MICROCLIMATE AND WATER STATUS OF SAND TAILINGS AT AN EX-MINING SITE IN PENINSULAR MALAYSIA

L. H. Ang,

Forest Research Institute Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia

W. E. Seel & C. Mullins

Plant and Soil Science Department, University of Aberdeen. United Kingdom

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ANG, L. H., SEEL, W. E. & MULLINS, C. 1999. Microclimate and water status of sand tailings at an ex-mining site in Peninsular Malaysia. Experimental plots, each of size of 12 × 7.5 m, were established on sand tailings at an ex-mining site in Peninsular Malaysia at 8 m above the standing water-table level (a.s.w.l.) (open and shade plots) and at 2.5 m a.s.w.l. (open plot only). The shade plot received about 45% irradiance while the open plot received full irradiance. *Acacia mangium* and *A. auriculiformis* seedlings were planted in both plots at 0.75 × 0.75 m spacing. Shading reduced air temperature, raised relative humidity (RH) and decreased air vapour pressure deficit (VPD_{air}). The results of 195 daily recordings of water-table levels in 3-m depth dipwells showed that ground water supply was limited at the site. The suction of sand at 0–15 cm depth at 1, 3 and 6 days after rainfall (> 37 mm per day) showed that the sand tailings at 8 m a.s.w.l dried rapidly from 3 to 6 days after rainfall. Days of available sand water (DAW) for *A. mangium* and *A. auriculiformis* were estimated based on root depths of each species and water release characteristics of the sand tailings. The DAW values for 9-month-old *A. mangium* and *A. auriculiformis* were 6 and 11 days respectively.

Keywords: Sand tailings - microclimate - acacias - rooting depths - available water content

ANG, L. H., SEEL, W. E. & MULLINS, C. 1999. Iklim mikro dan status air bagi hampas lombong di tapak bekas lombong di Semenanjung Malaysia. Petak penyelidikan, setiap satu seluas 12 × 7.5 m, didirikan di atas hampas lombong di tapak bekas lombong di Semenanjung Malaysia pada 8 m di atas paras air permukaan (petak terbuka dan petak naung) dan pada 2.5 m di atas paras air permukaan (petak terbuka sahaja). Petak naung menerima 45% cahaya manakala petak terbuka menerima cahaya penuh. Anak benih *Acacia mangium* dan *A. auriculiformis* telah ditanam di petak-petak tersebut pada jarak tanaman seluas 0.75 × 0.75 m. Naungan mengurangkan suhu udara, menambahkan kelembapan bandingan (RH) dan menurunkan tekanan wap udara. Keputusan bagi 195 catatan harian panas air permukaan dalam tanah sedalam 3 m menunjukkan kawasan tersebut mempunyai bekalan air yang terhad. Sedutan pasir pada kedalaman 0–15 cm pada 1, 3 dan 6 hari selepas hujan (> 37 mm sehari) menunjukkan bahawa kehilangan kelembapan hampas lombong pada 8 m di atas paras air permukaan berlaku dengan cepat tiga dan enam hari selepas hujan. Hari-hari hampas pasir tersedia (DAW) bagi *A. mangium* dan *A. auriculiformis* dianggarkan berdasarkan kedalaman akar bagi setiap spesies dan ciri-ciri kehilangan air hampas pasir tersebut. Nilai DAW bagi *A. mangium* dan *A. auriculiformis* yang berumur 9 bulan adalah masing-masing 6 dan 11 hari.

Introduction

Peninsular Malaysia has 113 700 ha of tin tailings (Chan 1990). About 80% of tin tailings is sand and the remainder is classified as slime and sandy slime (Lim *et al.* 1981). Slime and sandy slime tailings consist of larger amounts of clay and silt particles with higher nutrients and water retention capacity, and are more easily cultivated than sand tailings (Mitchell 1957). Sand tailings consist mainly of fine sand, coarse sand and gravel. Hence, they have low fertility due to lack of organic matter and fine particles such as clay and silt. In addition, sand tailings situated at more than 1.5 m above the standing water-table level (a.s.w.l.) are frequently subject to periodic drought due to their poor water retention capacity and high temperature environment (Ang *et al.* 1993). As high cost is needed to improve the irrigation and fertility of sand tailings for agricultural practices, large tracts of sand tailings remain idle. In addition, the presence of heavy metal contaminants in sand tailings may render the site unsuitable for agricultural purposes (Ang & Ang 1997). Hence, this is a serious cause for concern since sand tailings account for 2% of the land area of Peninsular Malaysia. The other alternative land use of sand tailings is for wood production. To date there has been no detailed study of either the microclimate or plant-available water on sandy tin tailings. Without detailed knowledge of these factors, planting of timber species in an attempt to reclaim sand tailings is unlikely to be successful , since it is impossible to accurately predict (1) the identity and timing of the factors that are the chief constraints on plant growth and survival, and (2) which timber species will most likely survive a minimum input approach for afforestation.

The key role of water in the determination of plant growth and survival is clearly illustrated by the fact that sand tailings that are > 4 m a.s.w.l. support only small, isolated patches of grasses and shrubs, but a large cover and high diversity of shrub and tree species regenerate on moist sand tailings <1.5 m a.s.w.l (Mitchell 1957, Ang 1994).

The two sources of water supply to sand tailings are soil water from the mining pool and fresh supply from rainfall. Records of the water- table levels and rainfall would help to determine the dry or wet periods in the sand tailings. Such monitoring would determine the supply of water to plants. However, whether or not a plant experiences water deficit depends not only on the supply of water, but also on its demand or loss. It is the atmosphere that ultimately controls the loss of water from plants. High air temperature and low relative humidity would normally affect water loss processes from plants (Grace 1983). Leaf water loss to the atmosphere during photosynthesis is mainly through stomata with some also from the cuticular transpiration (Grace 1983). Water loss from plants is mainly determined by the leaf-to-air vapour pressure deficit ($VPD_{leaf-air}$). VPD_{leaf} is calculated using leaf temperature. Air vapour pressure deficit (VPD_{air}) can be calculated from air temperature and relative humidity which are in turn affected by the irradiance (Gates 1980). High VPD_{air} is usually associated with high $VPD_{leaf-air}$ (Idso *et al.* 1981). VPD_{air} is also used as an indicator to characterise the canopy conditions in relation to transpiration or stomatal conductance. For example, in the tropics, Maruyama *et al.* (1994) found that stomatal conductance of *Shorea leprosula* is limited at VPD_{air} > 10 hPa. Hence, the dipterocarp experienced a measure of atmospheric drought at VPD_{air} > 10 hPa. VPD_{air} also plays an important role in the determination of Idso's stress index for leaf; high VPD_{air} is normally associated with high Idso's stress index of leaf during water deficits (Idso *et al.* 1981). Monitoring of irradiance, air temperature, RH and VPD_{air} is therefore essential to determine the drought effects of sand tailings on plants.

This paper summarises the environmental conditions of the study site taken to be representative of typical sand tailings in Malaysia. Hence, the objectives of this study were :

- to determine the magnitude of VPD_{air} fluctuations in relation to the micro-climatic parameters on sunny and cloudy days,
- to quantify the availability of soil water to *Acacia mangium* and *A. auriculiformis* during dry spells,
- to determine the effects of artificial shading on the water content and microclimate of the sand tailings.

Materials and methods

Study site

The study site was located in Au's mine which is about 4 km northwest from the town of Malim Nawar, Perak (4° 21" N, 101 °0 7" E). The two-year-old sand tailings that resulted from gravel pump mining were selected for this study based on accessibility, practical and security reasons.

The study site was located at 27 ± 0.5 m above sea-level surrounded by mining pools. The study site was colonised by patches of leguminous herbs and shrubs. The most common were *Cassia pinnata, Mimosa pudica* and *Desmodium triflorum.* In addition, *Imperata cylindrica, Tetracera scandens, Eupatorium odoratum, Mikania cordata, Paspalum conjugatum* and *Centrosema pubescens* were also present. The sporadic patches of vegetation were cleared during levelling. The sand tailings were levelled by a tractor at about 8 m above standing water level (a.s.w.l) and 2.5 m a.s.w.l.

The experimental plots were assessed for mechanical impedance using a portable hand-held cone penetrometer (Leonard Farnell and Co. Ltd, Hatfield, HERTS, England). The instrument has a 30-degree cone mounted on a relieved shaft and is pushed slowly into the soil. Penetrometer readings were taken along a line between the shade and open plots and also at the side of open plots. High mechanical impedance (> 1.5 MPa) was found at a depth deeper than 22.9 cm from the surface. The high mechanical impedance of the study site was due to the working of heavy machinery during site levelling. The site was ploughed at a depth of 30–45 cm before planting, resulting in low penetration resistance of 0–45 cm depth and high readings (> 1.5 MPa) at depths greater than 38.1 cm (Table 1).

Table 1. Mechanical impedance of the study site in Malim Nawar, Perak

Depth (cm)	Number of samples	Number of high readings	Mean (s.d.) (MPa)
0–7.5	14	0	0.48(0.20)
7.5–15.2	14	0	1.28(0.82)
15.2–22.9	14	0	2.2(1.15)
22.9–30.5	14	0	2.6(1.4)
30.5–38.1	10	4	2.49(1.53)
38.1–45.7	6	8	2.13(1.49)
45.7–53.3	4	10	2.07(1.6)
53.3–61.0	4	10	3.43(2.34)

Open and shade plots

An open plot and a shade plot were established on the high site only. The size of both open and shade plots was 7.5 × 12 m . Shade was provided by covering the desired area with a black polythene netting sheet, suspended from a wooden frame 1.5 m above the ground. This sheet allowed only 45% of the incident rays to reach the ground below.

Species and planting technique

Three-month-old seedlings of *Acacia mangium* and *A. auriculiformis* were planted in both the open and shade plots. The acacia seedlings were planted at 0.75 × 0.75 m spacing. The planting of the seedlings was carried out before 1030 h (Malaysian Standard Time). The seedlings were watered well, then placed in planting holes of 20 cm diameter and 20 cm depth. Each seedling was carefully removed from the potting bag to minimise root damage. The planting hole was filled with 1.5 kg of soil conditioner mixed with 20 g of NPK Green (15:15:15). The soil conditioner consists of a mixture of 80% peat and 20% burned rice husk with macro-nutrients of N (0.2%), available P (0.09 ppm), K (0.20 meq/100g) and Mg (0.39 meq/100g). For two weeks following planting one litre of water was given to each seedling daily.

Microclimate

Air humidity and temperature sensors were measured using Transmicor 120 series sensor-transmitters (T120.1.2, CORECIsa, France). Irradiance was measured by silicone pyranometers (DRS-5I, Didcot Instruments, United Kingdom). The readings of each sensor were recorded every 5 min (an average of readings at every 5 s) and stored in a datalogger [Datataker 500, Data Electronics (Aust.) Pty. Ltd., Australia]. Three typical sunny and cloudy days were selected from all the available data sets for analysis.

Rainfall was measured with eight home-made rain-gauges. Each was made from a funnel with an internal diameter of 12.7 cm joined to a 1.5-litre heat resistant plastic bottle via a 1.5 m heat resistant plastic tube. The funnel was attached perpendicularly to a vertical standing wooden stick. The bottle was buried at about 10 cm under the surface of the sand to prevent water loss by evaporation. The volume of water collected in each of the rain-gauges was measured during each site visit and then converted into mm of rain using a standard conversion formula.

Particle size distribution

Sand was sampled at 0–30 cm and 1.45–1.50 m during the installation of dipwells and sent for particle size analysis at the Malaysian Mine Research Institute, Ipoh, Perak. Six replications of soil samples at the specified depths were analysed according to BS 1377:1975.

Soil water status and water release characteristics

The water-table was monitored using dipwells. Two dipwells were installed on the high site (8 m a.s.w.l.) and four on the low site (2.5 m a.s.w.l.). They were each made from a 3-m length of PVC pipe with an internal diameter of 5 cm. One end of the pipe was covered with a 5-mm grid netting and then fitted with a perforated iron end-plate to prevent blockage by sand. The dipwell installation was done by piling and extraction using an auger and joints of steel pipe. Once the hole had been bored the PVC pipe was inserted with 20 cm length protruding above the surface. The top was sealed with a removable plastic cap. Dipwell readings were made by inserting a straight bamboo stick into the pipe until it touched the bottom of the well.

Water release characteristic curves of the sand tailings were determined for sand taken from three depths namely 0–5 cm, 25–30 cm and 1.45–1.50 m, using standard techniques (Mullins 1991).

The water-release characteristc curve was used to determine the volumetric water contents at field capacity (Θ_{field}) and permanent wilting point ($\Theta_{wilting}$). Available water content of the sand profile (AWC) = $\Theta_{field} - \Theta_{wilting}$. The number of days of available water (DAW) was estimated from the profile of available water (AWC x rooting depth/100) divided by potential evapotranspiration (Marshall & Holmes 1992). The rooting depths of 9-month-old *Acacia mangium* and *A. auriculiformis* seedlings growing on the sand tailings were determined as described below.

Periodic soil samples were also collected at 0–15 cm during each site visit (Table 2) in order to characterise the field water content of the site. On these occasions the filter paper method (Deka *et al.* 1995) was used to determine soil matric suction in the field. Sand at 0–15 cm depth was selected for suction determination because the planting hole was only at a depth of 20 cm; hence, in the early stage, most of the root systems of both the species were expected to be less than 20 cm deep.

Root measurement

Six seedlings of both species located at the edge of the plots adjacent to bare sand were marked for root extraction. A trench of 0.5 × 1 m was dug with a spade to 1.0 m depth, at about 80 cm away from the base of the seedlings. The sand was carefully chipped away using a sharp blade from the surface downward to search for the roots. Once a root was spotted the sand around the root was carefully knocked loose, and the position was recorded with reference to the stump of the seedlings using a measuring tape and ruler. The root depth and its horizontal position with respect to the base of the seedling were used to describe the extent of the root system.

Statistical analyses

The data were subjected to statistical analysis using ANOVA (Minitab Version 10.1 for Window). Comparisons between means by least significant difference (L.S.D.) were made as described by Parker (1983).

Results

Microclimate

The mean maximum irradiance (I_{cmax}) values for cloudy day were 733.4 and 265.2 W m^{-2} at 1300 h in the open and shade plots respectively (Figure 1). The I_{max} of sunny day in the open plots was as high as 967.2 W m^{-2} but only about 306.1 W m^{-2} in the shade (Figure 1a).

Mean hourly temperatures were significantly lower in the shade plot than open plot (Figure 1b). The mean maximum air temperatures (T_{max}) at 1400 h were as high as 39 and 34 °C in the open and shade plots respectively. The mean hourly air temperatures in the shade plot were similar regardless of the presence or absence of clouds (Figure 1b).

There was a lag of 1 h between the mean I_{cmax} and T_{max} (Figures 1a & 1b). This lag suggests that time is needed for the heating of air by irradiance which eventually raises the air temperature to its maximum. Mean hourly temperature from 1000 to 1500 h in the shade plot was significantly lower than in the open plot. Higher mean hourly air temperatures of shade than open plots at 1700 h were recorded on the sunny days. This was most probably due to the long wave radiation emitted from the soil trapped in the shade .

The mean hourly RH was recorded highest in the morning for both sites and dropped to its minimum at noon (Figure 1c). The minimum mean RH (RH_{min}) at 1400 h of cloudy days was only at 55 and 65% for open and shade plots respectively. The mean hourly RH_{min} of the open plot at 1400 h was as low as 32 and 53% on sunny and cloudy days respectively.

On cloudy days, the mean hourly VPD_{air} increased from 6.48 hPa at 0940 h to a maximum of 24.5 hPa and 16.8 hPa at 1300 h in the open and shade plots respectively (Figure 1d). On sunny days, the mean hourly VPD_{air} exceeded 10 hPa at 1000 h in the open and at 1100 h in the shade plots (Figure 1d). The mean VPD_{air} exceeded 10 hPa in the open until 1750 h whilst in the shade it was below 10 hPa shortly after 1600 h.

Rainfall

Figure 2 shows the rainfall distribution at the site from 15/6/94 to 30/7/95. The rainfall collected during the period when records were taken not daily but over short periods as shown is given in the figure as a mean daily rainfall. Two distinct periods of drought in mid-June to July '94 and mid-December '94 to mid-January '95 were recorded during the study period in Malim Nawar, Perak. The annual rainfall of the study site from 15/6/94 to 15/6/95 amounted to 1575 mm.

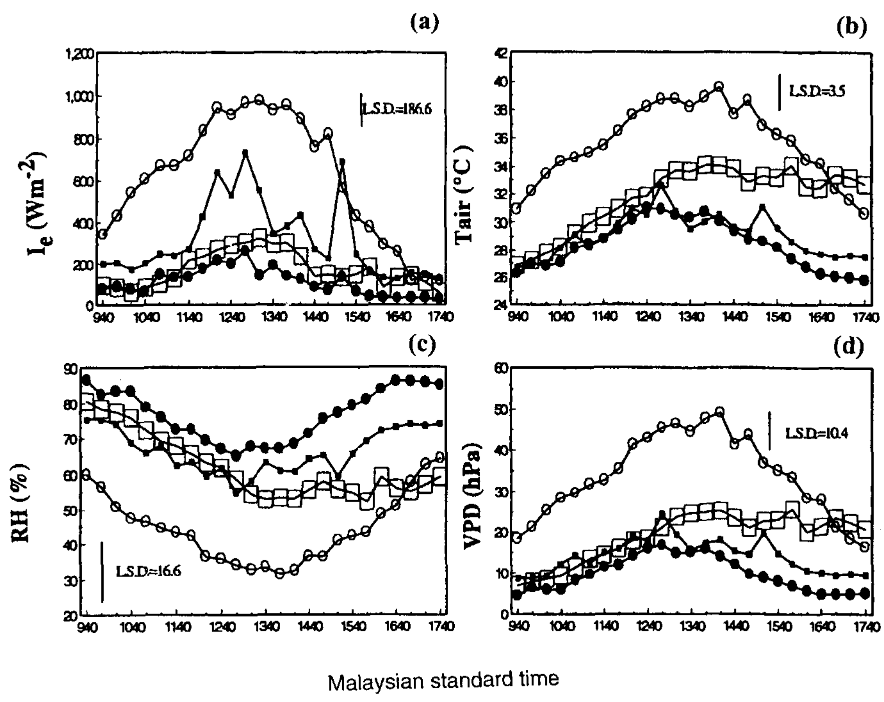

Figure 1. The mean irradiance (I_e) in Wm^{-2}, mean relative humidity (RH) in %, mean air temperature (T_{air}) in °C and mean air vapour pressure deficits (VPD_{air}) in hPa of the open plot on sunny (○) and cloudy days (■) together with the shade plot on sunny (□) and cloudy days (●). The data sets for sunny and cloudy days in open plots were collected on 14/12/94, 14/01/95, 25/01/95 and 04/10/94, 2/12/94,19/01/95 respectively. Data sets for sunny and cloudy days in shade plots were collected on 03/10/94, 23/12/94, 26/01/94 and 22/12/94, 19/01/95 and 27/01/94 respectively. The L.S.D. for each parameter was at $p< 0.05$.

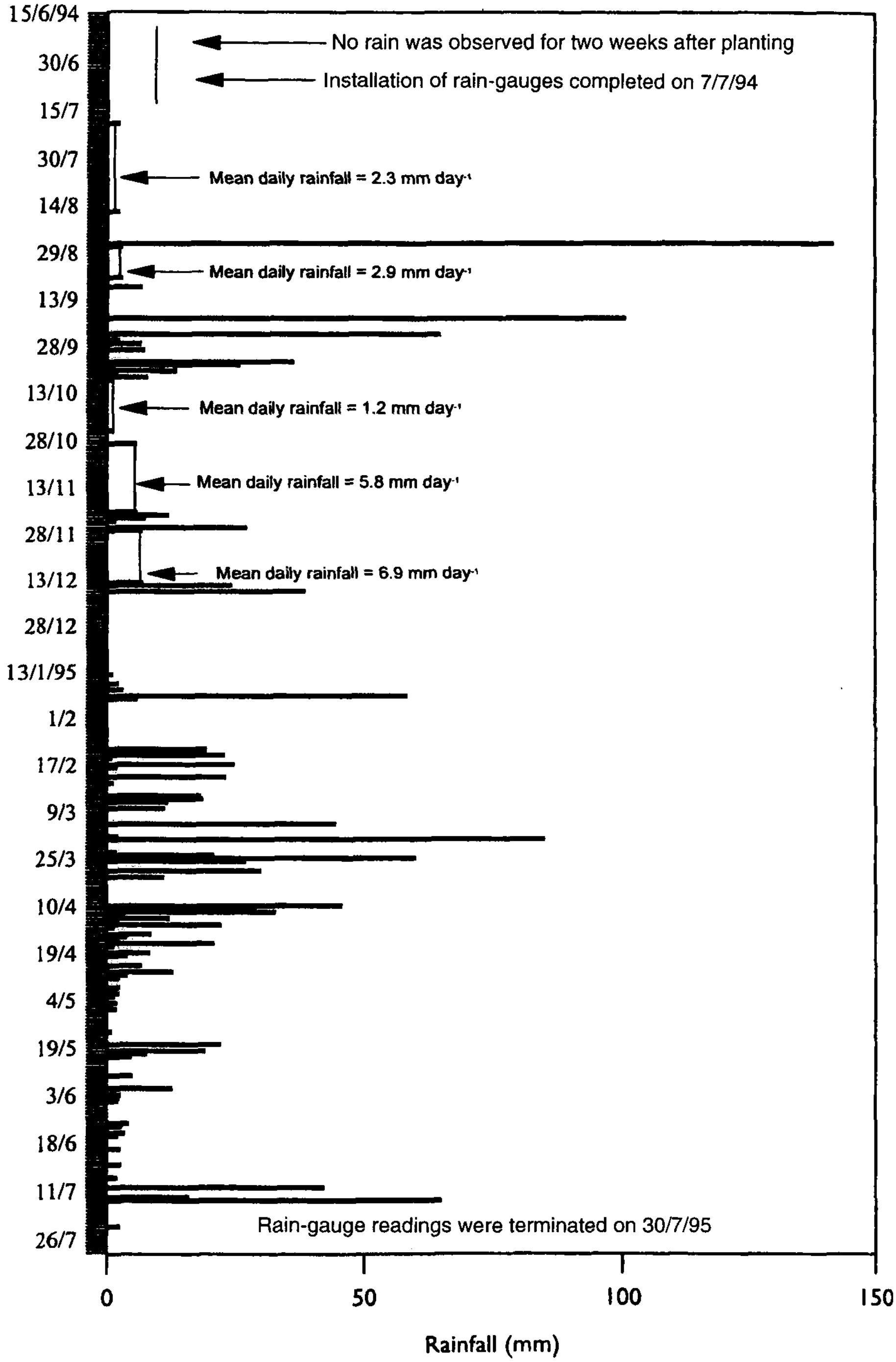

Figure 2. Rainfall distribution of the study site from 15/6/94 to 30/7/95, Malim Nawar, Perak

Root depths

The root depths of *Acacia mangium* and *A. auriculiformis* were 23.3 ± 4.9 cm and 40.8 ± 0.8 cm respectively. The roots of *A. auriculiformis* grew significantly deeper than those of *A. mangium.* The maximum root depth of *A. auriculiformis* was less than 45 cm, possibly as the result of the high mechanical impedance at 40–45 cm depth (Table 1).

Sand characteristics and water relations

Particle size analysis of the study site showed that it comprised 99% sand and only 1% clay and silt (Table 2). The largest portion was composed of coarse and medium-sized grain sand.

Table 2. Particle size analysis of the experimental plots in Malim Nawar, Perak given as means of three samples with their standard deviations (in parentheses)

Depth (cm)	0 - 30 cm	145 - 150 m
Cgravel	0(0)	0(0)
Mgravel	1.7(1.2)	3.3(1.5)
Fgravel	10.0(2.6)	8.7(3.2)
Sub-total	11.7(-)	12.0(-)
Csand	46.3(3.2)	48.0(8.0)
Msand	30.0(2.6)	28.7(6.5)
Fsand	11.0(1.0)	10.3(5.7)
Sub-total	87.3(-)	87.0(-)
Clay & silt	1.0(1.0)	1.0(1.0)
Total	100.0(-)	100.0(-)

Note: According to BS 1377:1975, Cgravel (12.500-20.000 mm), Mgravel (6.300-12.500 mm), Fgravel (2.000-6.300 mm), Csand (0.600-2.000 mm), Msand (0.212-0.600 mm) , Fsand (0.063-0.212 mm), Clay & silt (<0.063 mm).

Figure 3 shows the water release characteristics of the sand tailings. The volumetric water contents of the sand tailings at field capacity which were taken as -5 kPa matric suction were 11.5, 7.8 and 11.6% for 0–5 cm, 20–25 cm, and 1.45–1.50 m depths respectively. The volumetric water contents at the permanent wilting point were 1.5, 1.2 and 1.6% for 0–5 cm, 20–25 cm and 1.45–1.50 cm depths respectively. The available water capacity values were 10, 6.6 and 10% for 0–5 cm, 20–25 cm and 1.45–1.50 m depths respectively.

Figure 4 shows the suction of the sand tailings at the subplots at 0–15 cm depth. There was no significant difference in suction between the open and shade plots at one day after rainfall. However, the shade plot had significantly higher water content and suction than the open plot at three and six days after rainfall. Figure 4 shows progressive drying of the sand tailings at three and six days after rainfall, and shows how quickly this may occur.

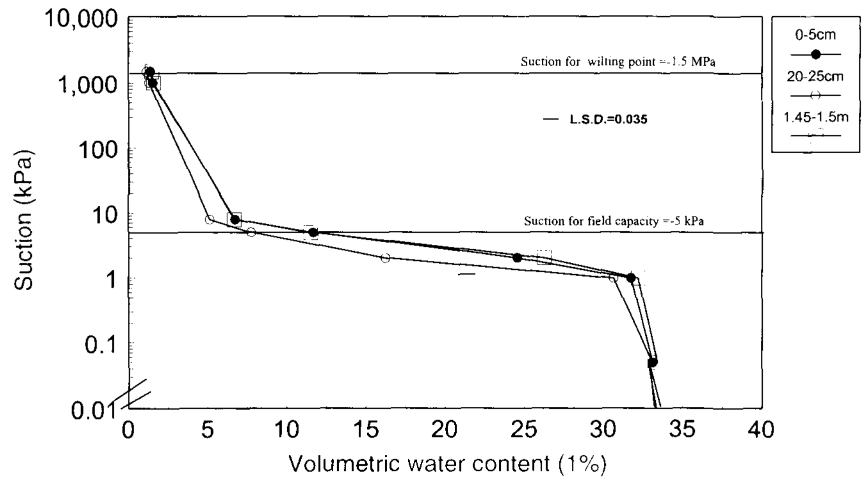

Figure 3. Water release characteristics of sand tailing at depths of 0 - 5 cm (●), 20 - 25 cm (○) and 1.45 - 1.5 m (❐).

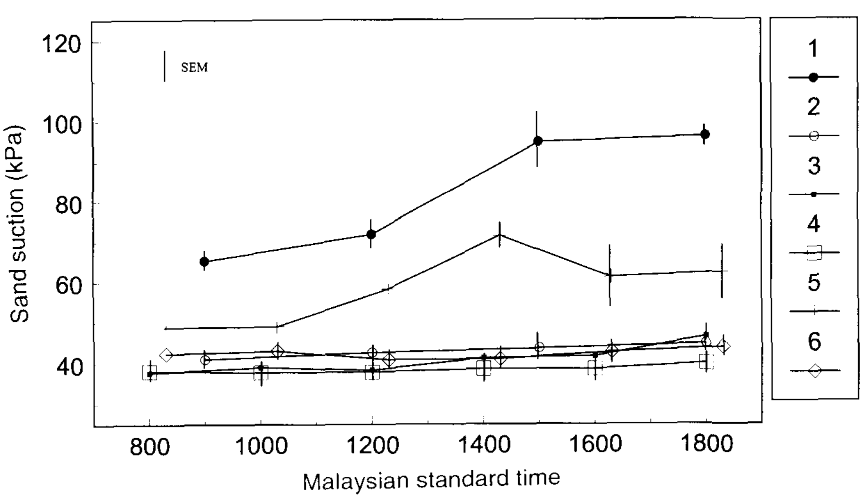

Figure 4. Sand suction at 0-15 cm depth of open and shade plots measured about 50 cm from the growth plots. The mean suction of each sampling point was an average of three samples and SEM denotes ± one standard error of mean. The codes are as follows:

Code	Site	Days after rain	Last rainfall (mm)	Date of last rainfall
●	Open	6	37.9	18/12/1994
○	Shade	6	37.9	18/12/1994
■	Open	1	37.5	17/02/1995
❐	Shade	1	37.5	17/02/1995
+	Open	3	84.7	18/03/1995
◊	Shade	3	84.7	18/03/1995

Mean water-table depths measured on 195 occasions between 30 June 1994 and 15 July 1995 at the low site (2.5 m a.s.w.l.) and the high site (8 m a.s.w.l.) respectively are given in Table 3. The water-table level for the high site was undetected. The mean water-table depth ranged from 1.93 to 2.25 m for the four dipwells.

Table 3. Readings of dipwells at the study site in Malim Nawar, Perak

	Mean (m)	Min. (m)	Max. (m)	Range (m)
DW1	2.24 ± 0.01	1.94	2.67	0.73
DW2	2.29 ± 0.01	1.93	2.73	0.80
DW3	2.36 ± 0.01	2.13	2.73	0.60
DW4	2.49 ± 0.01	2.25	2.78	0.53
DW5	>3.00	-	-	-
DW6	>3.00	-	-	-

SEM denotes standard error of the means, Min. and Max. denote minimum and maximum readings from 195 readings respectively.

Discussion

The microclimate of the sand tailings is harsh. The study site received an annual rainfall of 1575 mm but was still prone to atmospheric and soil drought. Modification of these dry conditions of the sand tailings is necessary before any tree planting on the site is to be attempted. The correct height of sand dunes above the water table level is crucial for successful establishment of the seedlings.

Microclimate of sand tailings

High mean hourly T_{air}, and low mean hourly RH resulted in high mean hourly VPD_{air} in the open plot. High mean hourly T_{air} in the open plot was due to high irradiance (Gates 1980). The values of air temperature and VPD_{air} in the sand tailings were slightly higher than those measured in gaps of forest plantations. For example, the maximum air temperature recorded in forest plantation gaps was about 34 °C during a sunny day (Maruyama *et al.* 1994). Sand surface temperature is also usually higher than the air temperature. The mean maximum air temperature of 40 °C was recorded during sunny days whereas Mitchell (1959) recorded a maximum surface temperature of 48.8 °C at 1430 h for sand tailings, which falls within the heat killing temperature range for primary rain forest species of 43.9 to 51.7 °C (Levitt 1972).

A mean maximum VPD_{air} of 47.4 hPa was recorded for sunny days at the sand tailings, a value much higher than the maximum VPD_{air} in forest plantation gaps of 32 hPa as reported by Maruyama *et al.* (1994). However, the mean maximum VPD_{air} in a forest plantation gap on sunny days is still higher than the mean maximum VPD_{air} of the shade plot and for cloudy days in the open plot. The high VPD_{air} of sand tailings on sunny days which exceeds 40 hPa would definitely limit the stomatal conductivity of many tropical rain forest species such as *Shorea leprosula,* which suffered atmospheric drought when VPD_{air} exceeded 10 hPa, and *Acacia mangium,* which experienced mid-day depression of stomatal conductance at VPD_{air} > 20 hPa from 1200 to 1400 h (Maruyama *et al.* 1994).

Lower mean hourly RH was recorded on sunny days compared to cloudy days, corresponding to higher mean hourly T_{air} and T_{max} on both open and shade plots. For the open plot this would be expected since the irradiance was more than twice as much on sunny days, heating the ground surface and hence the air. For the shade plot, where there was a small difference in irradiance between sunny and cloudy days, an additional effect due to movement of hot air from the surrounding into the shade plots is likely.

Higher mean hourly RH and lower mean hourly T_{air} resulted in lower mean hourly VPD_{air} on cloudy days. However, VPD_{air} on cloudy days was greater than 10 hPa in the open plot. RH in the shade was generally higher than in the open. However, shading failed to overcome the atmospheric drought effects on sunny days but managed to delay drought by about 30 min on the sunny days and about 2 h on cloudy days. On the cloudy days, shading significantly reduced the VPD_{air} to less than 10 hPa from 1500 to 1700 h.

Soil water status

Dipwell readings showed that soil water availability of the high sand dune at 8 m a.s.w.l. was not dependent on ground water from the nearby mining pools. Hence, the only source of water must come from rainfall. The available water capacity of sand tailings and measured rooting depth were used to indicate how long initially the sand at field capacity could maintain a water supply to the roots. This was less than 6 and 11 days for the 9-month-old *Acacia mangium* and *A. auriculiformis* seedlings respectively (Table 4). Hence, more than 6 days without rain would result in severe water deficit, especially to *A. mangium* which has a shallower root system. However, this value which is based on pan evaporation and ignores soil surface drying effects will be a considerable underestimate since evaporation from the bare sand surface is likely to drop sharply during one or two rain-free days. Nevertheless, it is clear that the supply of water in the sand that is available to the trees is limited, since dry periods of 15 days continuously without rain are common in the study site. Hence, the trees planted on the high sand tailings are expected to experience drought during the period of this study.

The difference of 0.3 m between DW1 and DW4 was due to the difference in height of the soil surface since DW4 was on the highest end of the sand dune (Table 3). The results showed that ground water supply was limited at both sites, although deep tree roots might be able to access the ground water on the low site if they were able to grow to say 1.8 m deep. However, 0.53–0.80 m fluctuation in the water-table depths suggests that waterlogging might limit rooting depth in the wet periods and the subsequent drop of the water- table in the dry period would put the roots beyond the zone of significant capillary rise. Consequently, because of the large range of its fluctuation, the whole water-table may not necessarily be able to improve tree water supply during dry periods.

Table 4. Number of seedlings excavated for root examination (n), available water capacity (AWC) of sand tailings, estimated evapotranspiration (PE) and days of available water (DAW)

Species	Number of seedlings (n)	Mean root depth (mm)	AWC (%)	PE* (mm day^{-1})	DAW (days)
Acacia mangium	6	233	10	4	5.8
Acacia auriculiformis	6	408	10	4	10.2

* The mean daily evaporation rate was calculated from daily evaporation data collected for June 1994 to July 1995 from three climatological stations in MARDI (Kuala Kangsar), Pusat Pertanian Titi Gantong and FELDA Chuping A.

Effects of artificial shade

Artificial shade managed to reduce the mean hourly air temperature and vapour pressure deficit but raised the mean hourly air relative humidity on sunny days. However, VPD_{air} during sunny days still exceeded 10 hPa which indicates that the shaded area is not free from atmospheric drought for some timber species. However, shading kept the high suction of sand tailings from falling to the water deficit level even at six days without continuous rain (Figure 4).

Conclusion

The results showed that for both the shade and open plots on the sand tailings, VPD_{air} was higher than 10 hPa which may reduce stomatal conductance of the two acacia species during clear sunny days. Both the open and shade plots had lower VPD_{air} on cloudy than sunny days. The study indicates that both the open and shade plots on the sand tailings would have dry atmospheric conditions on sunny and cloudy days. Hence, atmospheric drought would be anticipated particularly at midday of sunny days, and at the late afternoon of cloudy days. The results from the dipwells showed that the main source of soil water supply to the sand tailings at 8 m a.s.w.l. was solely dependent on the rainfall and not from the surrounding mining pool. Furthermore, in the open plot, sand tailings at 0–15 cm depth at six days after a rainfall of less than 37 mm had low sand suction showing soil water deficits for plant uptake. However, shading can prevent a water deficit of the sand tailings. In the open plot, the available water contents of sand at field capacity indicated 6 and 11 days of water availability for *Acacia mangium* and *Acacia auriculiformis* respectively. Hence, rainfall is a key factor to determine the establishment and growth of tree species on the sand tailings.

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