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THE IMPACT OF SOIL TYPE, SOIL COMPACTION AND WATER STRESS ON ABOVE AND BELOW GROUND COMPONENTS OF COCONUT (*COCOS NUCIFERA* L.) SEEDLINGS

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ABSTRACT

Although the requirement of coconut seedlings for the National Replanting Programme (NRP) was estimated to be around 1.45 million per year, the actual demand exceeds 3 million due to extremely high mortality (sometimes over 50%) during field establishment. Hence, the main objective of this experiment was to investigate the physiological aspects in coconut seedlings during the first few months following establishment in commonly available soil series in coconut growing areas in order to develop possible measures to rectify the problem.

Performance of open pollinated six-month-old CRIC 60 (*Tall x Tall*) coconut seedlings grown in soils from *Weliketiya*, *Wilpattu* and *Mavillu* soil series at two different compaction levels (Bulk density 1.3 and 1.6 $g.cm^{-3}$) was evaluated. Six weeks following the establishment in pots (pot size 0.067 m^3) in the plant house environment, an eight-week stress period was imposed by withholding water. Growth and development of above and below ground components were investigated at the end of the experiment.

The high nutrient content (N, P, K and Mg), cation exchange capacity and organic carbon content contributed to a better seedling growth in *Wilpattu* series soil. Total biomass in seedlings grown in *Weliketiya* and *Mavillu* soils was less by 16% and 14.5%, respectively. In *Wilpattu* series soil compaction has resulted in a reduced root system. Yet, sturdy roots have penetrated hardy soil to reach stored water in deeper layers. The resulting coconut seedling with a large canopy supported by a poor root system is more vulnerable in a subsequent drought.

Generally the improvement of *Weliketiya* and *Mavillu* soils with respect to the physical and chemical parameters would help in arresting the mortality rate and reduction in vegetative growth. Alleviation of high soil compaction to facilitate the root growth appears important in the establishment of coconut seedlings.

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INTRODUCTION

The dry spells, which prevailed in Sri Lanka during the last two decades, have adversely affected the NRP that was in operation for four decades for systematic replacement of senile palms by new cultivars in order to maintain the sustainability of the crop. The annual demand for coconut seedlings has always being higher than the estimated requirement for the NRP in recent years (Peiris and Samarajeewa, 1997) in spite of the fact that around 33% of growers use their own seedlings for replanting. According to Liyanage (1998), the current demand for coconut seedlings is over 3 million although the actual requirement for the NRP is only about 1.45 million per year. It was shown that the reason for this gap was due to the high mortality of coconut seedlings during the establishment phase resulting from the adverse conditions such as water stress (Fernando, 1996). This stress condition varies in different soils which have different chemical and physical characteristics and especially with different soil compaction levels. In view of this situation, this experiment was started with the objective to investigate the shoot and root growth of coconut seedlings established in different coconut growing soils having different compaction levels during the first few months of establishment. This study will enable to identify inherent characteristics of commonly available soils in coconut growing areas and their impact on growth and establishment of coconut seedlings. Information on growth of root and shoot systems in relation to the water stress in coconut is important in developing remedial measures for arresting the high mortality in young coconut palms in various coconut growing soils.

MATERIALS AND METHODS

Planting material

Six month old, open pollinated CRIC 60 (*Tall x Tall*) coconut seedlings from Isolated Seed Garden (ISG), *Ambakelle,* Sri Lanka were used in the experiment. Seedlings were released from a healthy stock of seed coconuts, which exhibited over 90% germination. Selection for the uniformity of material was made on growth parameters of the seedlings such as height, girth at collar region and the number of leaves at the commencement of the experiment.

Soils and preparation of pots

Three soils types representing three main soil series *viz. Weliketiya*, *Wilpattu* and *Mavillu* (Somasiri *et al.*, 1994) were collected from Puttalam. Large galvanized iron pots (33 cm diameter and 85 cm height) were filled with air-dried soil, free of foreign objects, up to 75 cm height amounting to a total volume of 0.067 m^3 (2.375 cubic feet) per pot. Two compaction levels having bulk densities of 1.3 and 1.6 g cm^{-3} that lie within the inherent compaction range of those soils were prepared. All externally visible roots were removed from seedlings and the seed portion was dipped in 1% *Benomyl* solution for one hour to prevent possible fungal infections. Seedlings were planted in pots after applying coal tar on cut surfaces of roots and allowed to establish for six weeks in the glass house environment under field capacity before imposing the watering treatments.

Plant house conditions

The level of Photosynthetically Active Radiation (PAR) in the plant house varied from 600-950 μmol m^{-2} s^{-1} during the day time while the day and night temperatures ranged from 30 to 34°C and 28 to 30°C, respectively. The daytime relative humidity (RH) varied from 25 to 45% and its variation was 14 to 27% during the night time.

Experimental design

A three factor factorial experiment with a completely randomized design (CRD) was conducted within the glass house environment. The factors (treatments) considered were watering treatments with two stress regimes (W_1, Watered to field capacity and W_2, continuous withholding for 8 weeks), soils from three different soil series *Weliketiya*, *Wilpattu* and *Mavillu* and soil compaction with two levels of bulk densities, C_1 (1.3 g cm^{-3}) and C_2 (1.6 g cm^{-3}). Altogether, there were 12 factor combinations and each had 6 replicates.

Analysis of soil

Soil chemical parameters such as electrical conductivity, pH, cation exchange capacity and macronutrient contents were determined using the methods described by Black *et al.,* 1979. Soil moisture content was measured using the gypsum resistance block method (Wellings *et al.,* 1985).

Investigations on shoot and root components

Roots were separated into three groups *viz.* primaries, secondaries and tertiaries after uprooting seedlings. Root diameter (mm) was taken at 2 - 3 cm away from the tip on 10 random samples of each group for all seedlings, using Starrett, Precision Vernier Caliper. Root lengths were also calculated by the modified line intersect method of Tennant (1975). Root and shoot dry weights were taken in grams after oven drying at 60°C.

Analysis of data

Data were analyzed by the procedure of Analysis of Variance (ANOVA) using the Statistical Analysis System (SAS) computer package. Models were chosen for factorial analyses indicating all 2-way and 3-way interactions. Significant interactions were computed for further analysis and discussion. The mean separations were obtained by restricted Least Significant Difference (LSD).

RESULTS

Soil comparison

Differences in the three soil series are clearly evident by their nutrient and chemical status. The organic carbon content was 46.0% and 7.6% higher in *Wilpattu* and *Mavillu* series soils compared to the *Weliketiya* series soil, which showed the lowest (Table 1).

Nitrogen, Phosphorous, Potassium and Magnesium levels were also significantly higher ($P < 0.001$) in *Wilpattu* soil than in both *Mavillu and Weliketiya* soils (Table 1). Electrical conductivity and cation exchange capacity were significantly higher ($P < 0.001$) in *Wilpattu* soil when compared to other two soil types (Table 2). This indicated the high capacity of *Wilpattu* soil in the retention of nutrients avoiding possible leaching.

Table 1. Nutrient status (Mean ± SE) of the three soils used in the experiment

Soil Series	Organic C %	N %	P (mg/g)	K (cmol/Kg)	Ca (cmol/kg)	Mg (cmol/kg)
Weliketiya	0.26 ± 0.008	0.20 ± 0.004	15.67 ± 0.18	0.16 ± 0.004	1.31 ± 0.02	0.27 ± 0.008
Wilpattu	0.38 ± 0.007	0.34 ± 0.002	30.35 ± 0.16	0.23 ± 0.004	4.25 ± 0.02	0.41 ± 0.008
Mavillu	0.28 ± 0.007	0.22 ± 0.008	17.71 ± 0.05	0.18 ± 0.005	2.46 ± 0.02	0.38 ± 0.01
LSD	0.02 ***	0.05 ***	0.44 ***	0.01 ***	0.07 ***	0.03 ***

*** Significant at $P < 0.001$

Table 2. Chemical properties (Mean ± SE) of the three soils used in the experiment

Soil series	pH	Electrical conductivity (µs/cm)	Cation Exchange Capacity (cmol/kg)
Weliketiya s	6.27 ± 0.01	4.37 ± 0.08	3.27 ± 0.05
Wilpattu	7.32 ± 0.03	10.17 ± 0.05	5.35 ± 0.07
Mavillu	6.48 ± 0.03	7.55 ± 0.07	4.06 ± 0.02
LSD	0.08 ***	2.20 ***	0.18 ***

*** Significant at $P < 0.001$

Shoot and root dry weight and root/shoot ratio

Both mean shoot and root dry weights declined by 37% and 28% respectively contributing to the reduction in total biomass by 35% under water stress. In addition, a change in partitioning pattern has also occurred in favour of roots, resulting in a 14% higher root/shoot ratio compared to that of regularly watered seedlings (Table 3 and Fig. 1).

Significantly higher values for shoot dry weight, root dry weight, and root/shoot ratio were observed in seedlings grown in *Wilpattu* series soil compared to those grown in other soils (Table 3). The impact of high soil compaction was positive (12%) on shoot dry weight while it was negative (38%) on root dry weight.

Seedlings grown in *Wilpattu* soil had a significantly higher root dry weight and shoot dry weight compared to those in other soils at both compaction levels (Table 4 & Table 5). The percentage reductions in root dry weight under high soil compaction were 40.7%, 25.8% and 35.0% in *Weliketiya*, *Wilpattu* and *Mavillu* soils, respectively. These results indicated that the root growth was less affected in *Wilpattu* soil compared to that in other two soil types.

Table 3. Mean shoot and root dry weight, and root/shoot ratio (Mean ± SE) at the end of the experiment

Treatment	**Shoot wt. (g)**	**Root wt. (g)**	**Rt. / St. ratio**
Regular watering to field capacity (Moisture 11-20%)	226.00 ± 9.5	46.98 ± 2.66[†]	0.21 ± 0.01[†]
NO watering (Moisture 1-6%)	143.32 ± 6.3	33.87 ± 1.47	0.24 ± 0.01
LSD	19.56 ***	3.11 ***	0.02 *
Weliketiya Series	171.87 ± 10.48	36.57 ± 2.81	0.22 ± 0.02
Wilpattu Series	199.87 ± 11.32	48.35 ± 2.59	0.26 ± 0.01
Mavillu Series	175.77 ± 9.97	36.35 ± 2.37	0.21 ± 0.01
LSD	22.95 *	3.81 ***	0.02 **
Low compaction	174.19 ± 10.18	49.36 ± 2.72	0.27 ± 0.01
High compaction	195.14 ± 10.37	30.49 ± 1.53	0.17 ± 0.01
LSD	19.56 *	3.11 ***	0.02 ***

* Significant at $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$

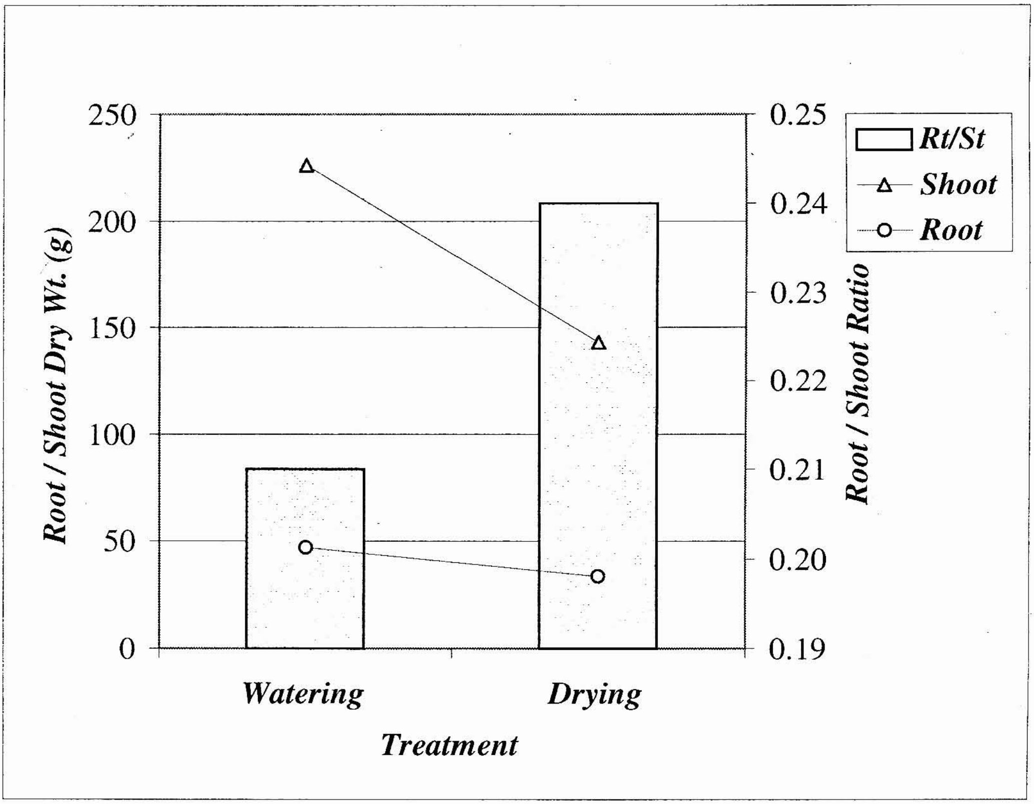

Fig. 1. Changes in shoot and root dry weights and root/shoot ratio in different watering treatments

Root/shoot ratio is relatively high in seedlings exposed to water stress conditions at both compaction levels (Table 6). The highest ratio was observed in seedlings grown under low compaction with the exposure to water stress. This development of a high root/shoot ratio indicated a shift in the existing balance in partitioning of assimilates between root and shoot towards root growth under water deficits and less physical obstruction under low soil compaction.

Table 4. Mean root dry weight (g) (Mean ± SE) at the end of the drying cycle as affected by soil series and levels of soil compaction.

Soil series	Levels of Soil Compaction	
	Low Compaction	High Compaction
Weliketiya Series	45.92 ± 3.17	27.21 ± 1.46
Wilpattu Series	55.54 ± 3.90	41.16 ± 2.79
Mavillu Series	43.61 ± 3.57	30.09 ± 1.02
LSD	5.38 ***	

*** Significant at $P < 0.001$

Table 5. Mean short dry weight (g) (Mean ISE) at the end of the drying cycle an affected by soil series and level of soil compactor.

Soil Series	Level of Soil Compactron	
	Low Compactron (C$_1$)	High Compactron (C$_2$)
Weliketiya	169.66 18.69	175.08 19.53
Wilpattu	179.58 13.14	220.16 19.19
Mavillu	171.03 18.45	205.16 12.71
LSD	33.87	

significant at $p < 0.05$

Table 6. Mean root/shoot ratio (Mean ± SE) at the end of the experiment as affected by levels of watering and soil compaction.

Levels of Watering	Levels of Soil Compaction	
	Low Compaction	High Compaction
Regular watering	0.243 ± 0.016	0.182 ± 0.009
No watering	0.279 ± 0.013	0.218 ± 0.012
LSD	*0.032* **	

** Significant at $P < 0.01$

Total root length

Seedlings grown under field capacity have a higher root length at both compaction levels (Table 6). Despite the increase in root/shoot ratio with respect to dry weights an increase in total root length was not desirable after the imposition of water stress. In the regularly watered seedlings roots were observed in large numbers with short or intermediate length in the shallow layers but only a few long roots had grown through the entire depth of soil column in most no watering seedling.

Table 7. Mean total root length (m) (Mean ± SE) at the end of the experiment as affected by levels of watering and soil compaction.

Levels of Watering	**Levels of Soil Compaction**	
	Low Compaction	**High Compaction**
Regular watering	27.25 ± 1.67	17.46 ± 1.84
No watering	10.63 ± 1.54	8.85 ± 0.84
LSD	*3.49* **	

** Significant at $P < 0.01$

Similar to root dry weights, seedlings grown in *Wilpattu* soil had a significantly higher mean total root length in comparison to those in other two soil types, at both compaction levels (Table 8). However, there was a significant reduction in root length under high soil compaction in all soils used.

Table 8. Mean root length (m) (Mean ± SE) at the end of the experiment as affected by different soil series and levels of soil compaction.

Soil series	**Levels of Soil Compaction**	
	Low Compaction	**High Compaction**
***Weliketiya* Series**	15.58 ± 2.03	8.11 ± 1.11
***Wilpattu* Series**	24.66 ± 3.43	15.62 ± 2.36
***Mavillu* Series**	16.58 ± 3.20	11.14 ± 2.06
LSD	*4.27* *	

* Significant at $P < 0.05$

Root diameter

The soil compaction showed a significant positive impact on root diameter. The diameters of secondary roots were increased significantly under high soil compaction in all soil types. This may have contributed in root penetration into the deeper layers in Wilpattu soil resulting the observed higher root length in that soil (Fig. 2). Although the mean root diameter of secondary roots was almost similar in three different soils under low soil compaction it was significantly higher in seedlings grown in *Wilpattu* soils under high soil compaction (Fig. 2). The percentage increases in mean root diameter due to high soil compaction were 13.6%, 27.3% and 20.2% in *Weliketiya*, *Wilpattu* and *Mavillu* soils respectively. The possible attempt to penetrate the compacted soil by being sturdy with the increased radial growth has well succeeded in *Wilpattu* soil due to its high organic matter and nutrient content.

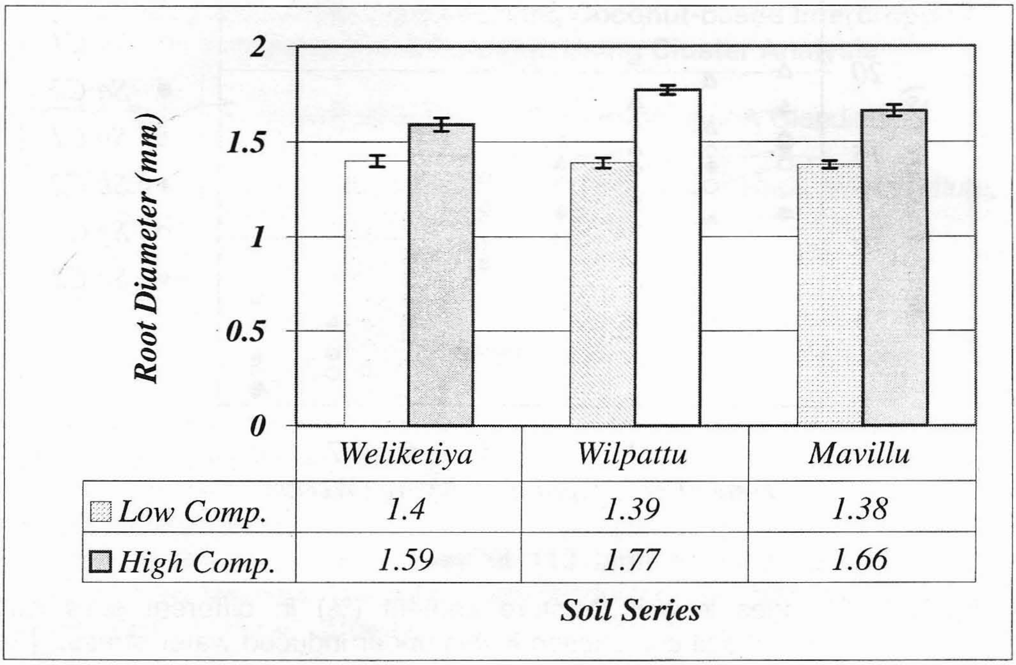

Fig. 2. Mean root diameter for secondary roots at the end of the experiment as affected by different soil series and levels of soil compaction. LSD = 0.07 ($p<0.01$)

Soil moisture content

The *Wilpattu* soil displayed the highest moisture content at the depth of 35 cm when most roots were aggregated the inception of the drying cycle due to its inherent high water holding capacity (Fig. 3). The lowest level was observed in *Weliketiya* series soil, which had a high draining ability due to high sand content with relatively more macro pores and low organic carbon and clay content resulting in low water holding capacity. The *Mavillu* soil having the sandy loam texture was at the intermediate level. The pattern was same throughout the drying cycle.

The first wilting symptoms on seedlings should be observed at 7th week of no watering in Weliketiya soil and has progressed by 8th week with an average of 2 leaves showing symptoms. The same could be observed in Mavillu soil but the average number of leaves wilted at the end of 8th week was only one leaf. However seedlings in Wilpattu soil did not show such symptoms even at the end of the eight-weeks water stress period.

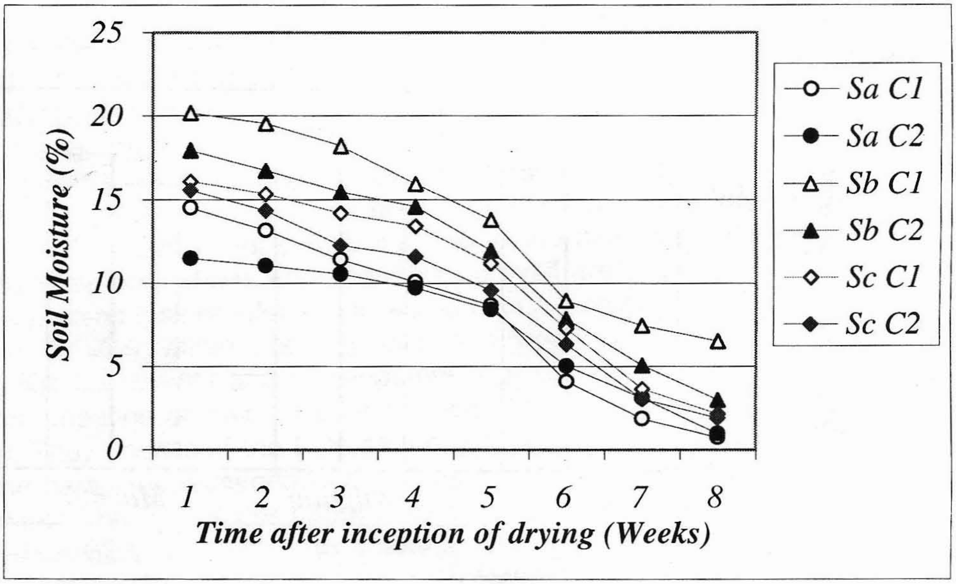

Fig. 3. Changes in soil moisture content (%) in different soils with different soil compaction levels under induced water stress. [Sa - *Weliketiya* Series; Sb - *Wilpattu* Series; Sc - *Mavillu* Series; C1 - Low compaction; C2 - High compaction]

DISCUSSION

Shoot and root dry mass and root-to-shoot ratio

The reduced amount of assimilates possibly due to the disturbed photosynthesis under extended water stress resulted in the reduction in shoot, root dry weights and total biomass. The reduction in pressure potential that would directly have an impact on cell expansion may also have contributed.

The significantly ($P < 0.05$) higher root-to-shoot ratio in the moisture stressed seedlings in Wilpotha soils clearly illustrated the well accepted theory of the shifting of assimilate partitioning pattern in favour of roots and against under water stress. Although biomass was mainly directed to the shoot under sufficient supply of soil moisture, a lower rate of overall biomass production was associated with increased allocation to the roots moisture stress. The maximization of water uptake is the obvious adaptive advantage of prioritizing allocation of limited photosynthate to roots under such a situation. Higher root dry weights under both soil compaction levels in *Wilpattu* soil indicated its better supportive ability for root growth compared to that of others. The high nutrient content, cation exchange capacity and water holding capacity have obviously contributed for this high dry matter accumulation. The high water holding capacity of Wilpattu soil probably has succeeded in supplying considerable amount of water for plants even at the end of eight-week dry period, while other soils were incapable of supplying. Although the moisture stress was developed in the Wilpattu soil, it has taken an extended time to reach a critical limitation that probably has provided a considerable time for the shifting of assimilate partitioning pattern. The rapid depletion of available moisture in other two soils might not have allowed seedlings for such alteration.

As a consequence of the reduced porosity under soil compaction, the amount of water that can be held by the soil would be low. In addition, plant roots would not grow deeper due to both mechanical impedance and availability of more nutrients in a given volume and close vicinity, that allow them to absorb sufficient nutrients without growing deeper. The contribution of the latter is explicitly indicated by the higher shoot growth with lower root growth under high soil compaction except in *Weliketiya* soil where nutrient content, cation exchange capacity and water holding capacity were the lowest. Consequently the resulted shallow, unspread roots have to extract water only from a small volume of this compacted soil that contains a relatively a small amount of water. In addition, physical obstacles would also restrict the water movements in the soil. Thus, the combined effect has caused the plants grown in the compacted soil, to experience a water deficit in a fairly short period of time after discontinuation of the water supply and hence, not favourable for the establishment of coconut seedlings. In addition, compacted soils restrict the rate of water infiltration and hence, such soils are soil water storage for subsequent uses by plants. According to Mathers *et al.* (1971) the adequate soil aeration (O_2), which is essential for roots for proper functioning would also be restricted and amounts would not be sufficient for meeting the demand fully, when soil compaction occurs. Poor aeration under high compaction may also cause the accumulation of CO_2 in soil, which enhance root death or interfere with water uptake. Therefore, the alleviation of the high soil compaction appears important in the establishment and long-term survival and existence of coconut seedlings.

Total root length and diameter

Presence of a large number of roots is common when sufficient water and nutrients are available in the microenvironment (Taiz and Zeiger, 1991) as a measure to increase the root surface area available for water and nutrient absorption to assist the rapidly growing shoot with abundant assimilates. However, under initial water deficit conditions which was restricted to the upper soil layers, the plant experiences only mild stress and the root number tends to decrease due to the reduction in root initiation. A few roots tend to elongate rapidly in order to explore deeper layers of soil for water at the expense of photosynthate partitioned towards roots. This was clearly evident in most drying imposed pots where only a few roots had grown through the entire soil column up to the bottom of the pot.

The higher root length in *Wilpattu* soil under both soil compaction levels is obvious because of its high nutrient contents compared to others High organic carbon content which contributed for high water holding capacity has succeeded in providing sufficient amount of water for plants even after eight-weeks no watering. This slow and gradual decline of available soil moisture has allowed seedlings to have more time to adapt themselves to stress situation resulting a shift of partitioning pattern up to shoots and more to roots.

Roots have attempted to penetrate the compacted soil by increasing the root diameter with enhanced radial growth. Sturdy roots are more advantageous in penetrating the hard soil as it can exert more pressure against this mechanical impediment. Based on an experiment using 22 plant species including both monocots and dicots, Materechera *et al.* (1991) have also inferred that the soil strength had increased root diameter in comparison to control. Nevertheless, that capacity has reduced significantly under the depletion of soil water at a particular soil compaction level because of the reduction of pressure potential which determines the root cell expansion. Also, the possible low oxygen condition created under high soil compaction may have promoted the ethylene production that has a direct impact on roots (Taiz and Zeiger, 1991). The penetration of compact soil with sturdy roots appears more successful in *Wilpattu* series than in other soils due to the reasons earlier mentioned.

It is clear that soil compaction has tended to reduce the ability of a coconut seedling to withstand the drought condition because of the impaired root growth. The shallow and weakly grown root system was not capable enough to absorb adequate quantities of water to compensate the amount of water loss through transpiration during the dry spell. The effect of the compaction has become more conspicuous when the clay content of the soil was high. Therefore, it appears essential that the alleviation of soil compaction through management practices is necessary to achieve satisfactory growth.

Taylor and Gardner (1963) reported the influence of soil bulk density and water content on the strength of the compacted zone. Thus, it is possible through management to circumvent the adverse effects of compaction by more loosed volume of soil at the time of planting, specially in hard soils.

High soil compaction leads to a reduced root system spread due to the availability of more nutrients in the close vicinity and physical obstruction exerted by the soil itself for further elongation. The attempted penetration of the hardy soil by roots becoming sturdy was exhibited as a success mainly in *Wilpattu* soil where water was stored in deeper layers. However, the resulting seedling with a larger canopy being catered to by a small root system would be more vulnerable in subsequent water deficit conditions. Hence, it appears imperative to alleviate this condition by adopting possible measures such as tillage and addition of organic matter to the soil through surface mulching and husk pits, though they were untested in this experiment. Preparation of larger seed holes in field planting would facilitate root growth at a young stage preventing possible impacts of high soil compaction on root growth. The preparation of 1.2 x 1.2 x 1.2 m (4 x 4 x 4 feet) seed holes appears more appropriate especially in compact soils compared to the recommended 0.9 x 0.9 x 0.9 m (3 x 3 x 3 feet) seed holes.

CONCLUSION

Different soils had different nutrient contents and organic carbon contents leading to different water holding capacities. This was the reason for observing varied impact of water stress on growth of coconut seedlings grown in different soils. The high nutrient content (N, P, K and Mg), high cation exchange capacity and high organic carbon content in *Wilpattu* series soil were the main factors that contributed to a better seedling growth compared to that observed in other soils. Therefore, the improvement of *Weliketiya* and *Mavillu* soils with respect to the soil physical and chemical properties through management practices like the addition of organic matter would obviously be beneficial in initial seedling growth and establishment through mitigation of the impact of water stress. The changes in assimilate partitioning pattern favoring root growth with a view to reducing further water loss and to capture more water to cope up with the water limited environment was common under all soil types.

High soil compaction has restricted the root growth in three soils tested but more nutrient and water availability in Wilpattu soil has still able to promote the shoot growth. Thus the large canopy maintained by relatively small root system would make them more vulnerable at subsequent droughts. So, the preparation of large seed holes with 1.2 x 1.2 x 1.2 m (4x4x4 feet) that would facilitate more root growth, appears more appropriate, specially in hard soils.

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