.589***	-0.,705***	-0.491*

n.s. = Not significant. * = Significant at P < 0.05.
** = Significant at P < 0.01 and *** = Significant at P < 0.001.

sidered to be a useful soil test tool. Distilled water extraction is both simple and inexpensive and where it succeeds in evaluating the nutrient status of soils, this must be considered to be a useful means of soil testing, particularly in developing countries. Distilled water, like neutral salt solutions, can only determine soil P intensity. The latter can become more important in predicting P uptake than P capacity under greenhouse compared to field conditions, due to probable greater plant root density under the former conditions. Soil solution P concentration (P intensity), in equilibrium with a pool of labile solid phase P, is known to be controlled by the soil's buffer capacity [17]. Thus P concentration in aqueous extracts of soils can only be interpreted in relation to the soils buffer capacity. Consequently distilled water extractions often fail to provide a useful P test. Contrary to this, distilled water extractions proved to be as effective as the other tests in the present study. This may imply that the soils used had buffering capacities that only varied within a small margin.

Although the primary objective of the present study was to test the compare the reliability of various extractants for P tests under Saudi soil conditions rather than to calibrate them, the data may throw useful impressions on critical levels (CL). Studies designed to determine C L usually involve addition of increasing rates of the nutrient to the test crop, ideally under field conditions. On the other hand, it is a basic concept in soil fertility that soil capable of supporting a "check" (unfertilized) yield that approaches that with fertilization, such soils contain enough nutrients and may not show response to applied fertilizers. Thus, in a manner similar to the method of Nelson and Anderson [2] the relationship between relative yields (%) and extractable P (dats summarized in Table 3) was graphically presented (Fig. 1) for distilled water, $NaHCO_3$, and AB–DTPA tests. The P test values corresponding to > 75% relative yield was considered to be the CL. These amounted to 1.9, 15.0, 19.3 and 5.2 ppm P for distilled water, Olsen, Colwell and AB–DTPA tests respectively. These would naturally vary for crops other than corn as well as under field relative to the greenhouse pot conditions.

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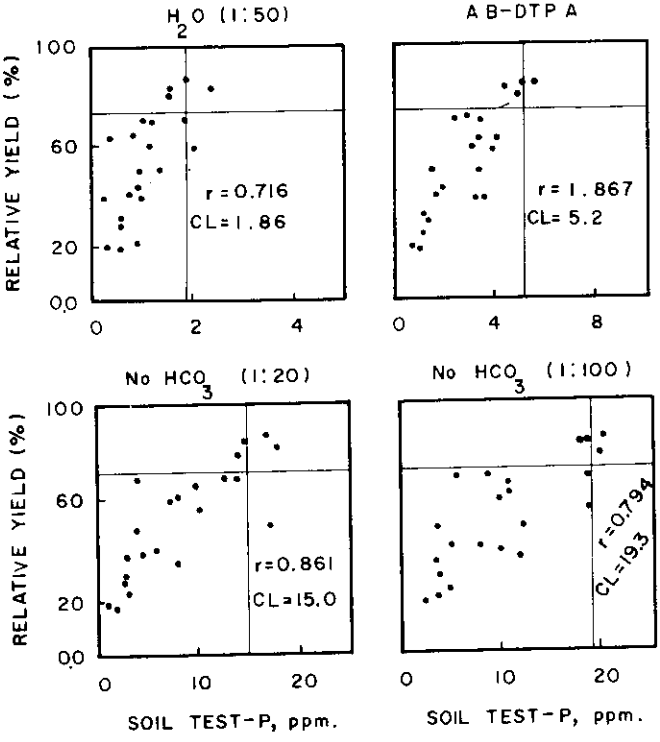

Fig. 1. The derivation of critical levels for the P extractants from simple soil test – relative yield relations.

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مقارنة عدة مستخلصات لتقدير جاهزية الفوسفور للنبات في ترب المملكة العربية السعودية

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ملخص البحث. أجريت الدراسة في إثنين وعشرين عينة تربة من مناطق زراعية مهمة في المملكة وقد اختلفت العينات في صفاتها الكميائية والفيزيائية كما اختلف مستوى الفوسفور المستخلص فيها.

استخدمت عدة مستلخصات كيميائية بينها الماء المقطر لتقدير الفوسفور المستخلص في الترب وقد وجد أن مستوى الفوسفور المستلخص بوساطة هذه المحاليل عدا محلول براى يتوافق معنويًا مع وزن المادة الجافة وكمية الفوسفور المستخلص بوساطة محصول ذرة زرع في إصص تحت ظروف محمية.

وتشير هذه النتائج إلى أن المحاليل التي استخدمت عدا محلول براى تتساوى في مقدرتها في التعبير عن مستوى الفوسفور الميسر في ترب المملكة.