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Phosphorus Availability Studies on Ten Ethiopian Vertisols

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Abstract

Three chemical extraction methods (Olsen, Truog, and Warren and Cooke) were earlier recommended for soil available P determination on Ethiopian soils. In the present study, the applicability of these methods and two others (Bray II and CAL methods) on ten Ethiopian Vertisols was tested using durum wheat and chickpea, which are traditional Vertisol crops in Africa. Results showed that the magnitude of soil available P extraction was in the order Truog $>$ CAL $>$ Olsen $>$ Bray II $>$ Warren and Cooke. The four methods excluding the CAL were highly significantly (P<0.001) correlated with each other and also with crop P uptake. The CAL method was also correlated with most of the parameters, but the significance was not as high as that with the other extraction methods. The highest correlation was also obtained between wheat P uptake and the four extraction methods. None of the correlations involving dry matter yield were significant. Based on the results it can be generalized that wheat is a better indicator for P availability than chickpea. The results also show that the earlier recommended three methods are applicable to Vertisols and each method may be used in substitution of the other (with the exception of the Warren and Cooke method , the applicability of which on high pH soils may be limited) in case of need. Due to the shortage of chemicals often encountered in soil laboratories in Ethiopia, the need for testing multi-element extraction methods is recommended.

Keywords: Available P, Ethiopian soils, Vertisols

1 Introduction

In Ethiopian agriculture, Vertisols or cracking clay soils have an important place since they are widely distributed (over 12 m ha) and have diverse chemical properties. A multidisciplinary Joint Vertisol Management Project has been in operation in Ethiopia since 1986 (Mamo *et al.*, 1993) in order to improve the productivity of these soils.

Next to nitrogen, phosphorus is often the limiting nutrient for crop production in tropical soils. In soil phosphorus availability studies, the selection of an appropriate methodology is a key factor. In Ethiopia, the Olsen's $NaHCO_3$ method (Olsen *et al.*, 1954) is often used for determining soil available P. In a recent study, Mamo and Haque (1991) reported that the Olsen, Warren and Cooke, and Truog methods were the best of the eight chemical methods they used to assess available P on 32 Ethiopian soils. The

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Ethiopian Society of Soil Science has discussed the need for standardizing methodologies and as a first attempt decided that until such time that P calibration studies are made the Olsen method (and any other additional method if laboratories feel the need for a second method) should be used to determine available P on Ethiopian soils.

Most Ethiopian soils including Vertisols are deficient in P when assayed by chemical methods; yet, with the addition of P fertilizers, field crop P responses on these soils, particularly in the central highlands are low, even under improved drainage conditions (MAMO *et al.*, 1993). Several possible chemical and biological theories may be given for the poor response to P fertilizer, but this may be beyond the scope of this paper. Our objective in this study was to check the applicability of the Olsen, Warren and Cooke, Truog, Bray II and CAL methods to Vertisols collected from locations differing geographically and ecologically using two traditional Vertisol crops, durum wheat and chickpea.

2 Materials and methods

Ten Vertisol surface samples (0-30cm) were collected from various locations in Ethiopia representing diverse conditions (Table 1). The samples were air dried and sieved through a 2mm sieve. Selected physical and chemical properties of the soils were determined at the National Soil Service Laboratory in Ethiopia. These included soil pH in a soil-to-water ratio of 1:2.5, particle size distribution by the hydrometer method (BOUYOUCUS, 1951), organic matter by the dichromate oxidation method of WALKLEY and BLACK (1934), and exchangeable cations by the neutral 1N ammonium acetate leaching method. Exchangeable Na and Mg were determined by flame photometry while Ca and Mg were read on atomic absorption spectrophotometer.

Table 1: Some characteristics of the experimental soils

Soil no.	*Location in Ethiopia*	*pH (H_2O) (1:2.5)*	*Clay (%)*	*Organic matter(%)*	*Exch. cations (cmol(+)kg^{-1})* Na	K	Ca	Mg
1	Akaki	7.37	84	2.28	0.95	1.90	50.6	8.0
2	Alemaya	7.75	72	3.45	0.55	1.49	50.0	5.2
3	Bichena	6.66	81	2.72	0.55	1.39	43.2	8.4
4	Chefe Donsa	7.15	78	1.82	0.71	2.00	49.0	5.9
5	Debre Zeit	6.91	75	1.83	0.71	1.86	31.4	7.6
6	Debre Brhan	5.98	39	1.95	0.55	0.83	26.1	5.2
7	Ginchi	6.74	74	3.15	2.00	1.50	39.5	7.5
8	Sheno	6.23	56	3.09	0.53	0.80	29.1	5.7
9	Mekelle	8.25	61	2.71	0.98	1.20	45.8	4.7
10	Sholla	5.81	69	2.87	0.59	0.86	34.2	7.9

Available phosphorus in the soils was extracted by five chemical methods. They were Olsen´s 0.5M $NaHCO_3$ (OLSEN *et al.*, 1954), 0.3N HCl (WARREN and COOKE, 1965), dilute H_2SO_4 buffered with $(NH_4)_2SO_4$ (TRUOG, 1930), the Bray II extractant

(Bray and Kurtz, 1945), and the CAL method (Schüller, 1969). Description of these methods is given in Table 2. The first three methods were recommended for Ethiopian soils by Mamo and Haque (1991). The Bray II extractant was included because it is sometimes used by few laboratories in Ethiopia. The CAL method which is the standard in Germany and some parts of Europe, is not used in Ethiopia but it was included in this study for comparison purposes. In all cases, available P was determined on duplicate samples following the Murphy and Riley method (Murphy and Riley, 1962) using a Hitachi U-2000 Spectrophotometer.

Table 2: Chemical P extraction methods used

Method	*Reagent*	*Soil to solution ratio*	*Shaking time*
Olsen	0.5 M $NaHCO_3$, pH 8.5	1:20	30 min
Warren & Cooke	0.3N HCl	1:12.5	1 min
Truog	0.002N H_2SO_4 buffered with $(NH_4)_2SO_4$ at pH 3	1:200	30 min
Bray II	0.03N NH_4F in 0.1N HCl	1:7	1 min
CAL	0.05M calcium lactate + 0.05M calcium acetate + 0.3M acetic acid	1:20	90 min

For plant phosphorus uptake study, two experiments were conducted using durum wheat (*Triticum durum* Desf.) variety Kilinto and chickpea (*Cicer arietinum* L.) variety Mariye in a glass house which was maintained at a day/night temperature of 20/15°C, 60% relative humidity and 10,000 lux illumination for 12 hours in a day. 500g sieved soil and 200g nutrient free sand were weighed and mixed in 0.75kg capacity plastic pots. For the experiment with wheat, 15 seeds were planted which were one week later maintained to 10 per pot. Chickpea, on the other hand, was kept at a constant number of 8 from an initial number of 12. The treatments were replicated three times and arranged in a randomized complete block design. Wheat plants were fertilized with NH_4NO_3 (at the rate of 50 mg N per pot in three splits). No other fertilizer was applied to both crops.

Plants were grown for 35 days during which they were supplied with a measured quantity of rain water as often as necessary. By the time of harvest, some wheat plants had developed P deficiency (reddish brown stems and pale yellow leaves) while chickpea plants were normal. After harvest, the aboveground parts were ovendried at 70°C and weighed. Samples were then ground using a tecator plant mill. For P determination by the yellow vanadomolybdate method, 0.2g sample was dry ashed at 550°C for 5 hours, diluted initially with 10ml concentrated HCl, and then with distilled water to 50ml. Data were analysed for statistical significance by computer using the SAS statistical package (SAS Institute, 1990).

3 Results and discussion

Soil available P values estimated by the five chemical extraction methods are given in Table 3. The order of magnitude of P extracted was Truog > CAL > Olsen > Bray II > Warren and Cooke. Consistently higher P was extracted by all the methods from soils number 4 (Chefe Donsa) and 5 (Debre Zeit). The two locations are research sites of the Debre Zeit Agricultural Research Center and the sites may have received more quantity of P fertilizer during the past years than the other locations. Unlike the other methods, the Warren and Cooke method extracted very little P from soil number 9 (which is a soil with the highest pH), thus indicating the limitation of the highly acid (pH<1) extractant on high pH soils.

Table 3: Soil available P extracted by different methods (ppm P)

Soil no.	*CAL*	*Olsen*	*Bray II*	*Warren& Cooke*	*Truog*
1.	19.59	10.65	9.39	5.68	37.58
2.	7.45	5.33	3.85	1.10	16.90
3.	10.47	7.76	3.53	1.72	8.70
4.	34.41	12.98	15.40	12.04	62.02
5.	43.08	23.50	22.20	23.94	102.18
6.	3.58	5.82	3.28	3.17	21.18
7.	9.94	9.23	5.24	2.99	11.34
8.	8.04	7.92	2.13	0.82	0.74
9.	41.11	10.10	8.64	0.01	14.94
10.	9.02	4.61	2.81	0.31	3.14
Mean	18.67	9.79	7.65	5.18	27.9

Table 4 shows the dry matter yield and P uptake data of the two crops. The soils´ability to supply P was different in both crops. For example, the yield of wheat was at its highest on soil number 5 (Debre Zeit), and it was significantly different from the yield obtained from soils 1, 8 and 9. The last two soils produced the lowest amount of dry matter. Chickpea, on the other hand, showed less sensitivity to soil P variation. This was also noted during the plant growth experiment since chickpea plants did not exhibit any P deficiency symptoms. From the dry matter yield data it is possible to note that variation existed between the two crops in terms of the highest and lowest yield obtained from the soils.

Wheat P uptake gave a better measure of the soils´variability in P status. Data presented in Table 4 show that soils 4 and 5 were the two soils from which there was the highest P uptake, while soil numbers 6 and 8 were the lowest. This agrees with the data given in Table 3. P uptake by chickpea was in most cases more than 2.5 times greater than wheat P, suggesting the presence of a possible mechanism in chickpea by which

Table 4: Shoot dry matter yield (g/pot) and P uptake (mg/pot) of wheat and chickpea plants grown on ten non-P-fertilized soils

Soil no.	*Location*	*Wheat*		*Chickpea*	
		Yield	P *uptake*	*Yield*	P *uptake*
1.	Akaki	0.74	1.07	1.47	3.72
2.	Alemaya	0.83	0.94	1.37	4.01
3.	Bichena	0.82	0.94	1.44	3.89
4.	Chefe Donsa	0.83	1.07	1.44	4.20
5.	Debre Zeit	0.91	2.22	1.43	3.19
6.	Debre Brhan	0.75	0.88	1.33	3.79
7.	Ginchi	0.84	0.92	1.36	3.33
8.	Sheno	0.70	0.68	1.25	3.52
9.	Mekelle	0.68	0.95	1.39	3.98
10.	Sholla	0.82	0.97	1.17	3.10
	$LSD_{(0.05)}$	0.117	0.292	0.118	0.439

it may acquire more available P from the soils. This finding is also in agreement with previous studies which indicated that chickpea did not respond to P fertilizer application on Vertisols (Mamo *et al.*, 1993).

The comparisons in Table 5 show that there were fairly good relationships between the P extraction methods. The CAL method was the least in terms of magnitude of significance of its correlation with the others, probably because the extracted P values were not very different among the soils when compared with the other methods. The higher correlation values ($P<0.001$) between the other methods indicate that substitutions could be made in the methodologies in case of need; the only exception may be the Warren and Cooke method which did not extract any amount of P from soil number 9 (high pH soil).

When crop P uptake was correlated with soil available P values, significant correlations were found with all methods. Although correlations between crop dry matter yield and soil available P extracted by all the methods were positive, none of them reached the significance level indicating that yield limiting nutrients other than P may have also been involved. This result also shows that crop yield alone may not be a good indicator of the best soil available P extractant. However, the correlations became significant when computation was made between crop P and the four methods of P extraction. Interestingly, the highest correlations were found between wheat P uptake and the four methods of P extraction. The correlations with chickpea P uptake were only significant at the 5% significance level, whereas correlation with wheat P was significant at 0.1% for the three methods (Olsen, Warren and Cooke, Truog), 1% for the Bray II method, and 5% for the CAL method. The highly significant correlations between wheat P uptake and the three P extraction methods support previous reports

Table 5: Correlation coefficients between crop dry matter yield, P uptake and soil available P values

	Warren& Cooke	Olsen	Truog	Bray II	CAL	Wheat yield	Wheat P	Chickpea yield
Olsen	0.936***							
Truog	0.978***	0.916***						
Bray II	0.935***	0.947***	0.965***					
CAL	0.655*	0.799**	0.723*	0.865**				
Wheat yield	0.624	0.453	0.553	0.471	0.122			
Wheat P	0.917***	0.900***	0.891***	0.862**	0.648*	0.653*		
Chickpea yield	0.458	0.522	0.551	0.568	0.503	0.179	0.390	
Chickpea P	0.718*	0.719*	0.789*	0.766*	0.689*	0.305	0.672*	0.709*

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

about the superiority of these methods in Ethiopian soils (Mamo and Haque, 1991). It can also be generalized that wheat gives a better indication of soil available P status when related with chemical methods than chickpea, which is known to thrive well under marginal soil fertility conditions.

4 Conclusion

As indicated earlier, Vertisols are important soils which are given priority in the present day agricultural activity of Ethiopia. Their wide distribution and variability also justify the attempt for determining the most suitable P availability estimation on this group of soils. In line with this, Muriuki and Barber (1983) have also examined the merits of separating tropical soils into groups and using different chemical extractants for different groups in the routine determination of soil available P. The confirmation of the applicability of the three previously recommended methods on these soils is useful when flexibility in the use of methodologies is often necessary, mainly due to shortage of laboratory chemicals (which at present are all imported) often encountered in Ethiopia. In this regard, the possibility of testing the use of multi - element extractants for the routine determination of soil available P and other elements (such as K, Ca, Mg) is encouraged since it is speedy and economical.

Moreover, researchers may direct their emphasis towards studying the causes of poor P response by crops or investigating the mechanisms by which traditional Vertisol crops are adapted to low soil P conditions rather further attempting to find the best chemical extractants for soil available P. However, all the findings from controlled environment studies need to be confirmed under field conditions, and determination of the critical soil P values for the major crops is necessary.

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