

COCOS, (1984), 29 - 43
Printed in Sri Lanka

Evaluation of the phosphorus status of some coconut growing soils of Sri Lanka*

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ABSTRACT

The phosphorus status of 58 soil samples representing 15 soil series and four soil Orders (Ultisol, Entisol, Alfisol and Oxisol) in the major coconut-growing regions of Sri Lanka was evaluated by determining the available P extracted by the methods of Olsen, Bray and Kurtz No. 1, Bray & Kurtz No. 2 and NH_4OAc (pH 4.8) and the various P forms. Total P in the soils ranged from 37 to 338 mg/kg with organic P and active P constituting only about 20 and 50% of the total P respectively. In general the sandy soils of the Entisols and Oxisols had lower total and organic P but higher active and available P than the rest. The relative abundance of the various inorganic P forms was generally in the decreasing order of inactive P, Fe-P, Al-P and Ca-P. Al-P and Ca-P were positively correlated with percentage sand and negatively correlated with percentage silt and percentage clay whereas total P and organic P had the opposite trend. Available P extracted by the four methods was very low in almost all soils except some of the sandy soils (Entisols) which had marginal to moderate P contents. They are positively correlated with Al-P, Ca-P, percentage sand and negatively correlated with percentages of silt, clay and organic carbon.

Phosphorus concentrations (0.074-0.116%) in the 14th leaf of coconut at the soil sites were all lower than the critical leaf-P concentration (0.120%). Leaf-P correlations with Bray & Kurtz No. 2-P and $\text{NH}_4\text{OAc-P}$ were significant ($P < 0.05$) and with Al-P and Ca-P were close to significant.

The study revealed that the coconut-growing soils of Sri Lanka were deficient in total as well as the active and available forms of P except perhaps some of the sandy soils of the Entisol. This was confirmed by coconut leaf P analysis.

* Reprinted from *Journal of Agricultural Science, Cambridge* 99, 25-33 (1982) by Courtesy of the Editors and Cambridge University Press.

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INTRODUCTION

Phosphorus is an important essential major nutrient for both immature (non-bearing) and mature (bearing) coconut. Phosphorus application has been shown to increase the number of leaves and the girth at collar of coconut seedlings (Mathew & Ramadasan, 1964) and, in young palms, increase leaf production, lower the age of flowering (Salgado, 1957) and reduce the incidence of the fungus *Helminthosporium incurvatum* attack on leaves (Salgado, 1955; Nathanael, 1961).

Of the coconut-growing countries in the world, Sri Lanka alone appears to have shown, consistently significant effects on nut and copra yield of the application of P fertilizer (Wahid, Kamala Devi & Haridasan 1977). Experiments carried out on mature palms at Madampe, Veyangoda, Ahangama (Nethsinghe, 1963), Bandirippuwa, Pothukulama and Bingiriya (Balakrishnamurti, 1972) in Sri Lanka showed spectacular yield responses to application of P.

Highly weathered soils of the humid tropics are very P deficient. This has been attributed to the strong fixation of the added P by the hydrous Fe and Al oxides in these soils (Syers et al. 1971; Udo & Uzu, 1972; Lathwell, 1979) and the low availability of native soil P (Enwezor & Moore, 1966; McKenzie, Kurtz & Melsted, 1977; Udo & Ogunwale, 1977). A large proportion of the nearly half a million hectares of soils of Sri Lanka supporting coconut is highly weathered and the soils are expected to be P deficient.

The P-fixing characteristics of these soils have been recently studied (Loganathan & Fernando, 1980) but no systematic studies on their P status have been reported. Information on the P status of these soils is helpful not only to provide a rough estimate of the P needs of coconut as well as the associated crops cultivated in the space between the palms but also to understand the unusual yield responses of coconut to P fertilizers obtained in several experiments.

This paper describes the relative distribution of the various P fractions in some important coconut-growing soils as determined by the procedure of Chang & Jackson (1957), available P extracted by various soil-testing procedures and P-nutritional status of the palms in some of these sites and discusses their relationship to each other.

MATERIALS AND METHODS

Sampling methods

Fifth-eight soil samples representing 15 soil series in the wet (approximately >1900mm), intermediate (approximately 1300-1900 mm) and dry (<1300 mm) zones of Sri Lanka were selected (Table 1). The sites were located to cover as far as possible the entire North-western, Western and Southern provinces of Sri Lanka which constitute the bulk of the coconut holdings in the country. The sites were all in coconut holdings where no fertilizer had been added for a long time. Soil samples from the centres of squares formed by four coconut palms were

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collected at depths 0.60 cm, at five points in each site and bulked to form the sample representing the site. The samples were air-dried in the laboratory, crushed with a wooden pestle, passed through a 2 mm sieve and stored for chemical and physical analysis.

In order to determine the P-nutritional status of the coconut palms in the sites where the soils were collected, leaflets from the middle portions of the 4th frond of ten palms in each of 35 selected sites were collected (during the dry period, July-August 1979) and the samples at each site were bulked.

Samples were taken from only 35 out of the 58 sites as it was not possible to select the required number of ten palms in healthy condition from the rest of the sites. Middle portions (20 cm) of the leaflets were taken and dried in the oven for 2 days at 100°C. Dried samples were ground to pass through a 0.5 mm sieve and stored for chemical analysis.

Analytical methods

Particle size analysis of the soil samples was done by the pipette method, cation exchange capacity by extracting the soils with 1 M NH_4OAc , pH 7, organic carbon by the method of Walkley & Black (1934) and pH on the soil to water ratio of 1:5. Total P in the soils was determined by HClO_4 digestion (Jackson, 1964) and organic P by extraction with 13 M-HCl before and after ignition (Legg & Black, 1955). Inorganic P was fractionated by the method of Chang & Jackson (1957) as modified by Peterson & Corey (1966). Available P was determined by extraction with acid fluoride; Bray & Kurtz No. 1 and Bray & Kurtz No. 2 methods (Bray & Kurtz, 1945), Olsen's NaHCO_3 (Olsen et al. 1954) and NH_4OAc , pH 4.8 (Pritchett & Gooding, 1975). Phosphorus in the extract was determined colorimetrically by the molybdenum blue method as modified by Alexander & Robertson (1970).

Ground leaf samples (2 g) were dry-ashed at 450°C and the ash was dissolved in 10 ml of 6 M-HCl. The solution was evaporated to dryness, 2 ml of 13 M-HCl was added, and the solution was again brought almost to dryness and dissolved in distilled water. Phosphorus was determined by the phosphovanado-molybdate method (Jackson, 1964).

RESULTS AND DISCUSSION

Some general properties of the soils are shown in Table 1. Particle size analysis indicates that all the soils were coarse textured; Ultisols had moderate amounts of clay, Alfisols and Oxisols, intermediate amounts and Entisols, the least amounts. Some of the soils belonging to Oxisols and Entisols had more than 90% sand.

The organic-matter content of the soils showed the same pattern as the clay content: Ultisols had moderate amounts of organic matter, Alfisols and Oxisols had low contents and Entisols had very low amounts. The soils were generally acidic except the dry zone soils which were close to neutrality. Cation exchange capacity was generally low. This is due to the low clay and organic-matter contents and the presence of mainly oxidic and kaolinitic type of clays in these soils (De Alwis & Panabokke, 1972-1973).

Total P and the various forms of soil P are shown in Table 2

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Total P

Total P content in the soils ranged from 37 to 338 mg/kg with mean values of 170, 165, 108 and 105 mg/kg in Ultisols, Alfisols, Entisols and Oxisols respectively. These values are much lower than the typical value of 395 mg/kg reported for the uncultivated mineral soils of U.S.A. (Robinson, Steinkoenig & Fry, 1917). They are also generally lower than the values reported in Nigeria for coastal plain sands (Udo & Dambo, 1979) and for soils under secondary forest, thicket and savannah grass fallow (Uzu, Juo & Fayemi, 1975) but similar to those of the Ultisols of Sierra Leone (Mckenzie et al. 1977) and savannah soils of Ghana (Halm & Bampoe-Addo, 1972).

Soils formed on residual sands generally had lower contents of total P as reported by others (Enwezor Moore, 1966; Manciot, Ollagnier & Ochs, 1979). Total P was correlated negatively with percentage sand but positively with percentages of silt, clay and organic carbon (Table 3). This indicated that the P in the soils is mostly concentrated in the finer fractions of the soil, probably because of the high fixation of P and Fe and Al hydrous oxides and kaolinite in the clay and silt fractions. The positive correlation of total P with organic carbon shows that organic P contributes significantly towards the total P content.

Organic P

Organic P content of the soil ranged from 1 to 96 mg/kg with mean values of 46, 38, 25 and 17 mg/kg in Ultisols, Alfisols, Oxisols and Entisols respectively.

This constituted 27, 23, 24 and 16% of the total P in the four Orders of soils. Organic P contents in these soils are generally low in comparison with other tropical soils such as the Nigerian coastal plain sands which contained 25-232 mg/kg (Udo & Dambo, 1979) and 67-208 mg/kg in the surface horizons of Ultisols of Sierra Leone (Mckenzie et al. 1977). The low organic P contents in the Sri Lanka soils are probably due to the lower organic-matter content of these soils. The surface horizons of Ultisols of Sierra Leone (Mckenize et al, 1977) and some of the forest soils of Nigeria (Uzu et al. 1975) which had 2-5 times the organic carbon as the Sri Lanka soils, had much higher organic P and this fraction constituted more than half of the total P. As in the case of total P, organic P had a very highly significant positive correlation with silt, clay and organic-carbon contents and a very highly significant negative correlation with sand content (Table 3). The positive relationship of organic P with organic carbon has also been reported by several others (Udo & Dambo, 1979; Uzu et al. 1975). The relationship of organic P with sand, clay and silt contents are indirect through their relationships with organic carbon: organic-carbon contents increase with increase in finer size fractions in soils which have a favourable influence on the retention and stabilization of organic P (Black & Goring, 1953).

Inorganic-P fractions

Total inorganic P is divided into active and inactive P forms : the former consists of Al-P, Fe-P and Ca-P and the latter, occluded, reductant-soluble and residual P (Chang & Jackson, 1957). It is generally accepted that the active forms are the main sources of available

Table 1. Description and some properties of the soils.

| Soil series ^a | Great soil ‡ group | Soil Order ** | Parent material & (or distinguishing feature) | Rainfall zone | pH in // water | Organic// carbon(%) | Cation// exchange capacity (m-equiv/ 100 g) | Particle-size analyses// | | |
|--------------------------|--|---------------|---|----------------------|------------------|---------------------|---|--------------------------|-------------------|---------------------|
| | | | | | | | | Clay (%) | Silt(%) | Sand(%) |
| Andigama | (3) Reddish brown | Alfisol | Granitic gneiss | Intermediate | 4.9-5.8 (5.2) | 0.68-1.04 (0.83) | 2.70-3.08 (2.83) | 15.0-20.5 (18.1) | 1.5-2.5 (2.0) | 72.5-79.5 (76.3) |
| Aruvi | (3) Alluvial | Entisol | Alluvium | Intermediate | 5.2-5.7 (5.4) | 0.18-0.43 (0.34) | 1.98-4.01 (2.96) | 2.0-9.0 (6.5) | 2.0-5.0 (3.2) | 83.5-94.0 (87.7) |
| Boratu | (12) Red yellow podzolic | Ultisol | Charnockite and biotite gneiss | Intermediate and wet | 4.8-5.5 (5.1) | 1.07-2.12 (1.46) | 3.75-4.62 (4.06) | 21.5-38.0 (26.4) | 4.0-9.0 (6.2) | 43.0-69.0 (58.3) |
| Cambura | (2) Red latasol | Oxisol | Sands of old beach ridges | Dry | 6.8-7.3 (7.1) | 0.76-0.88 (0.82) | 2.40-4.45 (3.43) | 11.0-12.5 (11.8) | 3.0-6.5 (4.8) | 81.0-87.5 (84.3) |
| Katunayake | (5) Regosol | Entisol | Recent marine sands | Wet | 4.9-5.8 (5.3) | 0.19-0.92 (0.45) | 0.57-3.12 (1.73) | 0.5-8.5 (3.6) | 0.5-2.0 (1.1) | 87.0-98.0 (93.7) |
| Kiriwana | (3) Red yellow podzolic | Ultisol | Quartzite | Intermediate | 5.9-6.2 (6.0) | 0.93-1.01 (0.98) | 4.81-6.51 (5.38) | 18.0-27.5 (21.2) | 6.0-7.5 (7.0) | 63.5-71.5 (69.3) |
| Kurunegala | (3) Red yellow podzolic | Ultisol | Charnockite and granitic gneiss | Intermediate | 5.8-6.3 (6.0) | 0.74-1.04 (0.84) | 3.86-7.32 (5.41) | 23.0-28.0 (24.8) | 5.0-11.0 (7.2) | 49.0-70.0 (62.3) |
| Madampe | (5) Regosol | Entisol | Old marine sands | Intermediate | 4.9-5.3 (5.0) | 0.15-0.22 (0.17) | 0.85-1.85 (1.37) | 1.8-4.5 (3.1) | 1.5-2.0 (1.7) | 91.5-94.5 (92.8) |
| Maho | (3) Reddish brown earth and non calcic brown | Alfisol | Hornblende gneiss | Intermediate | 5.1 (5.1) | 0.55-0.68 (0.62) | 5.02-9.59 (6.63) | 9.5-16.0 (12.8) | 5.5-7.0 (6.2) | 73.0-81.5 (76.2) |
| Negombo | (5) Regosol | Entisol | Recent marine sands | Intermediate and wet | 5.2-5.9 (5.5) | 0.08-0.27 (0.19) | 0.46-1.68 (1.13) | 0-2.0 (0.6) | 0.4-0.8 (0.5) | 98.0-99.0 (98.2) |
| Pallama | (3) Red yellow podzolic | Ultisol | Colluvium | Intermediate and wet | 5.2-5.4 (5.3) | 0.46-1.31 (0.82) | 2.09-2.58 (2.28) | 11.5-19.5 (14.8) | 2.0-2.5 (2.3) | 73.0-84.5 (78.8) |
| Ranurewa | (2) Reddish brown earth | Alfisol | Granitic gneiss | Dry | 6.9 (6.9) | 0.55-0.66 (0.61) | 12.3-13.3 (12.8) | 15.5-17.0 (16.3) | 1.5-4.5 (3.0) | 75.5-78.5 (77.0) |
| Rathu | (4) Regosol | Entisol | Sands of old beach ridges | Intermediate | 5.2-5.6 (5.4) | 0.29-0.37 (0.34) | 3.00-2.40 (2.20) | 5.0-10.5 (8.0) | 2.0-2.5 (2.4) | 85.5-90.0 (87.8) |
| Wariyapola | (2) Reddish brown earth and non calcic brown | Alfisol | Charnockite and biotite granitic gneiss | Intermediate | 5.7-6.3 (6.0) | 0.38-0.48 (0.43) | 4.71-7.99 (6.35) | 13.5-15.5 (14.5) | 2.5-3.0 (2.8) | 78.0-83.5 (80.8) |
| Wipattu | (3) Red latasol | Oxisol | Sands of old beach ridges | Dry and Intermediate | 5.8-6.2 (6.0) | 0.23-0.29 (0.26) | 2.74-3.77 (3.22) | 3.5-7.0 (4.8) | 2.0-2.5 (2.3) | 89.5-92.5 (91.0) |

^a Number of samples in each series within parentheses:

‡ De Alwis & Panabokke (1972-73);

[♠] Fraser (1962, 1962-73)

Range, and mean in parenthesis.

Table 2. Range and mean of values for the different forms of phosphorus

| Soil Series † | | Total P (mg/kg) | Organic P (mg/kg) | Active P (mg/kg) | | | Inactive inorganic P | Olsen P | Available P | | NH ₄ OAc P |
|---------------|------|--------------------|----------------------|------------------|---------------|--------------|-------------------------|-------------------|----------------------------|---------------------------------------|-----------------------|
| | | | | Al-P | Fe-P | Ca-P | | | Bray & Kurtz No. 1 P | (mg/kg) Bray & Kurtz No. 2 P | |
| Andigama | (3) | 97-174 (132) | 14-22 (19) | 5-7 (6) | 14-23 (18) | 5-6 (6) | 44-135 (84) | 0.4-2.2 (1.0) | 1.9-3.1 (2.0) | 1-5 (3) | 0.9-2.2 (2.0) |
| Aruvi | (3) | 37-94 (73) | 15-28 (20) | 3-6 (5) | 6-21 (14) | 4-6 (5) | 6-54 (29) | 0.4-1.2 (0.7) | 0.2-2.6 (1.0) | 3-11 (6) | 0.6-1.6 (0.9) |
| Boralu | (12) | 115-238 (174) | 22-96 (50) | 3-9 (6) | 13-32 (23) | 2-12 (5) | 30-171 (89) | 0.1-1.8 (0.5) | 0.3-2.4 (0.8) | 1-8 (2) | 0.2-2.0 (0.6) |
| Gambura | (2) | 102-110 (106) | 28-31 (30) | 13 (13) | 14-15 (14) | 8-16 (12) | 35-38 (37) | 0.6-0.8 (0.7) | 1.0-1.8 (1.4) | 6 (6) | 1.0-1.3 (1.2) |
| Katunnyake | (5) | 113-244 (145) | 12-54 (32) | 5-7 (34) | 20-30 (24) | 6-14 (8) | 43-114 (72) | 3.8-9.1 (6.0) | 5.3-15.9 (10.0) | 12-34 (24) | 4.0-9.0 (6.0) |
| Kiriwana | (3) | 143-338 (241) | 38-64 (49) | 5-7 (6) | 17-28 (22) | 4-6 (5) | 76-252 (158) | 0.3-1.8 (1.0) | 1.1-3.2 (2.0) | 2-6 (4) | 0.7-1.7 (1.0) |
| Kurunegala | (3) | 123-233 (174) | 32-73 (48) | 3-6 (4) | 21-32 (24) | 3-8 (6) | 57-162 (91) | 0.1-0.5 (0.2) | 0.3-0.9 (0.5) | 1-3 (2) | 0.2-1.1 (0.5) |
| Madampe | (5) | 40-45 (42) | 1-10 (7) | 5-11 (7) | 9-21 (13) | 3-6 (5) | 2-19 (10) | 0.3-3.5 (3.0) | 2.2-7.3 (4.0) | 4-9 (7) | 0.4-3.3 (2.0) |
| Maho | (3) | 2111 (185) | 24-95 (67) | 10-31 (18) | 20-39 (29) | 6-7 (7) | 47-74 (63) | 0.7-2.7 (2.0) | 1.6-3.2 (2.0) | 6-10 (7) | 0.9-2.7 (2.0) |
| Negombo | (5) | 95-125 (122) | 2-15 (7) | 14-25 (20) | 16-40 (25) | 8-26 (20) | 28-49 (39) | 3.4-13.6 (6.0) | 4.0-16.8 (9.0) | 12-30 (20) | 3.4-13.3 (7.0) |
| Pallama | (3) | 68-107 (83) | 11.39 (24) | 6-9 (7) | 14-21 (18) | 2-4 (3) | 21-39 (31) | 0.3-0.7 (0.5) | 0.7-1.7 (1.0) | 2-8 (5) | 0.7-1.1 (0.8) |
| Ranorewa | (2) | 173-191 (182) | 37-41 (39) | 5-6 (5) | 24-32 (28) | 3-5 (4) | 98-113 (105) | 0.4-0.7 (0.6) | 0.6-0.7 (0.6) | 4.5 (5) | 0.7-2.0 (1.4) |
| Rathu | (4) | 119-215 (152) | 5-34 (19) | 5-12 (8) | 14-26 (16) | 3-6 (5) | 82-156 (105) | 0.4-1.1 (0.7) | 1.0-3.4 (2.0) | 2-4 (3) | 0.4-2.9 (1.0) |
| Wariyapola | (2) | 121-216 (169) | 19-21 (20) | 5-9 (7) | 13-26 (20) | 6 (6) | 78-154 (116) | 0.5-0.6 (0.6) | 1.0-1.1 (1.0) | 2-6 (4) | 0.8-1.1 (1.0) |
| Wilpattu | (3) | 91-140 (105) | 16-28 (22) | 8-17 (13) | 10-33 (22) | 5-10 (7) | 16-75 (52) | 0.9-1.6 (1.0) | 3.5-3.6 (3.6) | 6-12 (9) | 1.1-4.1 (2.5) |

† Mean in parentheses.

‡ Number of samples within each series in parentheses.

Table 3. Correlation coefficients between soil P and some general soil properties

| Soil Properties | Correlation coefficient | | | | | | | | |
|--------------------------|-------------------------|-----------|----------|-------|---------|----------|----------|----------|-----------|
| | Total P | Organic P | Al-P | Fe-P | Ca-P | Olsen P | NO.1 P | NO.2 P | NH4 OAc P |
| Sand | -0.46*** | -0.67*** | 0.42*** | -0.20 | 0.40*** | 0.50*** | 0.60*** | 0.58*** | 0.55*** |
| Silt | 0.52*** | 0.65*** | -0.37** | 0.19 | -0.33** | -0.47*** | -0.56*** | -0.55*** | -0.51*** |
| Clay | 0.49*** | 0.67*** | -0.45*** | 0.22 | -0.40** | -0.54*** | -0.64*** | -0.63*** | -0.59*** |
| Organic carbon | 0.48*** | 0.54*** | -0.24* | 0.22 | -0.22 | -0.27* | -0.36** | -0.37** | -0.35** |
| Cation exchange capacity | 0.30* | 0.38** | -0.18 | 0.16 | -0.09 | -0.32* | -0.40** | -0.30* | -0.29* |
| pH | 0.02 | -0.05 | -0.14 | -0.01 | 0.14 | -0.21 | -0.20 | -0.11 | -0.14 |

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

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inorganic P for plants (Thomas & Peaslee, 1973). The relative abundance of the inorganic forms gives also an indication of the degree of chemical weathering of the soils; the strongly weathered ones have a higher proportion of inactive inorganic forms and Fe-P than others (Chang & Jackson, 1957). The data in Table 2 show that in the majority of soils inactive inorganic P constitutes a major portion of the total P.

Inactive inorganic P constituted 53% of the total P in Ultisols and Alfisols and 47 and 43% in Entisols and Oxisols respectively. This corresponds to 73, 75, 53 and 53% of the total inorganic P in the four Orders of soils respectively. High proportions of this form indicate limited supply of available P to plants. Inactive P and Fe-P together accounted for 91, 87, 75 and 73% of the total inorganic P in Ultisols, Alfisols, Oxisols and Entisols, respectively. These high percentages indicate intense degree of chemical weathering of these soils especially the Ultisols and Alfisols. The rest of the Entisols except Rathu did not contain as high a percentage of inactive P. Rathu soils had high content of iron oxides (Waikkala soil: Loganathan & Fernando, 1980) and this may have increased P fixation and reductant-soluble P and hence increased the inactive P fraction.

The relative abundance of the various inorganic forms were in the order of inactive P \gg Fe-P \gg Al-P \gg Ca-P for all soil series of Ultisols and Alfisols. This pattern is in good agreement with the observation made on the well drained members of Ultisols and Alfisols of Nigeria (Uzu et al. 1975). The pattern also holds for the Wilpathu, Rathu and Aruvi series of the other soil Orders. For soils of Katunayake (Entisol), Negombo (Entisol) and Gambura (Oxisol) the distribution was inactive P \gg Al-P \gg Fe-P \gg Ca-P. Madampe soils which had the lowest content of total P had Fe-P \gg inactive P \gg Al-P \gg Ca-P. The smaller influence of inactive P and Fe-P in the above four soils indicates that they are not as highly weathered as the members of Ultisols and Alfisols and are capable of supplying P available to plants from a larger inorganic pool

The amounts and relative distribution of the three active inorganic forms, Al-P, Fe-P and Ca-P and organic P determine the capacity of the soils to supply available P to plants. Organic P is important in soils high in organic matter and neutral to alkaline in reaction where mineralization of organic P is significant. Of the three active inorganic forms, Al-P is considered to be most available P under acidic upland conditions, Fe-P under flooded conditions, and Ca-P in calcareous soils, although exceptions have been observed in many studies (Thomas & Peaslee, 1973). Mean values of the active inorganic P forms for the various soil series range from 4 to 34 mg/kg (2 to 20% of total P) for Al-P, 13 to 29 mg/kg (9 to 31% of total P) for Fe-P, and 3 to 20 mg/kg (2 to 18% of total P) for Ca-P (Table 2). Al-P and Ca-P were generally high in the sandy soils which belong mostly to Entisols. Al-P and Ca-P had significant positive correlations with sand content and significant negative correlations with clay and silt contents (Table 3).

Available P

Available P extracted by the methods of Olsen, Bray & Kurtz No. 1 Bray & Kurtz No.2 and NH_4 OAc are shown in Table 2. Of the four methods, Bray & Kurtz No. 2 removed the highest amounts of P, ranging from 1 to 12 mg/kg with a mean of 4 mg/kg for all soils except those from the Katunayake and Negombo series where the range was 12-34 mg/kg and mean

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was 22 mg/kg. This constituted on average less than 16% of total P for soils of Katunayake and Negombo and less than 3% for the other soils. The least amounts of P were extracted by the methods of Olsen and by NH_4 OAc, the amounts ranged from 0.1 to 5.5 mg/kg for all soils except those from Katunayake and Negombo where the range was 3.4-13.6 mg/kg. The soils of Sri Lanka are, therefore, in general not only low in total P but also in available P, indicating that the soils are infertile with respect to P. Bray & Kurtz No. 1P ranged from 0.2 to 3.6 mg/kg with a mean of 1.3 mg/kg for all soils except soils of Madampe, Negombo and Katunayake where the range was 2.2-16.8mg/kg with a mean of 7.7 mg/kg. Reclaimed, alluvial, laterite, sandy loam and coastal sandy soils of coconut-growing regions of India (Wahid et al. 1977) contained Bray & Kurtz No. 1 P of 5.4, 8.1, 8.5, 10.8 and 16.1 mg/kg respectively.

Though the total P was highest in Ultisols and Alfisols, the available P was the lowest. This is due to the higher clay contents of these soils which have higher P fixation capacities due to the higher degree of weathering which reduced the active P fraction in the soils (Table 2). Table 3 shows that available P extracted by all four methods was positively correlated with percentage sand and negatively correlated with percentages of silt, clay and organic carbon. The effects of sand, silt and clay contents on P availability are as expected; the higher the clay and silt content, the higher the P fixation lower the availability of P (Tisdale & Nelson, 1966). Though increase of organic carbon was shown to increase P availability (Tisdale & Nelson, 1966), the data on Sri Lanka soils showed a negative relationship. The organic C/organic P ratio of most of the soils was above 200 and available inorganic P may have been immobilized rather than organic P mineralized in most of these soils (Tisdale & Nelson, 1966). This provided a possible explanation for the negative relationship which may, however, be indirect and result from the association of organic carbon with the clay fraction of the soil; the relationship is therefore probably the effect of clay on P availability rather than that of organic carbon.

Thomas & Peaslee (1973) reported that most soils containing extractable P of less than 15 mg/kg as determined by Bray & Kurtz No.1 method and less than 5 mg/kg by Olsen's method were low in available P, and values of 16-30 and 6-10 mg/kg by the respective methods were 'medium' with respect to P availability. Pritchett & Gooding (1975) considered that NH_4 OAc (pH 4.8) extractable P of 1.5-2.0 mg/kg was the critical soil P range limiting the growth of slash pines. Although the above values were reported for different crops under soil conditions other than those of Sri Lanka, nevertheless they serve as a guide in evaluating the P availability in the soils of Sri Lanka. Based on these values, the soils of Sri Lanka appear to have low to very low contents of available P, except the sandy soils of Negombo and Katunayake series. Nethsinghe (1965) reported that coconut grown on soils containing 8.8 mg/kg Olsen's extractable P did not respond to P fertilizer applications and coconuts on soil containing P of 4.6 mg/kg responded to P. On this basis, too, all soils except those of Negombo, Katunayake and perhaps Madampe series were low in available P.

Manciot, Ollagnier & Ochs (1979) reported that the lowest value of Olsen's P considered satisfactory for coconut was 25 mg/kg. Although this threshold value is high compared with the rest of the values reported in literature, this too supports the view that the coconut-growing soils of Sri Lanka are P-deficient.

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Available P extracted by all four methods was highly correlated with AL-P and Ca-P, the relationship being stronger with Al-P; Fe-P was weakly correlated and only with three of the methods (Table 4) Udo & Dambo (1979) reported that the four forms, Al-P, Ca-P, Fe-P and organic P were correlated with available P extracted by the methods of Bray & Kurtz No.1 and Olsen in acid soils of Nigeria; the relationship was strongest with Al-P and least with organic P. Halm & Bampoe-Addo. (1972) on the other hand showed that only Al-P was correlated with P extracted by Bray & Kurtz No.1, Bray & Kurtz No.2 and Olsen's methods in the upland, predominantly acid of Ghana. The data on the soils from Sri Lanka agree with the above results that Al-P is most selectively extracted by the four methods used to estimate available P. A weak negative correlation was observed between organic P and Bray & Kurtz No.1 extractable P; none of the other methods showed any significant correlation with organic P.

Table 4. Correlation coefficients between available P and P fractions

| Available P | Total P | Organic P | Al-P | Fe-P | Ca-P |
|-----------------------|---------|-----------|---------|-------|---------|
| Olsen P | -0.03 | -0.20* | 0.68*** | 0.28* | 0.42*** |
| Bray & Kurtz No. 1 P | -0.06 | -0.03* | 0.68*** | 0.16 | 0.42*** |
| Bray & Kurtz No. 2 P | -0.04 | -0.19 | 0.81*** | 0.26* | 0.48*** |
| NH ₄ OAc P | -0.01 | -0.22 | 0.71*** | 0.32* | 0.45*** |

* P<0.05; *** P<0.001.

Coconut leaf P

Leaf-P concentrations in the 14th leaf of coconuts in the 35 selected sites ranged from 0.074 to 0.116% with only palms in Negombo (0.116%) and Katunayake (0.116%) series having values close to 0.120%, the critical 14th leaf-P concentration in coconut (Fremont, Ziller & De Nuce De Lamothe, 1966; Kanapathy, 1971; Magat, 1979; Manciot et al. 1979). This is in accord with the soil data which also showed that, except for the above two series, the soils were deficient in P. Table 5 shows the correlation of leaf-P concentrations with available P and P fractions. Of the available P methods only Bray & Kurtz No. 2 and NH₄ OAc extractable P were statistically correlated with Leaf P. These extractants are also a satisfactory measure of P availability to other tree crops. Wells (1965) reported that available P extracted by Bray & Kurtz No. 2 method was significantly correlated with P concentration in needles of loblolly pine and Pritchett & Gooding (1975) recommended NH₄ OAc (pH 4.8) extractable P as the best method to diagnose P deficiency in slash pines. Only Negombo and Katunayake soils had leaf-P values close to the critical leaf-P concentrations and therefore Bray & Kurtz No. 2 and NH₄ OAc extractable-P values for these soils could reasonably be considered as critical soil-P values for coconut. On this basis Bray & Kurtz No. 2 and NH₄ OAc-P values should be at least about 24 and 7 mg/kg respectively to meet the P needs of coconut. Though the correlation between P extracted by the other two methods (Olsen and Bray & Kurtz No.1) and leaf-P were not statistically significant, the Negombo and Katunayake soils had much higher values of P than the other soils even by these methods (Table 2). Olsen's value of 6 mg/kg obtained for these soils is reasonably close to the value of 8.8 mg/kg reported by Nethsinghe (1965) for soils where coconut failed to respond to P application.

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Table 5. Correlation coefficients between leaf P and soil P

| | |
|-----------------------|-------|
| Olsen P | 0.33 |
| Bray & Kurtz No. 1 P | 0.43 |
| Bray & Kurtz No. 2 P | 0.56* |
| NH ₄ OAc P | 0.52* |
| Total P | -0.09 |
| Organic P | -0.38 |
| Al-P | 0.44 |
| Fe-P | -0.04 |
| Ca-P | 0.49 |

* P<0.05.

Of the P fractions only Al-P and Ca-P showed positive correlations with leaf P and the relationship was close to statistically significant at $P < 0.05$ (Table 5). This agrees with the relationships between P fractions and available soil P extracted by the four chemical methods noted earlier (Table 4). Susuki, Lawton & Doll (1963) also observed that Al-P and Ca-P were important in supplying P to plants in 17 Michigan soils ranging in pH from 4.8 to 7.8 although other evidence was cited to indicate that Fe-P was also important in supplying P to plants (Thomas & Peaslee 1973). Loganathan & Nalliah (1977) observed that P concentrations in the 14th leaf of coconut were significantly correlated with Fe-P and Al-P but not with other forms of P in an experiment comparing rock phosphate and concentrated superphosphate in a sandy soil. The absence of correlation with Ca-P was perhaps due to the presence of larger proportions of undissolved apatite from the added rock phosphate in the soil which did not contribute towards P availability to coconut.

CONCLUSIONS

The results of the study showed that soil supporting coconut in Sri Lanka were generally deficient in total as well as the active and available forms of P. Except some of the sandy soils (Negombo, Katunayake and perhaps Madampe) of the Entisols the rest of the soils were severely deficient in P. Although soils of the Ultisols and Alfisols had marginal to moderate amounts of total P, the active and available fractions were extremely low. Negombo, Katunayake and Madampe generally had marginal to moderate amounts of active and available P but low total P indicating that though the P intensity factor (available P) is marginal to moderate, the P capacity factor (total P) is low and as a result, with long-term cropping, even these soils may become P-deficient. Phosphorus deficiency in the soils was confirmed by the low levels of leaf-P in the palms. The data explain the general response of coconut to P fertilizer applications observed in many experiments in Sri Lanka compared with other countries such as the Philippines (Magat, 1979; Prudente & Mendoza, 1976), Tanzania (Thomas & Nandra, 1973), Jamaica (Smith, 1969), and Malaysia (Kanapathy, 1976), all of which appear to contain sufficient soil P. Application of P fertilizers is therefore essential to achieve high production of crops on soils in Sri Lanka. With the present trend of intercropping in coconut lands, deficiency of P would be aggravated unless adequate P fertilizers are added.

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Only in a few instances in Sri Lanka did coconut not respond to P fertilizers. One such case was reported in a factorial NPK experiment at Bandirippuwa where no response to P fertilizer was obtained for the first 27 years of the experiment (Nethsinghe, 1983). This was explained as due to residual effects of heavy dressings of bone meal applied to the soils prior to the commencement of the experiment; the residual P from the early applications had remained in the soil for a long time. Soils could be tested to determine whether such a situation exists in lands, before making decisions on P fertilizer application. The present study showed that Bray & Kurtz No. 2 and NH_4OAc (pH 4.8) extractable P were better indices of P availability, though Nethsinghe (1965) observed that Olsen's extractable P could demarcate P deficiency and adequacy. NH_4OAc (pH 4.8) extraction has an additional advantages as it extracts active Al which is a good predictor of P fixation (Loganathan & Fernando, 1980) and hence this method could, in addition, indicate the P fertilizer needs these soils and the type of P fertilizer to be applied as proposed for slash pines (Ballard & Pritchett, 1974).

We thank Mr. V. Abeywardene, Biometrician, Coconut Research Institute of Sri Lanka for help in the statistical analysis of the data.

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