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Characterization of Soil Physical Properties in Andigama Series in Relation to Coconut Root Growth

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ABSTRACT. A study was conducted to characterize soil physical properties of the Andigama series in relation to its moisture status, which is useful for developing management practices for coconut cultivation in this soil. Results showed that clay fraction and % of different gravel sizes (>12,12-5,5-3,3-2 mm) were significantly higher in the B horizon compared to the other horizons. In the B horizon, gravel particles were cemented by the clay fraction forming a hard layer of which the bulk density (1.62 ± 0.07 g/cc) was significantly greater compared to that of other horizons. The field capacity (17.09 ± 3.58% m^3/m^3) and permanent wilting point (13.6 ± 3.3% m^3/m^3) were significantly higher in the B horizon compared to the other horizons but its total and readily available water fractions were lower. The available water fraction in horizons A, AB and B decreased by 66% before reaching 1 bar (100 kPa) suction. Neutron probe studies showed that in 10 days, there was a depletion of 3, 1.5 and 1% from the field capacity in A, AB and B horizons, respectively. Steady infiltration rate of the series was 4.6 ± 2.5 cm/h. Due to the above soil physical constraints, coconut roots become inactive by suberization and dehydration process. It was found that 75% of the effective root zone of coconut was confined within the depth range of 20 to 80 cm.

INTRODUCTION

The Andigama series is classified under the major soil group of Red Yellow Podzolic with soft or hard laterite and is located in the agroecological

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region IL1 (semi-wet Intermediate low country region), of Sri Lanka. This soil is a moderately well-drained, shallow to moderately deep, sandy clay loam mixed with considerable amount of ironstone gravel (Somasiri *et al.*, 1994).

Total extent under this series in the coconut triangle is 28664 ha. Coconut grown in this soil show low yields due to its poor physical conditions and moisture status. Soil physical conditions affect the physiological functions such as absorption and respiratory process of the root system (Boone and Veen, 1994). The need to identify the major soil constraints and favourable factors of this series is important to implement better management practices for optimizing coconut production.

Therefore, objective of this study was to characterize soil physical conditions with respect to coconut root growth of Andigama series.

MATERIALS AND METHODS

The experiment was conducted during September 1992 to December 1993 for different locations in the Andigama series soil situated in the coconut triangle. Ten soil pits (1 x 1.5 x 1.5 m) were cut randomly in different locations in this series.

The examination of the soil profiles at the experimental sites showed three distinct soil horizons namely A, AB and B corresponding to 0-15, 15-50, 50-100 cm depths, respectively. Undisturbed soil core samples were taken from each 5 cm interval up to 1.2 m depth to measure bulk density, texture and percentages of different classes of gravel. Sieves of different mesh sizes (12, 5, 3 and 2 mm) were used to separate the gravel sizes. Undisturbed soil core samples were taken using steel core samplers of 7.5 cm in diameter and 5 cm in height for bulk density and 4.5 cm in diameter and 3.5 cm in height for soil moisture retention determination. Soils in core sampler were transferred to aluminium rings (4.5 x 3 cm) for water retention measurements. The core samples were wrapped in polythene to prevent drying and were transported to the laboratory. Undisturbed samples were saturated and water retention measurements were taken using standard pressure plate apparatus as described by Klute (1986) for different suction intervals ranging from 1 to 1500 kPa. The gravimetric water content at each suction level was estimated and converted to the volumetric water content using the corresponding bulk densities. The mean values of volumetric water content between 10 kPa and 100 kPa suction was used to calculate the percentage of readily available water fraction (Mapa and Bodhinayake, 1988).

Moisture depletion pattern of the soil was determined using neutron probe apparatus (Troxler model no. 3332). The field calibration was carried out carefully as mentioned by Bell (1987) at four sampling sites. Each soil horizon was exposed, saturated and allowed to drain to determine their moisture depletion patterns.

Steady infiltration rate was measured in ten experimental sites by means of the falling head method with double ring infiltrometer as described by Bouwer (1986).

Hydrometer method (Gee and Bauder, 1986) was used for soil texture analysis. Total porosity was obtained using bulk density and partial density values. Particle density was assumed as 2.65 g/cm^3 (Danielson and Sutherland, 1986). Total porosity was used to estimate the volumetric water content at saturation corresponding to zero suction level. Pores which were unable to hold water at 10 kPa suction (diameter 0.03 mm) were estimated as macropores and rest as micropores.

Root measurements within the radius of 3 m from the bole of coconut palm were taken to evaluate the root distribution pattern. The volume of soil core samples used was 1000 cm^3.

RESULTS AND DISCUSSION

Texture, gravel distribution and bulk density

The primary particles, gravel sizes distribution and bulk density data in each 5 cm depth increments of profile are shown in Figure 1a and 1b. Results indicated that sand fraction decreased with the depth of the soil profile.

Silt and clay fractions of soil profile increased significantly ($P>0.001$) with the depth and the highest clay and silt contents were observed in the B horizon compared to A and AB horizons. Existing high clay and silt particles in soils are important because clay and silt are more responsible in creating micropores which will result in increasing nutrient and water retention ability of soil (Russell and Goss. 1976).

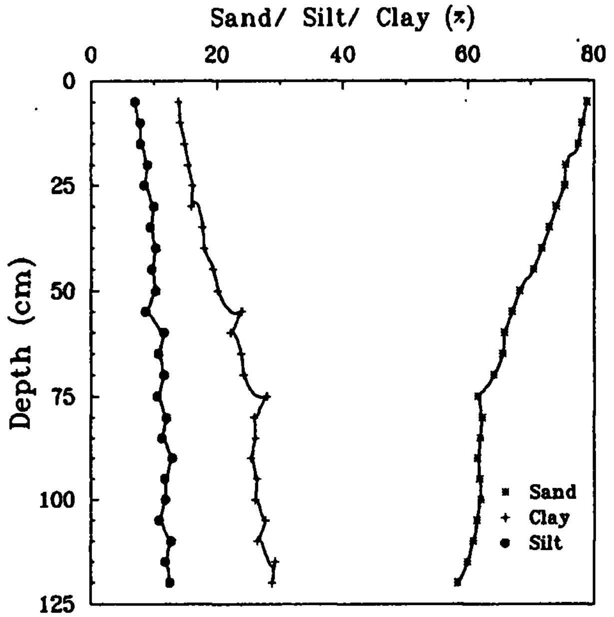

Figure 1a. **Texture profile of Andigama series.**

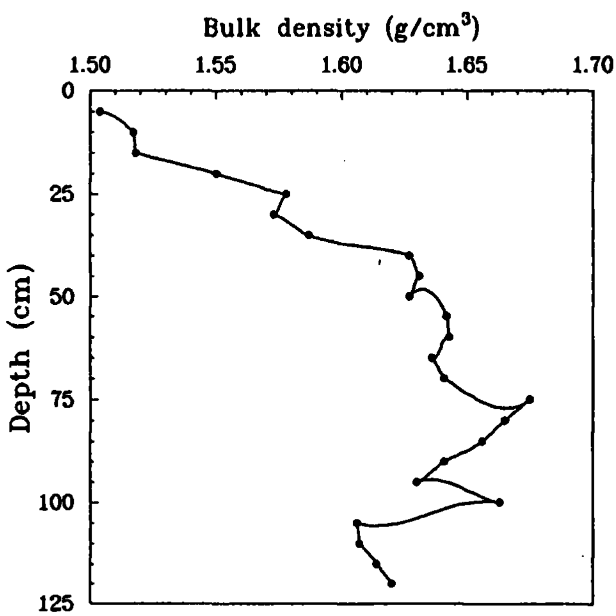

Figure 1b. **Bulk density of Andigama series.**

Sand fraction in A and AB horizons was significantly (P>0.001) higher than that in B horizon. Increased sand particles is beneficial in increasing the macropore volume that results in increasing aeration capacity and drainage ability of soil (Brady, 1990).

The gravel distribution down to 1.2 m depth of soil profile is shown in Figure 2. Results showed that percent of gravel particles, <2 mm size was higher in A horizon and it remained almost constant beyond the 65 cm depth, while percent of 2-3 mm gravel particles remained almost constant throughout the soil profile. Furthermore, percent of >3 mm gravel particles (3-5, 5-12 and >12 mm) were gradually increasing to the depth of 65 cm and remained almost constant. Statistical analysis revealed that distribution of gravel particles such as >12, 12-5, 5-3 mm is significantly higher (P>0.001) in AB and B horizons compared to A horizon of the soil profile. As described by Lal (1981) the distribution of gravel particles in soil affects the pore size distribution, bulk density, resistance to root penetration, water retention and accuracy of techniques monitoring these properties.

Results in Figure 1b shows that bulk density of soil profile of Andigama series increased down 65 cm depth and thereafter remained as a constant.

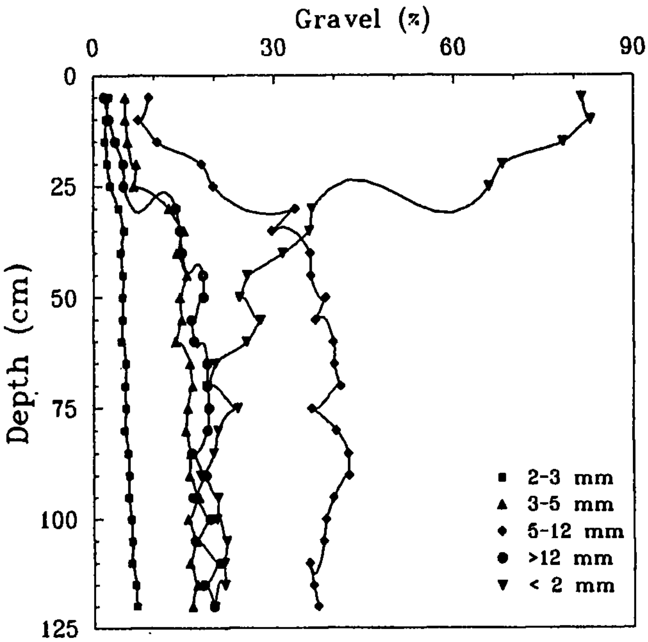

Figure 2. Gravel distribution in Andigama series.

The bulk density was significantly ($P>0.001$) lower in the A horizon compared to AB and B horizons. In addition, a high bulk density value (1.65 g/cm^3) was observed in the B horizon. High bulk density (>1.6 g/cm^3) is one of the major constraints in soils (Brady, 1990) that adversely affects crop production. High clay content of B horizon of Andigama series could be the reason for high bulk density as clay particles cement with gravel particles which results in increasing bulk density. This soil compaction process limits the supply of necessary gases, water and nutrients (Boone and Veen, 1994) that could result in retardation of root growth and proliferation.

Pore size distribution

The total porosity, macroporosity and microporosity for the major horizons of Andigama series are shown in Figure 3. The total porosity and macroporosity were highest in A horizon, while the lowest macroporosity was observed in the B horizon. Water in macropores drain under the influence of gravity and will form the basis for aeration capacity where the limiting value for highland crops is 10% (Landon, 1984). It was observed that these soils do not have any waterlogging problem in rainy season. In addition, good aeration capacity lead to increased drainage that could enhance coconut root growth and proliferation with better functioning of respiratory organs. Joshua (1988) explained that aeration is the process responsible for maintaining the supply of oxygen in soil. Oxygen due to its direct involvement in respiration, is necessary for proper functioning of roots and is beneficial for the decaying process (Brady, 1990). Results also showed that the micropores of B horizon (17%) are significantly ($P<0.001$) higher than that of other horizons. This may be due to the high clay content of B horizon and higher micropores that help to retain more nutrients and water in the soil profile. However, the high compaction in B horizon tend to reduce water percolation and retention. Complimentary to this study, Kooistra and Tovey (1994) documented that compacted soil conditions can hamper infiltration, root growth and proliferation, or can result in filling and blocking voids below the surface. Consequently, total porosity is reduced and most of the continuous voids disappear.

The soil moisture retention relationships

The soil moisture parameters in Tables 1 and 2 were obtained from the moisture characteristic curves of the Andigama series (Figure 4). Field capacity

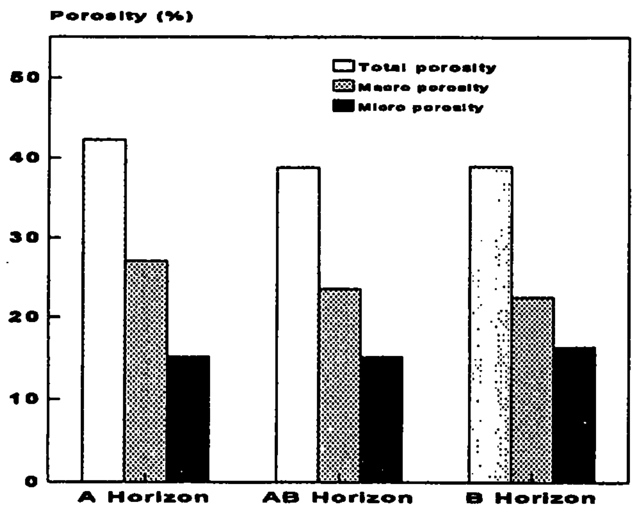

Figure 3. Total macro and microporosity of Andigama series.

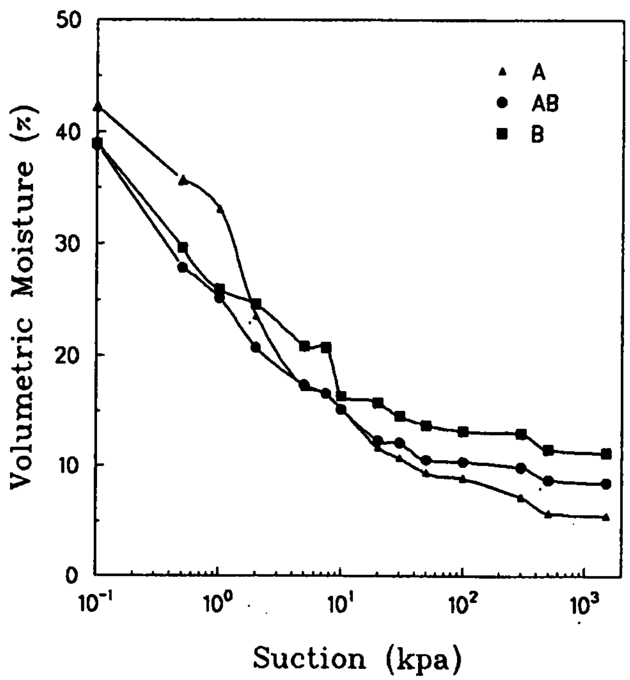

Figure 4. Moisture characteristic curve for Andigama series.

Table 1. **Soil moisture parameters obtained from moisture characteristics for Andigama series.**

Parameter	Volumetric water (%)		
	A	AB	B
FC (10 kPa)	15.86 ± 2.6	15.65 ± 2.7	17.09 ± 4.0
PWP (1500 kPa)	6.81 ± 2.5	9.29 ± 1.9	13.60 ± 3.3
AW	9.05	6.38	3.54
RAW (10-100 kPa)	6.46	4.55	2.20

FC - Field capacity
PWP - Permanent wilting point
AW - Available water
RAW - Readily available water

Table 2. **Depletion of available water as a percentage of total available water at selected suction increments for Andigama series.**

Suction increments (kPa)	Depletion (%)		
	Horizons		
	A	AB	B
10 - 20	36.20	42.57	11.31
10 - 30	46.06	45.70	34.89
10 - 50	60.58	69.06	51.26
10 - 100	65.35	71.43	62.18
10 - 300	82.63	78.87	65.89
10 - 500	97.61	95.83	94.93
10 - 1500	100.00	100.00	100.00

and permanent wilting point increased with depth of soil profile and were positively correlated with clay content. This was agreeable with the findings of Mapa and Bodhinayake (1988) on their work with Non-calcic Brown soils. In addition, Ley *et al.* (1993) also reported that metric potential and soil strength were positively related to clay content, bulk density and certain fractions of water suspendable solids. However, available water in A and AB horizons of Andigama series was significantly higher (P<0.001) compared to the its B horizon. This may be due to the characters of B horizon of Andigama series. Highly compacted clay with gravel in the B horizon could replenish available water fraction from their pores. Stepniewski *et al.* (1994) also reported that soil compaction reduces void ratio and available water fraction of soil which resulted in retardation of crop growth. Furthermore, the highest available water retention was observed in the A horizon and the lowest in the B horizon. However, Mapa and Bodhinayake (1988) reported that surface horizon of Non-Calcic Brown soil has less available water in surface horizon compared to sub surface horizons.

The water depletion from field capacity was computed and 66% of water was lost before reaching 100 kPa (1 bar) suction (Table 2). Readily available water (RAW) fraction is important for plant growth and RAW can be absorbed by plants without stress (Brady, 1990). In Andigama series existence of RAW fraction in the soil pores of each horizon was almost similar except that in B horizon. RAW was lowest in B horizon of Andigama series due to the existing compacted clay layer. Moisture characteristics curve of A horizons showed better performance compared to that of AB and B horizons. Other physical characteristics discussed above also proved that A horizon of the soil profile provided better conditions for crop growth and development compared to other horizons.

Neutron probe studies on moisture depletion pattern of soil profiles revealed that moisture depletion from B horizon is slow compared to depletion time of A and AB horizons. This may be due to the high amount of micropores present in B horizon as a result of higher clay content.

The moisture depletion pattern of each soil horizon revealed that water in A and AB horizons deplete rapidly compared to the B horizon. Depleted volumetric moisture percentage from field capacity of A, AB and B horizons during 10 days were about 3%, 1.5% and 1% respectively. The highest depletion in A horizon could be due to the contribution of more macropores compared to AB and B horizons (Figure 5). Similar results were reported by Mapa and Bodhinayake (1988) for Non-Calcic Brown soils.

Infiltration

The cumulative infiltration *vs* time data for ten locations of the series Andigama was fitted to the Kostiakove equation to obtain the infiltration parameters as explained by Clemments (1983).

The steady infiltration rate of Andigama soil series was 4.6 ± 2.5 cm/h and time taken to wet the 1.5 *m* depth of soil profiles upto the field saturation was 7 hrs.

Infiltration rates are important to plan irrigation projects and decide the irrigation frequencies. Infiltration values can also be used to compute runoff component in planning soil conservation measures (Mapa and Pathmarajah, 1995). Further, these results explain that runoff component is higher in Andigama series. Therefore low inflow rate with low irrigation frequency and moisture conservation practices are required for Andigama series to increase coconut production.

Coconut root distribution

Knowledge on the root distribution of adult coconut palm throughout soil profile is important and useful to implement the irrigation and fertilization practices efficiently.

Data on root distribution pattern throughout soil profile of Andigama series within the manure circle of coconut are shown in Figure 6. Results revealed that root proliferation significantly ($P<0.001$) reduced with the depth of soil profile and is limited up to the 1.5 m depth of soil profiles. This may be due to high compaction of soil as explained by Boone and Veen (1994).

Experimental results have shown that about 75% of effective coconut root zone occur within the depth ranging from 20 to 80 cm vertically and about 5% of roots mass occurred in the top 10 cm layer and beyond 100 cm depth (Figure 6).

Neutron probe studies also revealed that active coconut roots were higher within the radius from 50 cm to 200 cm horizontally from the coconut bole. Therefore, roots occurring in this zone up to 80 cm depth should be protected from drought stress. About 5% roots occur beyond 100 cm depth (Figure 6) which could be beneficial to compensate evapotranspiration demand.

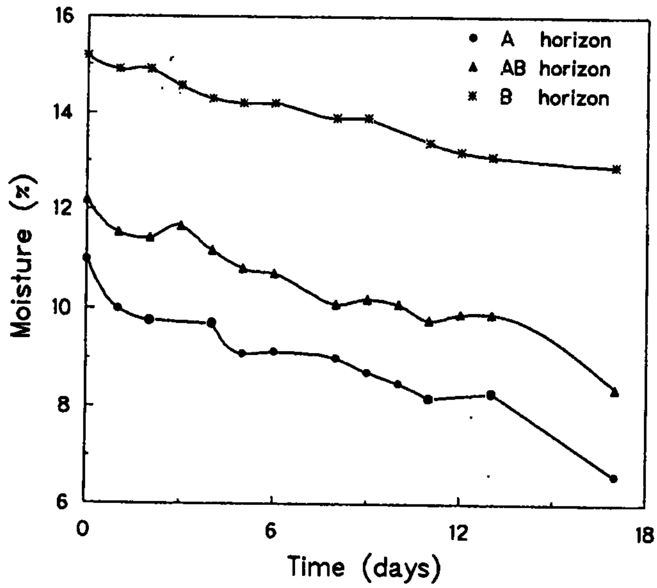

Figure 5. **Moisture depletion in different horizons.**

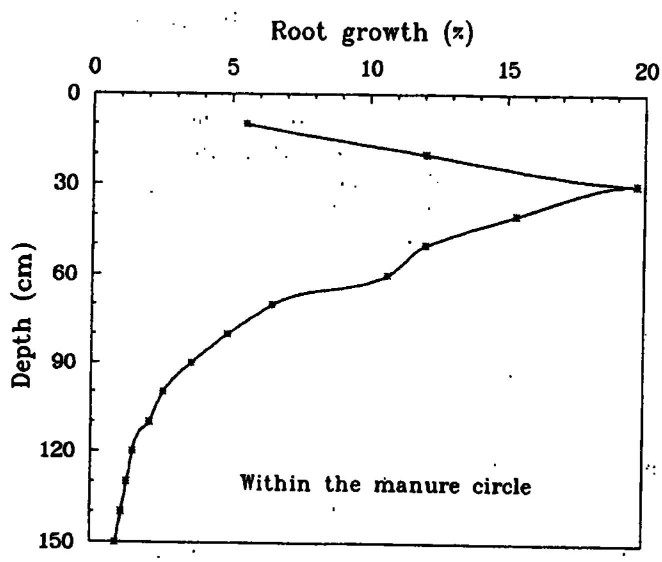

Figure 6. **Coconut root distribution in Andigama series.**

Supporting these findings, Tardieu *et al.* (1992) reported that absorption of water from deeper layers by 5% of the root mass in deep loamy soils would be sufficient to compensate the evapotranspiration demand of plants, but it would not completely nullify the moisture stress of coconut during dry periods.

During the dry period, effective root zone of coconut in most soils suffer from moisture stress due to poor moisture availability. Experimental results showed that drought stress induces coconut roots to re-produce more roots, but those roots become inactive very soon under the drought stress by the process of suberization and dehydration. Moreover, results explained that during dry period, roots which can tolerate water and soil physical stress promoted suberization process itself and immature roots tend to dehydrate. This can be clearly observed in B horizon of Andigama series. As immature roots are more active in absorption of water and nutrient than suberized mature roots they need to be protected from drought. Therefore, proper moisture in the root-soil interface enhances efficient nutrient movement towards coconut roots and also assure the root survival for absorption.

Therefore, reduction of coconut yield due to drought could be a result of (1) inefficient fertilizer absorption and (2) dehydration of immature coconut roots.

Precautions

Studies on root characteristics under stress conditions have revealed the importance of following moisture and soil conservation practices recommended by Coconut Research Institute such as mulching, cover crop establishment, soil amelioration using organic manure, and husk/coir dust pits establishment in the effective root zone of coconut to minimize "drought damage". Such practices help to conserve rain water in the soil and irrigation practices with low flow rates and frequencies such as drip or basin irrigation linked with moisture conservation practices can be successfully adopted in severe dry period to remedy the "drought damage" and soil physical stress.

In addition, growing of deep rooting crops such as nitrogen fixing trees in the center square of coconut plantations and establishment of husk/coir dust pits in AB and B horizons can improve poor soil physical conditions and moisture status of the Andigama series which could result in increasing effective and viable root mass of coconut.

CONCLUSIONS

It is evident from these results that aeration, drainage status and freely available water fraction were higher in the A horizon compared to AB and B horizons. However, the above conditions were poor in B horizon due to compaction of clay with gravel fractions and replenishment of available water fraction. Low infiltration ability of the Andigama series soil increased surface runoff, while infiltrated water depleted slowly throughout the profile. The adverse soil physical conditions and water stress of the soil series led to dehydration and suberization processes and resulted in production of more inactive coconut roots. Moreover, results revealed that the 75% of effective coconut root zone was restricted within the depth range from 20 to 80 cm and about 5% roots were in the top soil layer and beyond 100 cm depth.

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