ISSN: 1394-7990
Malaysian Journal of Soil Science Vol. 16: 23-42 (2012) Malaysian Society of Soil Science

Association between Soil Moisture Gradient and Tree Distribution in Lowland Dipterocarp Forest at Pasoh, Malaysia

Marryanna, L., A.K. Rahman, S. Siti Aisah and M.S. Mohd

Forest Research Institute of Malaysia (FRIM), 52109 Kepong Selangor, Malaysia

ABSTRACT

A study was conducted on soil moisture in Pasoh 50-ha demography plot, Pasoh Forest Reserve, Negeri Sembilan, Malaysia to assess the variations of moisture content for different soil types and depths and the association between soil moisture and tree community. The soil types examined were dry alluvial (DA), wet alluvial (WA) and ridge areas (RD). Soil moisture was measured at 15, 30, 45, 60 and 75 cm depths using AquaPro Frequency Domain Reflectometry (FDR) system. The average monthly soil moisture measurement for a two-year period varied between soil types with 48% for dry alluvial soils, 56% for ridge soils and 68% for wet alluvial soils. However, maximum moisture was recorded for wet alluvial soils at 100%, followed by ridge soils at 92% and dry alluvial soils at 80%. Wet alluvial soils showed highest soil moisture at all soil depths. Soil moisture increased with increasing soil depth with moisture at 75 cm depth being significantly different from moisture at other depths. Though soil moisture increased with soil depth, the difference was only significant at 75 cm depth. The species distribution based on soil types in the Pasoh 50-ha demography plot showed that *Euphorbiaceae, Lecythidaceae, Myrtaceae* and *Sapidaceae* were abundant at wet alluvial soil. At DA, the abundant species were *Annonaceae, Myrsinaceae,* and *Clusiaceae,* while *Burseraceae, Alanggiaceae, Anisophylleaceae, Fabaceae, Ulmaceae* and *Sterculiaceae* were abundant at RD. This indicates that species abundance at the Pasoh 50-ha demography plot is associated with site condition.

Keywords: Soil moisture, Pasoh 50-ha demography plot, monitoring, FDR

INTRODUCTION

Plant growth depends very much on the soil for water and nutrients (Foth and Turk 1972). Furthermore, soil is important for plant rooting. Soil moisture is one of the important components in the soil that serve the plant and microorganism. Also, soil moisture is an important component in the water cycle. Plants depend at any time more on soil moisture available at root level than on precipitation occurrence. Knowledge of soil moisture content is important for management and hydrological studies (Lukanu and Savage 2006). In a forest ecosystem, the level of soil moisture may influence the community structure of the forest. Such

*Corresponding author : E-mail: *marryanna@frim.gov.my*

information will be useful to determine species suitability for rehabilitation and enrichment planting programmes.

Pasoh 50-ha demography plot is one of the ecological plots established by the Centre for Tropical Forest Science (CTFS) network around the world. Pasoh is one of the most intensively researched rainforests in Asia; it is also one of the best understood (Okuda *et al.* 2003). Many studies in these plots have indicated that the spatial distribution patterns in tropical species is associated with topography (e.g. Svenning 1999; Harms *et al*. 2001; Wan Juliana 2001; Nur Supardi 2003; Davies *et al.* 2003). Such an association has also been documented for smaller 6-ha plots in the Seraya-Ridge Forest of Peninsular Malaysia (Niiyama *et al.* 1999). In the Pasoh 50-ha plot, Davies *et al.* (2003) identified 5 distinct plant community types which are associated with the topography of the sites. Nur Supardi (2003) and Wan Juliana (2001) had also indicated a marked association between plant and soil type within the Pasoh 50-ha plot, despite the fact that the differences in elevation within the plot is only 25.5 m. Studies in Panama Barro Colorado Island (BCI) plot revealed similar findings. Although the BCI site was chosen for its relative uniformity of relief and other physical conditions, many species vary in distribution across the gentle slope, plateau, and swamp habitats (Hubbell and Foster 1983; 1986). Newly developed statistical procedures indicate that many of the topographic associations on BCI are not simply the artifact of spatial autocorrelation in recruitment patterns (Harms *et al.* 2001). Completion of vegetation mapping at other large CTFS plots encompassing greater variation in relief than the BCI plot has revealed similar association patterns, for example, the study of Hirai *et al*. (1995) and Debski and Burlsem (2000) for Lambir, Malaysia, Plotkin *et al.* (2000) for Pasoh, Malaysia, John (2003) for Mudumalai, India, and Svenning (1999) for Yasuni, Ecuador.

Pasoh 50-ha plot was established in 1985 by the Forest Research Institute of Malaysia in collaboration with Smithsonian Tropical Forest Research Institute and Havard University, and since then five censuses have been completed. Community and population structure of trees have been described (Manokaran and LaFrankie 1990; Manokaran *et al.* 1991; Kochumen *et al*. 1992; and Davies *et al.* 2003) and some analyses on population dynamics have also been attempted (Abd. Rahman 2004; Manokaran *et al.* 1992). Efforts are being made to look into the community and population dynamics of trees from the repeated census data with the assistance of the CTFS through a series of training sessions in the Analytical Data Workshop. Studies by Condit *et al*. (1996) at BCI plot in Panama suggest that the sharp decline in the population size of slope-specialist tree species is associated with two severe drought periods which strongly implies the differences in moisture requirements among species. Liza and Bettina (2009) mentioned that the interaction of spatial and temporal variation in water availability is likely to be important for driving plant population dynamics and shaping species distributions across habitats, but the variations in water availability have rarely been examined.

Many studies have been conducted on soil moisture in tropical forests. At Pasoh, topographic associations have been attributed to differences in soil-moisture gradient between slopes of wet and dry area habitats (Noguchi *et al.* 2002). Several studies on the BCI plot have revealed the association of topography, soil and moisture regime. For example, Becker *et al.* (1988) showed that soil-water potentials are maintained at higher levels on the BCI plot slopes compared to the principal plateau, while Daws *et al.* (2002) showed that slopes experience a shorter duration of drought period during the dry season. Variation in soil-moisture availability across topographic gradients in tropical forests might also maintain a substantial fraction of local diversity if species differ in their 'hydrological niches' (Noguchi *et al.* 2002).

It is timely that further in-depth research is carried out to determine the association of tree population dynamics with soil moisture regime. The objective of this study was to examine the changes in soil moisture regime in tree habitat in the Pasoh 50-ha plot by continuous monitoring over a period of two years. The interest of this assessment was to look at the temporal pattern of the soil moisture based on different soil depths and drainage conditions. Our aim was to clarify any significant differences in the soil moisture regime that might be associated with species preferences at the site.

Site Description

The study was conducted at Pasoh Forest Reserve, a typical lowland rain forest in Peninsular Malaysia. Pasoh Forest Reserve (2° 58'N, 102° 18'E) is located near Simpang Pertang in Negeri Sembilan (*Fig.1*) about 140 km south-east of Kuala Lumpur in Peninsular Malaysia. Pasoh Forest Reserve lies approximately at the junction of west and south-west climatic regions, and in Jelebu district. Based on the data collected from Pasoh climate station, the highest monthly precipitation for 2006 occurred in November and the lowest in July. Total rainfall was 1880 mm in 2006 and 1511mm in 2007 (*Fig. 2*).

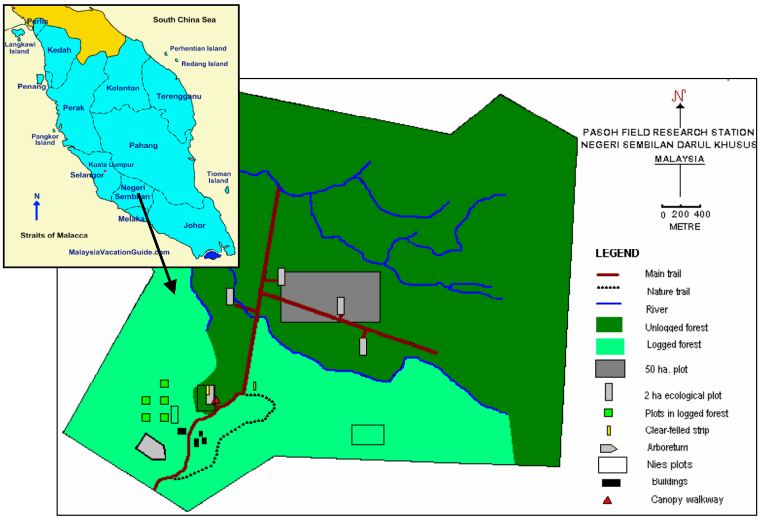


Fig. 1: Location of the study area

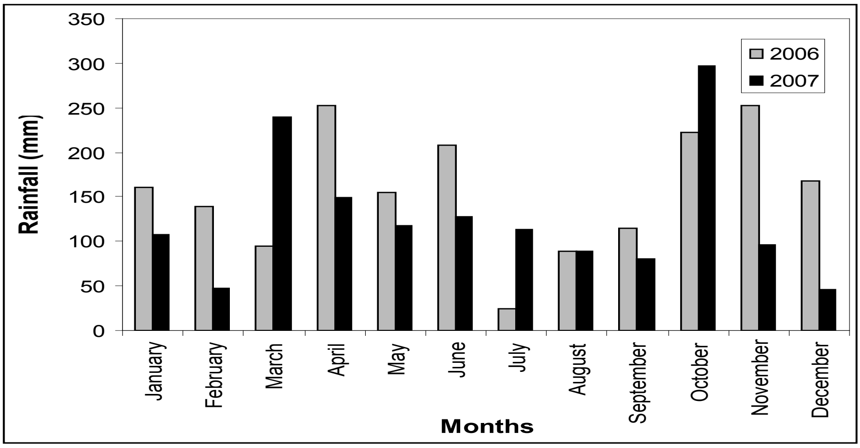


Fig. 2: Average monthly rainfalls at Pasoh F.R for years 2006 and 2007

The Pasoh demography plot is 1000 x 500 m in dimension; the long axis lies in the east-west direction. The south-west corner of the plot is located at 2 58’47” N, 102 18’29”E (Manokaran *et al.* 1991). The 650 ha core area of the forest of the total reserve area of 2450 ha is covered with a primary lowland mixed dipterocarp forest which consist of various species of Shorea and Dipterocarpus, homogenous in topography and community structure, with no evidence of major human disturbance.

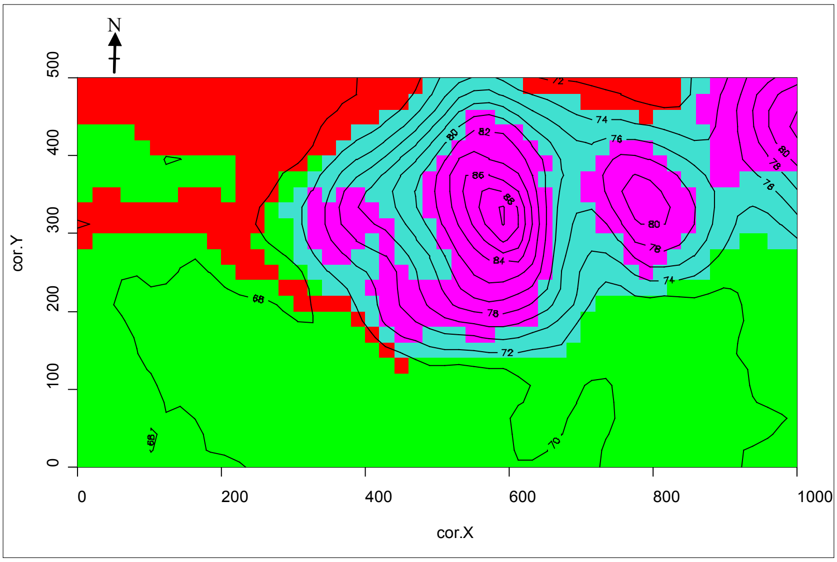
MATERIALS AND METHODS

Sampling Location

Three sampling plots were selected based on soil drainage condition at Pasoh 50-ha plot (*Fig. 3*). The plots were Dry Alluvial (DA), Wet Alluvial (WA) and Ridge (RD). Dry alluvial is characterized by well-drained alluvial soils which consist of: (1) TBK – Tebok Series, (2) TBK (ms) - Tebok medium coarse sand, (3) TWR-Tawar Series and (4) TWR (p) – Tawar pale variant. Poorly drained alluvial soils which consists of: (1) AWG – Awang Series, (2) AMA – Alma Series, (3) KPU – Kampong Pusu Series and (4) KPU (cS) - Kampong Pusu coarse sand which represents wet alluvial soils. The profile characteristics of each site are described in Table 1.

100-cm moisture sensor access tubes were installed randomly within the plots (20 x 20 m). Soil moisture readings were taken monthly at depths of 15, 30, 45, 60 and 75 cm. Measurements was replicated three times to ensure representative results. The forest is characterised by the large trees of dipterocarps such as *Dipterocarpus spp*., *Shorea spp.* and *Neobalanocarpus heimii,* and *non-dipterocarps* such as *Dyera costulata, Triomma malaccensis, Canarium apertum,* and *Koompassia malaccensis*. WA is characterised by the Euphorbiaceae, Lecythidaceae, Myrtaceae, Celastraceae and Sapindaceae family. *Glyptopetalum quadrangulare* is the most abundant species found within the WA habitat.

Annonaceae, Myrsinaceae, Clusiaceae and Dipterocarpaceae are the abundant tree family within the DA habitat, while *Shorea maxwelliana* is the most dominant species in the area. In the shale area, seven tree families found in abundance are Euphorbiaceae, Burseraceae, Annonaceae, Anisophylleaceae, Fabaceae, Ulmaceae and Sterculiaceae. The most abundant species associated with this area is *Anisophyllea corneri* from the family of Anisophylleaceae. Alangiaceae is the only tree family found within the lateritic area.



Dimensions are in meters and North is facing upward direction. The color code indicates soil types, Red=Wet Area (poorly drainage alluvial), Green=Dry Area (Well drainage alluvial), Turqoise=Shale, and Magenta=Laterite. Contour lines are at 2 m intervals.

Fig. 3: Major soil drainage conditions in Pasoh 50 ha Plot

TABLE 1

Profile characteristic of sites in Pasoh 50-ha plot, Pasoh Forest Reverse

Site	Soil Characteristics
Wet Alluvial (Floodplain)	- Thin muck, over mottled pale brown wet layered, over moist brownish less mottled; sandy clay subsoil (Awang series) and sandy clay loam subsoil (Alma series). Drainage class: 3-4 (Imperfect poor)
	- Thick muck over mottled grey wet layered loam, over moist brownish mottled; Kampung Pusu series, fine & medium sand. Drainage class 1-2 (poorly drained)
Dry Alluvial (Low terrace)	- Thin dark brown topsoil over unmottled yellowish/brownish loam to 1 m+, mottled below. Sand predominantly medium or fine (Tebuk series); sand predominantly coarse (Tawar series); Drainage class 5-6 (Moderately drained).
Ridge (Crest and slopes)	- Thin dark brown fine loam topsoil over strong brown fine loam or clay subsoil. Massive laterite or dense gravel within 50 cm (Gajah Mati Series); Many laterite gravel at 50-100 cm (Terap Series); Few laterite gravel below 100 cm (Bungor series). Drainage class 7-8 (Well drained)

Adzmi *et al.* (2010)

Soil Moisture Measurement

AquaPro Portable Moisture Probe from AquaPro Sensor Company based in California was used to measure soil moisture within the 50-ha plot. AquaPro sensors utilize radio frequency technology to measure the dielectric coefficient of soil with varying moisture content to a high level of accuracy, +/- 1%. The readings are independent of soil conductivity. The sensor was inserted into the polypro access tubes to take soil moisture readings. This tube was constructed of specially extruded polycarbonate plastic, and their wall dimensions have been factored into the calibration and moisture reading functions of the probe. Substituting other tubes such as PVC pipe will result in inaccurate and erroneous readings. Noguchi *et al.* (2002) used Amplitude Domain Reflectrometer (ADR) sensor at 20 m intervals with 1326 points to measure the surface soil moisture. Wan Juliana (2001) conducted a similar study using the gravimetric technique, in attempting to determine the association of plant community with the environmental factors including soil moisture in the 50-ha plot at Pasoh. Soil moisture was measured monthly at three different plots for two years.

Data Analysis

The experimental design of the study was a completely randomized design. Exploratory data analysis was conducted to inspect the relationship between soil depths, and soil moisture and its interaction and differences between soil types. ANOVA was used to determine the significant differences in soil moisture at differing soil depths and soil types using S-Plus version 6.1. Post-hoc multi comparison test was conducted using Tukey-HSD test to determine the significant mean differences between the factors.

RESULTS

Soil Moisture across the Sites

WA showed the higher moisture compared to RD and DA (*Fig. 4*), where the mean moisture at WA reached up to 68%, being higher at deeper soil depths. However, means comparison between RD and DA shows that DA was much drier compared to RD. Means of moisture based on soil depth was much higher at depths of 60 to 75 cm. Therefore, soil depth and soil types could be among the factors to account for soil moisture differences in this area. The boxplot (*Fig. 5*) shows the differences in soil moisture observed at different soil depths with all the soil types combined. It shows an obvious difference in moisture among soil depths. Moisture at 15 cm and 30 cm depth was not statistically significant. However, moisture at 30 cm and 75 cm depth statistically varied significantly. Looking at the differences between the moisture of different soil types (*Fig. 6*), WA clearly showed greater moisture variation as compared to DA and RD, but DA seem to have small changes in moisture. *Fig.7* shows the mean monthly moisture content at DA area. In 2006, the highest soil moisture was 66.7% which occurred in May at a soil depth of 75 cm and the lowest was 7.0 % observed in January at 60 cm depth. Soil moisture at

DA area in 2006 was 22.0% with the average being 39.5%. Soil moisture patterns were similar in January, February, March and April showing a decrease at 15 cm to 60 cm depths and an increase at 75 cm depth. The months of July, June and May showed decreasing moisture at 15 cm to 30 cm depths, but increasing moisture at 75 cm depth even though these months were not influenced by rainfall events.

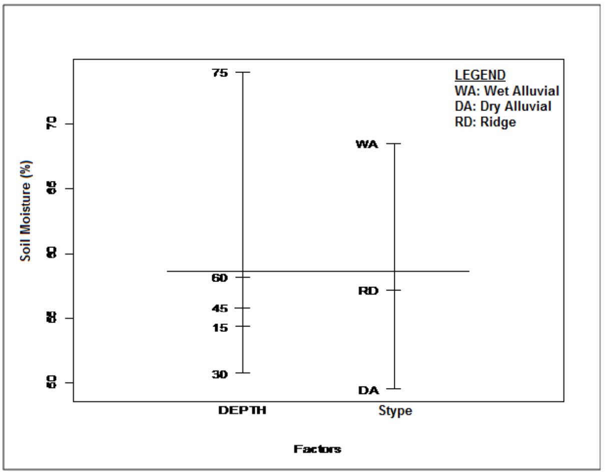


Fig. 4: Diagnostic plot showing mean of soil moisture among soil type (STYPE) and soil depth (DEPTH)

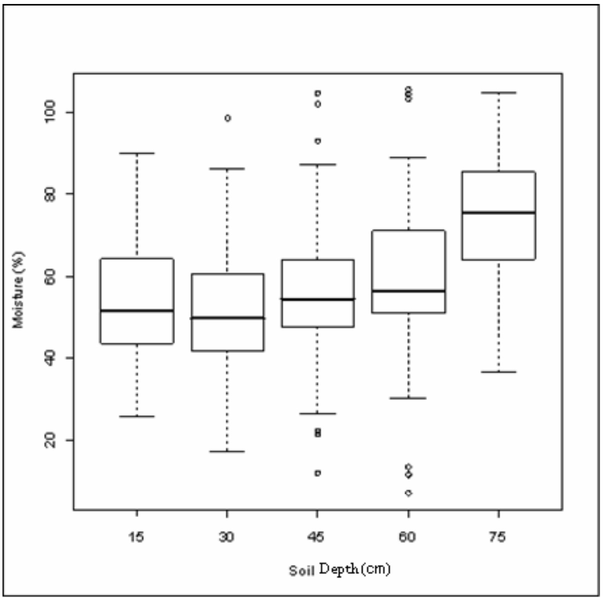


Fig. 5: Boxplot of soil moisture measured at different soil depths with all sites combined

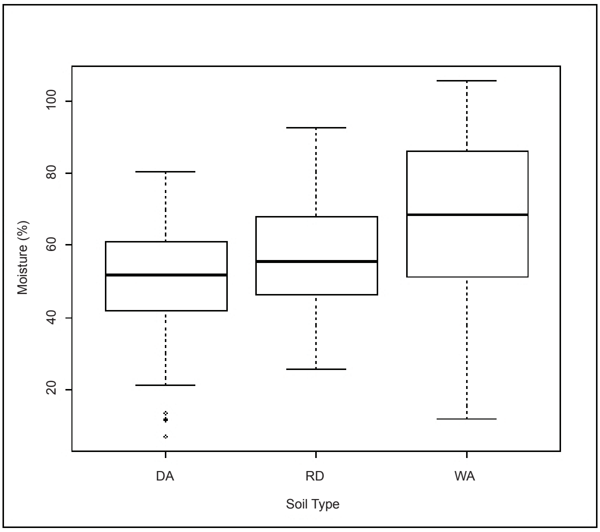


Fig. 6: Boxplot of soil moisture measured for different soil types with all soil depths combined

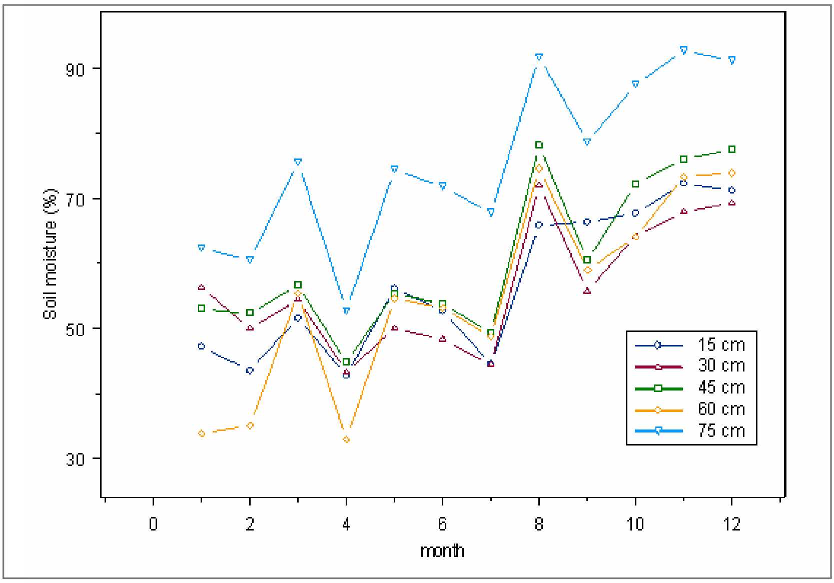


Fig. 7: Mean monthly soil moisture at dry alluvial area

In 2007, the maximum moisture was recorded in August at 80% while the minimum was recorded in April at 25%. The average moisture was 59%. Overall, soil moisture showed similar patterns with moisture decreasing at 15 cm to 30 cm depths and increasing at the deeper layers. The DA was well drained and the water content reached equilibrium quickly. Overall, the trend of the soil moisture at DA showed a relative increase towards deeper layers.

Figure 8 shows the combined mean monthly moisture content at the ridge area for 2006 and 2007. The maximum soil moisture was 73.6 % which occurred in May at 75 cm depth and the minimum was 32.6 % at the surface layer (15 cm) in July. The soil moisture mode was 52.0 % with the average being 50.9 %.

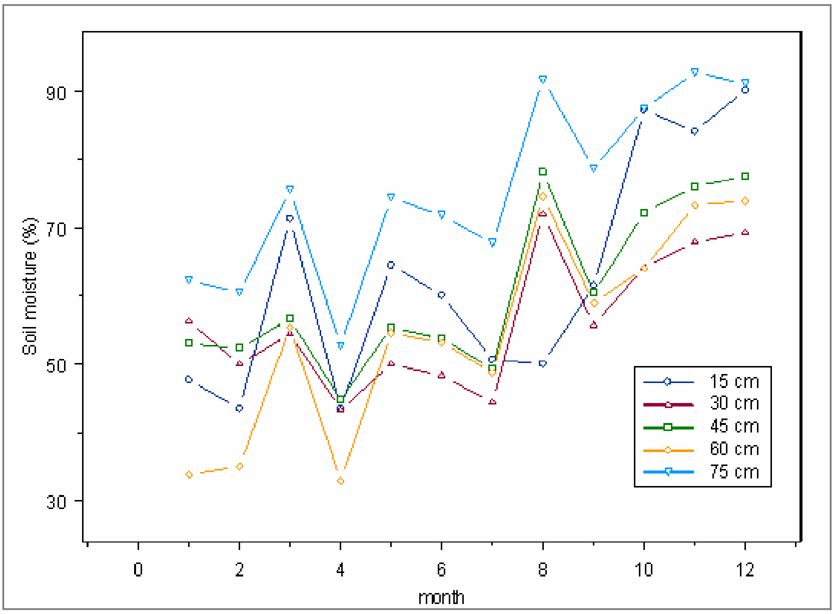


Fig. 8: Mean monthly soil moisture at ridge area

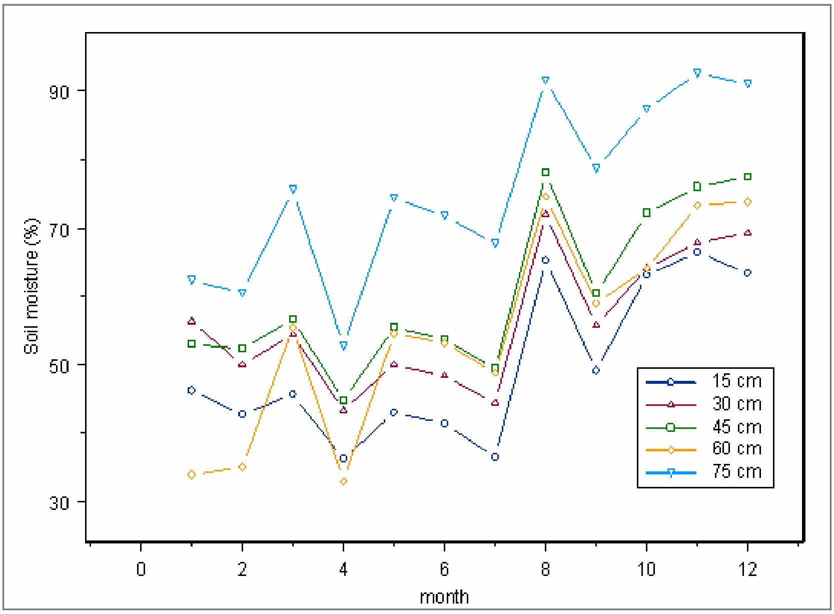


Fig. 9: Mean monthly soil moisture at wet alluvial area

Overall, the July soil moisture for RD showed similar patterns where soil moisture increased at 15 cm to 45 cm depths because of excessive infiltration, and decreased between 46 cm to 60 cm depths where the gravel layer does not hold water. Moisture was higher at 60 cm to 75 cm depths because the soil texture at this depth improved and was able to hold more water compared to the gravel layer. Generally, the upper soil profile was much drier compared to the deeper soil because of the drainage situation at higher elevations where water from the surface infiltrated into the deeper layer within a short time duration due to the quick passage of water through the substrate. In 2007, the highest soil moisture was 92% and the lowest was 25%. The moisture mode was 72% with the average moisture being 61%. The results showed similar fluctuation of soil moisture which increased at all depths due to the excessive rainfall except for the 45 cm to 60 cm depths where the gravel layer accelerated the infiltration. Generally, soil moisture was driest at the upper surface due to the evaporation process and wettest at the deepest soil due to percolation.

In 2006, January had the highest soil moisture at 89.2 % at a depth of 60 cm depth while the lowest was in February at 12.0% at a depth of 45 cm depth. The frequency of soil moisture was 86.0% and the average was 63.7%. Overall, most of the observations showed a similar moisture fluctuation where soil moisture decreased at 15 to 30 cm depths and increased towards the deeper layers. A small variation in soil moisture was observed in March where it increased until 60 cm depth. A rapid increase in soil moisture at 30 cm depth was observed in January, February and April, probably due to the fast infiltration rate caused by frequent rainfall events and poor drainage where water retention time was longer in the soil. In 2007, maximum soil moisture was recorded in December at 100.0%, while minimum was in April at 38.0%. The frequency of moisture reading was 60.0% with an average moisture of 73.0%. Generally, WA had the drier surface layers compared to the deepest soil which was probably due to evaporation at the surface and retention at the deeper layer. Fine soil texture in this area facilitated the increase in the water holding capacity at the deepest layer.

The regression analysis output between rainfall and soil moisture shows that the R-squared statistic of the model, as fitted, explains 0.425 of the variability in soil moisture for 2006 and 0.096% for 2007. The correlation coefficient equals to 0.0652 (2006) and 0.0311 (2007), indicating a relatively weak relationship between the variables. Since the P-value in the ANOVA is greater or equal to 0.10, there is no statistically significant relationship between soil moisture and rainfall at the 90% or higher confidence level.

Comparison of Soil Moisture between Different Soil Types and Depths

Generally, comparison between the two dataset of 2006 and 2007 for soil moisture in Pasoh 50-ha show a similar trend where the WA showed high moisture, followed by RD and DA. Both data sets have similar soil moisture distribution where the distribution slightly decreased at the 30 cm soil depth. The difference in moisture content between soil types (Table 2) was 36 % between WA and DA, while it was 26% in comparison with the RD at 60 cm soil depth. The difference in soil moisture content between ridge and dry area was about 13 % at 75 cm depth. WA and RD have a strong soil moisture association with soil depth. This is shown by the correlation analysis between soil depth and moisture (Table 3) according to soil types where WA was strongly correlated with soil depth at 0.91 and at 0.88 by the RD. DA showed a weak association between soil moisture and soil depth.

TABLE 2
Difference in moisture content between plots and depth

	Difference between (%)		
Soil Depth (cm)	Wet Alluvial and Ridge area	Wet Alluvial and Dry Alluvial area	Ridge and Dry Alluvial area
15	13.86	6.45	-7.41
30	-0.94	8.89	9.84
45	8.12	23.84	15.72
60	25.77	36.01	10.24
75	14.42	27.03	12. 61

TABLE 3
Correlation between depth and soil moisture for 2006 and 2007

	2006	2007
Wet Alluvial area	0.8884	0.9068
Ridge area	0.7212	0.8832
Dry Alluvial area	0.0210	0.4437

There was significant interaction between soil moisture and soil type and soil depth (Table 4). This shows that a difference in soil moisture is associated with soil type and soil depth factor. This could be the basic factors that influence the variation in moisture content. There could be other environmental factors that contribute to the variations in moisture content such as rooting system, soil properties and climatic and hydrological conditions like evaporation and transpiration.

At the WA plot, the moisture increased sharply at 45 cm depth to the deeper soil. This interaction was similar to the DA where the surface moisture tends to decrease until the 30 cm depth. However, soil moisture interaction at the deeper soil was slightly different where moisture took a longer period to increase at the DA plot. It started to increase at 60 cm depth with increasing points for the DA and RD being similar. There are two interaction patterns observed; decreasing point at 15 to 30 cm at the WA and DA, while the increasing point started at 31cm depth at the WA and 60 cm at the DA and there were two increasing points observed at RD, that is, at 15 to 45 cm depths and 60 cm depth.

TABLE 4(a)
Means and standard deviation for soil moisture at different soil types and depth in 2006

Depth	Wet Alluvial area		Ridge area		Dry Alluvial area	
	Means	SD	Means	SD	Means	SD
15	54.40	10.54	41.53	4.68	48.13	5.79
30	43.84	21.89	49.64	6.21	35.60	9.61
45	61.14	23.55	52.47	3.82	32.84	14.19
60	76.13	14.13	44.16	9.15	28.47	22.39
75	82.98	4.74	66.70	5.10	52.38	10.42

TABLE 4(b)
Means and standard deviation for soil moisture at different soil types and depth in 2007

Depth	Wet Alluvial area		Ridge area		Dry Alluvial area	
	Means	SD	Means	SD	Means	SD
15	65.90	16.79	51.05	13.36	59.27	12.51
30	60.78	21.41	56.87	12.46	51.24	10.73
45	69.78	23.03	62.22	14.29	50.41	10.61
60	79.00	20.25	59.42	13.39	54.64	10.48
75	90.77	15.88	78.21	15.29	67.31	12.63

TABLE 5
Analysis of variance of soil moisture between soil type (STYPE), soil depth (DEPTH) and their interaction

	df	SS	MS	F value
STYPE	2	16006	8003	33.4981***
DEPTH	4	16961	4240	17.7386***
STYPE DEPTH	8	6559	820	3.4299***

'***' $F < 0.001$

The multi comparison tests (Table 6) on soil moisture between soil depths show differences between soil depths. However, a comparison of moisture at 45 cm and 15 cm depths showed small differences. Generally, 75 cm has the largest difference for all monitored soil depths with the highest being between the 75cm and 30 cm depths.

Table 7 shows the species distribution based on soil types in Pasoh 50-ha plot. It shows that *Euphorbiaceae, Lecythidaceae, Myrtaceae* and *Sapidaceae* are abundant at wet alluvial soil. At DA the abundanct species are *Annonaceae, Myrsinaceae, and Clusiaceae, while Burseraceae, Alanggiaceae, Anisophylleaceae, Fabaceae, Ulmaceae* and *Sterculiaceae* are abundant at RD.

DISCUSSION

High soil moisture was observed in Pasoh 50-ha plot due to the natural characteristics of the undisturbed forest where less surface evaporation occurred because of the dense canopy. The highest moisture was found at WA area. Even though Guha (1969) mentioned that moisture stress is likely to be more intense

TABLE 6
Multi-comparison test on soil moisture between soil depths using Studentized range statistic, Tukey's 'Honest Significant Difference' method

Soil depth comparison	diff (%)
15 and 30 cm	3.6360
30 and 45 cm	5.1402
30 and 60 cm	7.4346
30 and 75 cm	23.3192
15 and 45 cm	1.5042
15 and 60 cm	3.7987
15 and 75 cm	19.6833
45 and 60 cm	2.2944
45and 75 cm	18.1790
60 and 75 cm	15.8846

in the ridge soils, the study found that RD is more moist compared to DA. Adzmi *et al.* (2010) found that the upper subsoil at WA area is wet for most parts of the year and augering hits water at less than 1 m, usually less than at 50 cm depth. In WA, the soils contain a high percentage of water and are unable to disperse this moisture within a short time. It has very firm and compact consistency which makes this horizon slowly permeable (Adzmi *et al.* 2010). The heavy textured soil which mostly contains clay or silt often has poor water penetration because of the soil aggregation. Clay particles in the soil may swell as they become wet and thereby reduce the size of the pores. Poorly drained soil has an effect on plant growth as it will suffocate the plant roots and this is related to the oxygen diffusion rate (Foth and Turk 1972). This results in oxygen deficiencies. In Pasoh, *Glyptopetalum quadrangulare* are in abundance at the wet alluvial area where the moisture tends to be the highest. Belonging to the Celastraceous family, it is a type of vascular plant which transports water in either xylem or phloem: xylem carries water and inorganic solutes upward toward the leaves from the roots, while the phloem carries organic solutes throughout the plant. Therefore, this plant tends to concentrate within the high moisture area because of self- adaption to the site characteristics. Usually, rooting depth in plants is decreased due to the poor drainage. That is why most dipterocarp species prefer a well-drained soil.

The RD and DA are better drained with the soils being generally low in moisture content and drying out quickly due to the quick passage of water movement through the substrate. This has been stated by DOA (1987) that the entire ridge soils drain freely and qualify for class 7 (well drained) of the West Malaysian drainage classification system. Generally, soil moisture is lowest at the surface and wettest at greater depths as indicated at WA and RD areas. However,

TABLE 7

Five characteristic species of each soil type with indicator value (IV) of indicator species analysis, and Pearson-r for Axis 1 (r1) and Axis 2 (r2) of non-metric multidimensional scaling analysis.

No.	Species	Family	IV (%)	r1	r2	Soil type
1	*Aporosa globifera*	Euphorbiaceae	51.400	0.768	-0.972	Wet Alluvial
2	*Barringtonia macrostachya*	Lecythidaceae	54.400	0.524	-0.979	Wet Alluvial
3	*Eugenia cerasiformis*	Myrtaceae	50.300	0.816	-0.937	Wet Alluvial
4	*Glyptopetalum quadrangulare*	Celastraceae	58.800	0.841	-0.903	Wet Alluvial
5	*Lepisanthes tetraphylla*	Sapindaceae	51.800	0.590	-0.983	Wet Alluvial
6	*Anaxagorea javanica*	Annonaceae	42.100	-0.091	-0.661	Dry Alluvial
7	*Ardisia crassa*	Myrsinaceae	41.200	-0.930	0.786	Dry Alluvial
8	*Mesua ferrea*	Clusiaceae	37.800	-0.385	-0.425	Dry Alluvial
9	*Shorea maxwelliana*	Dipterocarpaceae	51.300	-0.683	-0.093	Dry Alluvial
10	*Xerospermum noronhianum*	Sapinda ceae	34.600	0.565	-0.904	Dry Alluvial
11	*Aporosa bracteosa*	Euphorbiaceae	40.700	-0.008	0.759	Ridge
12	*Aporosa prainiana*	Euphorbiaceae	38.600	-0.523	0.980	Ridge
13	*Dacryodes rugosa*	Burseraceae	31.900	-0.867	0.896	Ridge
14	*Oncodostigma monosperma*	Annonac eae	33.300	-0.663	0.982	Ridge
15	*Popowia pisocarpa*	Annonaceae	31.500	-0.663	0.983	Ridge
16	*Alangium ebenaceum*	Alangiaceae	43.100	-0.772	0.975	Ridge
17	*Anisophyllea corneri*	Anisophylleaceae	46.900	-0.433	0.957	Ridge
18	*Archidendron bubalinum*	Fabaceae	38.100	-0.814	0.951	Ridge
19	*Gironniera parvifolia*	Ulmaceae	42.000	-0.882	0.914	Ridge
20	*Scaphium macropodum*	Sterculiaceae	37.700	-0.555	0.980	Ridge

Note: The selected species are those with the five highest IV in each soil type.

TABLE 8

Peninsular Malaysian Soil Classification and international correlation of soil of 50 ha plot, Pasoh FR (Adzmi *et al*., 2010)

Physiographic		Soil Features		West Malaysian soil classification (DOA 1987, Paramananthan 1989)		Main international correlations	
Group	Subgroup	Shared	Distinguishing	Soil Series	Drainage class	World reference base (FAO 2006)	Soil Taxonomy (Soil survey staff 1999, 2006)
Ridge	Crest	Thin dark brown fine loam topsoil over strong brown fine loam or clay subsoil	Massive laterite or dense gravel within 50cm	Gajah Mati	7-8 (Good)	Acric Plinthosol	Typic Plinthudult or Plinthic Kanhapludult
	slopes		Many laterite gravel at 50-100 cm	Terap	7-8 (Good)	Plinthic Acrisol	Plinthic Kanhapludult
			Few laterite gravel below 100 cm	Bungor	7-8 (Good)	Haplic Acrisol	Typic (or Plinthic) Kanhaplludult (& Kanhaplaquult)
Alluvial	Low terrace	Thin dark brown topsoil over unmottled yellowish/brownish loam to 1 m=, mottled below	Sand predominantly medium or fine	Tebuk	5-6 (Good–Imperfect)	Haplic Acrisol	Typic (or Oxyaquic) Kanhapludult (& Kanhaplaquult)
			Sand predominantly coarse	Tawar	5-6 (Good–Imperfect)		
Alluvial	Floodplain	Thin muck, over mottled pale brown wet layered, over moist brownish less mottled	Sandy clay subsoil	Awang	3-4 (Imperfect–poor)	Umbric Acric Stagnosol	Umbric & Humic Epiaquept (& Kanhaplaquult)
		Thick muck, over mottled grey wet layered loam, over moist brownish mottled	Sandy clay loam subsoil	Alma	3-4 (Imperfect–poor)		
				Kampung Pusu	1-2 (Poor)	Umbric Acric Gleysol (& Stagnosol)	Humic Endoaquept (& Epiaquept)

the DA plot shows that moisture on the surface has a similar pattern with the moisture at the deeper soil layers. According to Adzmi *et al.* (2010), the DA area has a thin, friable, crumb structured topsoil which tends to be less dark than those on the ridge or floodplain. The subsoil in this area is mostly yellowish brown, with few or no mottles in the upper meter. Grey and rust-colored mottles increase in frequency and contrast below 1 meter, and the matrix tends to become paler, often pale brown or pale yellow. The coloration indicates imperfect drainage, in classes 4-5 (Table 8). *Shorea maxwelliana* is the Dipterocarpaceae family found to be abundant at this dry alluvial area. This species prefers the terrestrial ecosystem and is categorized under the IUCN red list as threatened species.

The difference in spatial distribution of soil moisture at Pasoh Forest could be affected by the slope of the ground surface, the vegetative canopy cover, water retention properties of the soil and rooting system. The difference in canopy openness has an effect on the amount of through fall and evaporation. Therefore, canopy openness is an important factor to be considered in soil moisture study in the future. This could be one of the factors which explain the variation in soil moisture among the soil types (WA, RD and DA) at 5 m, 10 m and 15 m tree spacings as stated in Marryanna *et al.* (2007). They found that moisture tended to decrease at a wider tree spacing. The results from Noguchi *et al.* (2002) showed that the soil moisture at the valley and riverine areas and the lower part of the slope was higher than at the ridge top. Also, the results showed that flat areas are drier. Based on these findings, it is suggested that the soil properties/types, ratio of vegetation cover and groundwater are among the factors influencing the soil surface moisture distribution. Additional information from Wan Juliana's (2001) study showed that the largest group of species (49 species, 42.6%) was habitat generalist with respect to soil conditions.

Pasoh is well suited to further investigation of responses and adaptations of tropical forests to variations in soil drainage and aeration, and also of soil mediation of moisture supply in a seasonal but marginal climate (Adzmi *et al.* 2010). Studies on soil moisture are important for a understanding of the hydrological cycle and also for ecological purposes. Therefore, more related studies should be undertaken to have a better understanding of the hydrological cycle and its connectivity to ecological parameters such as interception of trees, water uptake by different species with regard to their locality etc. As an overall observation, we found that soil moisture fluctuation in August was not in line with the rainfall amount received by the area which requires further investigation. Long-term spatial and temporal changes in soil moisture observation could reflect the need for a major study for a better understanding of the moisture variation in Pasoh. Noguchi *et al.* (2002) mentioned that spatial distribution of soil moisture is one of the factors which influence the complex structure of the rain forest and, therefore, predicting spatial distribution of soil moisture will contribute to the understanding of the ecological function and structure of this complex tropical rain forest.

According to Wan Juliana (2001), soil types did affect tree growth in Pasoh 50-ha plot. Assessment on the 115 species found that for relative growth rate

(RGR), 55 species (47.8%) had growth rates that were significantly different between soil types. For absolute growth rate (AGR), 79 species (68.7%) had growth rates that were significantly different between soil types, 71 species had their AGR on alluvial soil and 4 species had their highest AGR growth on ridge areas (shale and laterite).

In an ecological study, information on moisture content would be beneficial to determine the habitat classification in relation to the water gradient. Some species may have their own water relation characteristics. Based on soil moisture data, ecologists may make preliminary assumptions on the species distribution throughout the plot. Moisture availability in soil indicates the distribution of nutrient availability in soil which, in turn, is associated with the species or habitat classification. For example, pH gradient, soil depth, soil water availability and concentration of major mineral nutrients have been found in a Eucalyptus forest in Australia (McColl 1969; Wan Juliana 2001). Asthon (1964) found that in a mixed dipterocarp forest, tree species distribution in the Andulau Forest Reserve, Brunei was associated with a topographic gradient that was correlated with variation in soil nutrient availability (Austin *et al.* 1972; Wan Juliana 2001). In this study, findings on the water content throughout the plot support the function of water in promoting the relative importance of nutrient availability across the plot. It is suggested that further detailed analysis be carried out to confirm the relationship between nutrient and soil water availability at Pasoh.

CONCLUSION

The colonisation of trees in Pasoh 50-ha plot is associated with the soil and topography condition, for example, *Shorea maxwelliana* is the Dipterocarpaceae family found to be abundant at the dry alluvial area. This species prefers to live at the terrestrial ecosystem. The association of trees and sites condition could be one of the indicators that shall be considered in site-matching for future forest rehabilitation or replanting programmes. Other factors such as nutrients and soil chemical properties could also lead to trees and habitat association. Therefore, more detailed studies are suggested to understand the factors underlying species specialisation and adaptation to soil drainage variation in Pasoh 50-ha demography plot.

REFERENCES

Abd Rahman Kassim. 2004. Population dynamics of dipterocarps at the 50 ha Pasoh Forest Dynamics plot: Inside CTFS (Centre for Tropical Forest Science) Summer 2004.

Adzmi, Y., W.C. Suhaimi, M.S. Amir Husni, H. Mohd Ghazali, S.K. Amir and I. Baillie. 2010. Heterogeneity of soil morphology and hydrology on the 50 ha long term ecological research plot at Pasoh, West Malaysia. *Journal of Tropical Forest Science.* 22(1): 21-35.

Ashton, P.S. 1964. Ecological studies in the mixed dipterocarp forest of Brunei State. Oxford Forestry Memoirs Number 25. Clarendon Press, Oxford.

Austin, M. P., P.S. Ashton and P. Greg-Smith. 1972. The application of quantitative methods to vegetation survey. III. A re-examination of rain forest data from Brunei. *Journal of Ecology.* 60: 305-324.

Becker, P., P.E. Rabenold, J.R. Idol and A.P. Smith. 1988. Water potential gradients for gaps and slopes in Panamanian tropical moist forest's dry season. *Journal of Tropical Ecology.* 4:173-184.

Condit, R., S.P. Hubbell, and R.B. Foster. 1996. Changes in tree species abundance in a neotropical forest: Impact of climate change. *Journal of Tropical Ecology.* 12: 231-256.

Davies S.J., M.N. Nur Supardi, J.V. Lafrankie and P.S. Ashton. 2003. The trees of Pasoh forest: Stand structure and floristic composition of the 50-ha forest research plot. In: *Pasoh. Ecology of a Lowland Rain Forest in Southeast Asia,* eds. T. Okuda, N. Manokaran, Y. Matsumoto, K. Niiyama, S. C. Thomas, and P. S. Ashton pp. 35-50. Tokyo: Springer.

Daws, M. I., C.E. Mullins, D.F.R.P. Burslem, S. Paton and J.W. Dalling. 2002. Topographic position affects the water regime in a semi-deciduous tropical forest in Panama. *Plant and Soil*. 238:79-90.

Debski, I and D.F.R.P. Burslem. 2000. Spatial pattern and habitat preference in Aporosa (Euphorbiaceae) in two Malaysian rain forests: implications for coexistence. Singapore Meeting abstracts, Center for Tropical Forest Science.

DOA. 1987. *Panduan Penyiasatan Tanah*. Cawangan Tanah dan Analisa, Jabatan Pertanian Semenanjung Malaysia, Kuala Lumpur.

FAO. 2006. World Reference Base for Soils. World Soil Resources Report 84. Rome: Food Agriculture Organization of United Nations.

Foth, H. D. and L. M. Turk. 1972. *Fundamentals of Soil Science* (5th ed). USA: John Wiley & Sons, Inc.

Guha, M.M. 1969. A preliminary assessment of moisture and nutrients in soils as factors for production of vegetation in West Malaysia. *Malaysian Forester*. 32: 423–433.

Harms, K. E., R. Condit, S.P. Hubbell and R.B. Foster. 2001. Habitat associations of trees and shrubs in a 50-ha neotropical forest plot. *Journal of Ecology*. 89: 947-959.

Hirai, H., H. Matsumura, H. Hirotani and K. Sakurai. 1995. Soils and the distribution of *Dryobalanops aromatica* and *D. lanceolata. In: Studies of Global Environmental Change with Special Reference to Asia and Pacific Region*. Vol II-3, pp. 110-118, Ehime University, Japan.

Hubbell, S.P. and R.B. Foster. 1983. Diversity of canopy trees in a neotropical forest and implications for conservation. In: *Tropical Rain Forest: Ecology and Management, eds*. S.L. Sutton, T.C. Whitmore and A.C. Chadwick, pp. 25-41. Oxford: Blackwells.

Hubbell, S.P. and R.B. Foster. 1986. Biology, chance, and history and the structure of tropical rain forest tree communities. In: *Community Ecology,* ed. J. Diamond and T. J. Case, pp. 314-329. New York: Harper & Row.

John, R. 2003. Distributions of tropical deciduous forest trees in Madumalai, Southern, India. Inside CTFS.

Kochummen, K. M., J.V. Lafrankie and N. Manokaran. 1992. Diversity of trees and shrubs in Malaya at regional and local levels. *Malayan Nature Journal*. 45(1-4): 545-554.

Liza S. Comita and Bettina M. J. Engelbrecht. 2009. Seasonal and spatial variation in water availability drive habitat associations in a tropical forest. *Ecology.* 90:2755–2765.

Lukanu, G. and M.J. Savage. 2006 . Calibration of a frequency domain reflectometer for determining soil-moisture content in a clay loam soil. *Journal Water SA.* 32(1): 37-42.

Manokaran, N. and J.V. Lafrankie.1990. Stand structure of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science.* 3(1): 14-24.

Manokaran, N., J.V. Lafrankie and Roslan Ismail. 1991. Structure and composition of the Dipterocarpaceae in a lowland rain forest in Peninsular Malaysia. In: *Fourth Round-Table Conference on Dipterocarpaceae. Biotrop*, ed. I. Soerianegara, S. S. Tjitrosomo, R. C. Umaly and I. Umboh, pp. 317-331, Special Publication No. 41. Bogor: SEAMEO BIOTROP.

Manokaran, N., Abd. Rahman Kassim, Azman Hassan, Quah, E. S. and Chong, P. F. 1992. Short-term population dynamics of dipterocarp trees in a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science*. 5(1):97-112.

Marryanna, L., S. Siti Aisah and K. Saiful Iskandar. 2007. Small scale variations of soil moisture in the Pasoh 50-ha Plot. Paper presented at *ECOMOD 2007 2nd Regional Conference*, 28-30 August 2007, Penang.

McColl, J. G. 1969. Soil-plant relationships in a Eucalyptus forest on the South coast of New South Wales. *Ecology.* 50: 354-362.

Niiyama, K., K. Abd. Rahman, S. Iida, K. Kimura, R. Azizi and S. Appanah. 1999. Spatial patterns of common tree species relating to topography, canopy gaps and understorey vegetation in a hill dipterocarp forest at Semangkok Forest reserve, Peninsular Malaysia. *Journal of Tropical Forest Science*. 11(4): 731-745.

Noguchi, S., N. Adachi, Y. Tan, N. Osada and N. Abdul Rahim. 2002. Spatial distribution of surface soil moisture in a tropical rain forest, Pasoh Forest Reserve. *Proceedings of the 4th Asian Science and Technology Congress* 2002, 25-27 April, Kuala Lumpur.

Nur Supardi M.N. 2003. Palms of Pasoh. In: *Pasoh: Ecology of a Lowland Rain Forest in Southeast Asia*, eds. T. Okuda, N. Manokaran, Y. Matsumoto, K. Niiyama, S.C. Thomas and P.S. Ashton, pp. 114- 195. Tokyo: Springer-Verlag.

Okuda, T., M. Suzuki, N. Adachi, K. Yoshida, K. Niiyama, M.N. Nur Supardi, H. Nor Azman, N. Manokaran, and H. Mazlan, H. 2003. Logging history and its impact on forest structure and species composition in the Pasoh Forest Reserve - implications for the sustainable management of natural resources and landscapes. In: *Ecology and Natural History of a Southeast Asian Tropical Rain Forest,* eds. T. Okuda, K. Niiyama, S. C. Thomas and P. S. Ashton. Tokyo: Springer-Verlag.

Paramananthan S. 1987. *Field Legend for Soil Survey in Malaysia*. Serdang: Penerbit Universiti Pertanian Malaysia.

Plotkin, J. B., M.D. Potts, N. Leslie, N. Manokaran, J. Lafrankie and P.S. Ashton. 2000. Species-area curves, spatial aggregation, and habitat specialization in tropical forests. *Journal of Theoretical Biology* 207: 81-99.

Soil Survey Staff. 1999. *Soil Taxonomy* (2nd ed). Agricultural Handbook 436. Washington DC: United States Department of Agriculture.

Soil Survey Staff. 2006. *Keys to Soil Taxonomy* (10th ed). Washington DC: United States Department of Agriculture.

Svenning, J-C. 1999. Microhabitat specialization in a species-rich palm community in Amazonian Ecuador. *Journal of Ecology* 87:55-65.

Wan Juliana W. A. 2001. Habitat specialization of tree species in a Malaysian Tropical Rain Forest PhD. Thesis. Department of Plant and Soil Science, University of Aberdeen, Scotland. U.K.