MANNITOL-INDUCED WATER DEFICIT STRESS IN OIL PALM (Elaeis guineensis Jacq.) SEEDLINGS

SURIYAN CHA-UM*; NANA YAMADA**; TERUHIRO TAKABE† and CHALERMPOL KIRDMANEE*

ABSTRACT

The aim of this study was to investigate the biochemical, physiological and morphological responses of oil palm seedlings to mannitol-induced water deficit. Proline content and the percentage of relative membrane leakage in seedlings increased when subjected to water deficit, depending on the degree of water deficit. Relative membrane leakage was positively associated with chlorophyll degradation. Chlorophyll a (Chla), chlorophyll b (Chlb), total carotenoids (C_{x+c}), maximum quantum yield of PSII (F_{v}/F_{m}) and photon yield of PSII (\Phi_{psii}) in the seedlings under water deficit conditions dropped significantly in comparison to the control group, leading to a reduction in net photosynthetic rate (P_n) and growth. In addition, the physiological changes and growth parameters of the plants responding to severe water deficit underwent a greater reduction than those of the plants responding to mild water deficit. These data may be applied to establish criteria for water deficit tolerance screening in breeding programmes.

INTRODUCTION

The oil palm is one of the most important oil-producing crops in the world and is widely cultivated in the tropical zone, especially in Southeast Asia (Malaysia, Indonesia and Thailand) (Wilcove and Koh, 2010). Yield, including oil yield and productivity, is the focus of oil palm genetic improvement in the form of breeding programmes (Jalani et al., 1997; Cochard et al., 2005). Oil yield is dependent not only on genetic background, but also on environmental factors, i.e. relative humidity, water availability, soil structure, fertiliser application, agricultural management and light conditions (Kallarackal et al., 2004; Henson and Harun, 2005). Hybrid seed production has been used to exploit heterosis or hybrid vigour for the improvement of productivity (Wahid et al., 2005). As the next step, tolerance to abiotic stresses, such as water deficit, extreme temperature, mineral deficiency, heavy metal toxicity and ultraviolet irradiation, will be the target in oil palm improvement. The water content of the soil in oil palm plantations may play a key role in plant growth (Henson and Harun, 2005), and may also function as a signal for female sex representation (Jones, 1997). In non-irrigated areas, there is a higher proportion of male flowers and growth retardation, leading to low productivity. Basic knowledge relating to water shortage responses in oil palm is a fruitful topic which should be investigated further for application in water deficit tolerance screening.

Water deficit is a major problem worldwide, limiting the growth and productivity of many crop species, especially in rainfed agricultural areas (totalling >1.2 billion hectares) (Chaves and Oliveira, 2004; Passioura, 2007). Plants show physio-biochemical changes, such as decreased Rubisco activity, reduced photochemical efficiency,
enhanced accumulation of stress metabolites, increased antioxidant enzymes, loss of membrane stability, reduced leaf water potential, pigment degradation, decreased stomatal conductance, reduced internal CO₂ concentration, reduced net photosynthetic rate ($P_a$) and inhibited growth prior to plant death in response to water deficit (Chaves and Oliveira, 2004; Cattivelli et al., 2008). Mannitol-induced water deficit has been widely explored in many plant species, e.g., tomato (Weng, 2000), sugar-cane (Cha-um and Kirdmanee, 2008), rice and sorghum (Cha-um et al., 2009). In the case of the palm family, ecophysiology in coconut palms, including membrane lipid composition (Repellin et al., 1997), photosynthetic ability and growth performance have been investigated (Gomes and Prado, 2007; Gomes et al., 2008). Polyethylene glycol (PEG) is well-known as a candidate osmoticum for water deficit induction being an agent of membrane injury (Ahmad et al., 2007). Moreover, PEG not only plays a role as an osmoticum but also reduces oxygen-dissolution in the culture medium. The toxic symptoms of plants grown under PEG treatment are more evident than those induced by mannitol in terms of iso-osmotic potential (Pandey et al., 2004; Slama et al., 2007).

The aim of this study was to investigate the responses of oil palm seedlings, in terms of proline accumulation, relative membrane leakage, photosynthetic ability and growth characters, to mannitol-induced water deficit.

**MATERIALS AND METHODS**

**Plant Materials**

Oil palm fruits were obtained from Suksomboon Palm Co. Ltd, located in Chonburi province, an eastern region of Thailand. The kernel of each fruit was removed. The seeds, with seed coat intact, were dried in a hot-air oven at 45°C for 12 hr, then the seed coat was broken. The embryos, along with the endosperm, were surface-disinfected once in 15% Clorox® for 20 min and once in 5% Clorox® for 30 min. The embryos were then excised and germinated on MS media (Murashige and Skoog, 1962). The media were adjusted to pH 5.7 before autoclaving. Oil palm seedlings were cultured in vitro under conditions of 25±2°C ambient temperature, 60±5% relative humidity (RH) and 60±5 µmol m⁻² s⁻¹ photosynthetic photon flux density (PPFD) provided by fluorescent lamps with a 16 hr per day photoperiod. After two months, the seedlings were transferred aseptically to MS-liquid sugar-free media. The uncovered vessels containing photoautotrophic seedlings were transferred aseptically to culture box chambers (Carry Box Model P-850, size 26×36×19 cm, Japan) where RH was controlled at 65±5% by 1.5 litres saturated NaCl solution. The number of air exchanges in the culture box chambers was increased to 5.1±0.3 µmol CO₂ hr⁻¹ by punching 32 holes in the sides of the plastic chambers and placing gas-permeable microporous polypropylene film (0.22 µm pore size) over the holes (Cha-um et al., 2003). The seedlings were acclimatised for 14 days by placing the chambers in a plant growth incubator under a temperature shift of 28±2°C/25±2°C (light/dark), CO₂ concentration of 500±100 µmol mol⁻¹, RH of 60±5%, and PPFD of 120±5 µmol m⁻² s⁻¹ provided by fluorescent lamps with a 16 hr per day photoperiod. Mannitol in the culture media was adjusted to -0.23 (control), -0.392, -0.674, -0.939 or -1.205 MPa water deficit maintained for a period of one month. Relative membrane leakage, proline content, contents of photosynthetic pigments, chlorophyll a fluorescence, net photosynthetic rate ($P_a$) and growth characters were measured.

**Experiment Design and Statistical Analysis**

The experiment was arranged as a completely randomised design (CRD) with eight replicates ($n=8$). The means obtained were compared by the Duncan’s New Multiple Range Test (DMRT), with analyses performed using the SPSS software. The correlations between physiological, biochemical and growth parameters were evaluated using Pearson’s correlation coefficients.

**Data Collection**

Relative membrane leakage (%) was determined according to the Dionisio-Sese and Tobita (1998) method. Leaves were cut into pieces of 5.0±0.2 mm length, and placed in glass vessels (Opticlear®, KIMBLE, Vineland, New Jersey, USA) containing 10 ml deionised water. The glass vessels were capped and maintained at room temperature (25°C) for 15 min. Initial electrical conductivity ($EC_0$) was measured using an electrical conductivity meter. The leaf tissue was then incubated at 100°C in a water bath for 15 min, cooled down to 25°C before electrical conductivity ($EC$) was measured again.

Proline in the root and leaf tissues was extracted and analysed according to the method of Bates et al. (1973). Fifty milligrams of fresh material were ground with liquid nitrogen in a mortar. The homogenate powder was mixed with 1 ml aqueous sulfoalicylic acid (3% w/v) and filtered through filter paper (Whatman #1, England). The extracted solution was reacted with an equal volume of glacial acetic acid and ninhydrin reagent (1.25 mg ninhydrin in 30 ml glacial acetic acid and 20 ml 6M H₃PO₄), then incubated at 95°C for 1 hr. The reaction was terminated by placing the container in an ice bath. The reaction mixture
was mixed vigorously with 2 ml toluene. After cooling to 25°C, the chromophore was measured by a spectrophotometer DR/4000 at 520 nm using L-proline as a standard.

Contents of chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll (TC), were analysed following the methods of Shabala et al. (1998), and total carotenoid (C x+c) concentration was assayed according to Lichtenenthaler (1987). One hundred milligrams of leaf materials were collected and placed in a 25-ml glass vial, along with 10 ml 95.5% acetone, and blended using a homogeniser. The glass vials were sealed with parafilm to prevent evaporation, and then stored at 4°C for 48 hr. The Chl a and Chl b concentrations were measured using a UV-visible spectrophotometer at 662 nm and 644 nm wavelengths, respectively. The C x+c concentration was also measured by the spectrophotometer at 470 nm. A solution of 95.5% acetone was used as a blank.

Chlorophyll a fluorescence emission from the adaxial surface on the leaf was measured using a fluorescence monitoring system in the pulse amplitude modulation mode, as previously described by Loggini et al. (1999). A leaf, adapted to dark conditions for 30 min using leaf-clips, was initially exposed to the modulated measuring beam of a far-red light (LED source with typical peak at a wavelength of 735 nm). Original (F o) and maximum (F m) fluorescence yields were measured under weak modulated red light (<0.5 µmol m⁻² s⁻¹) with 1.6 s pulses of saturating light (>6.8 µmol m⁻² s⁻¹ PAR), and calculated using Fluorescence Monitoring System (FMS) software for Windows®. Variable fluorescence yield (F v) was calculated by the equation of F m-F o. The ratio of variable to maximum fluorescence (F v/F m) was calculated as the maximum quantum yield of PSII photochemistry. Photon yield of PSII (Φ PSII ) in light was calculated by Φ PSII = (F m′-F o)/F m′ after 45 s of illumination, when steady state was achieved. In addition, non-photochemical quenching (NPQ) was calculated as described by Maxwell and Johnson (2000).

Net photosynthetic rate (P n) was calculated by comparing the different concentrations of CO₂ inside (C in) and outside (C out) the glass vessel containing the oil palm seedlings. The CO₂ concentrations at steady state were measured by gas chromatography (GC; Model GC-17A, Shimadzu Co. Ltd., Japan). The P n of the in vitro cultivated seedlings was calculated according to the method of Fujiwara et al. (1987).

 Shoot height (SH), root length (RL), leaf area (LA), fresh weight (FW) and dry weight (DW) of the oil palm seedlings were measured. The seedlings were dried at 80°C in a hot-air oven for two days, and then incubated in desiccators before measuring dry weight. Leaf area of the seedlings was measured using a leaf area meter DT-scan.

RESULTS AND DISCUSSION

Proline content and relative membrane leakage in the leaf tissues of oil palm seedlings increased in relation to the reduction in water potential caused by mannitol in the culture media (Figure 1). Compared to the control conditions (Ψw = -0.238 MPa), proline content and relative membrane leakage in leaf tissues under extreme water deficit (Ψw = -1.205 MPa) increased by 3.68 and 3.05 times, respectively. The increase in relative membrane leakage was positively related to chlorophyll a (Chl a) degradation (Figure 2A). The Chl a, Chlorophyll b (Chl b), total chlorophyll (TC) and total carotenoids (C x+c) levels in the leaf tissues dropped significantly when the plants were exposed to water deficit stress (Ψw values ranged from -0.674 to -1.205 MPa) (Table 1). Under extreme water deficit conditions (Ψw = -1.205 MPa), the degradation percentages of Chl a, Chl b, TC and C x+c in the leaf tissues of the oil palm seedlings were 59.08%, 63.28%, 60.32% and 34.09%, respectively. The Chl a content in the water-deficit stressed leaves correlated with maximum quantum
yield of PSII \( (F_v/F_m) \) (Figure 2B) and with photon yield of PSII \( (\Phi_{PSII}) \) (Figure 3A). The \( F_v/F_m \) and \( \Phi_{PSII} \) in the leaf tissues of plants undergoing water deficit treatments decreased significantly, while non-photochemical quenching (NPQ) increased, especially under extreme conditions of water deficit \( (\Psi_w = -1.205 \text{ MPa}) \) (Table 2). A positive correlation between \( \Phi_{PSII} \) and net photosynthetic rate \( (P_n) \) was demonstrated in Figure 3B. It was found that \( P_n \) was significantly reduced in plants exposed to water deficit treatments (Table 2). Bio-chemical and physiological parameters including Chla, Chlb, TC \( C_{x+c} \), \( F_v/F_m \), \( \Phi_{PSII} \) and \( P_n \) were found to have positive correlations using Pearson’s correlation coefficients, except in the case of proline, which displayed a negative relationship (Table 3). LA, FW and DW of water deficit stressed seedlings were drastically retarded in comparison to those under control conditions (Table 4). In contrast, SH and RL in the plants subjected to mild water deficit

Table 1. Chlorophyll a (Chla), Chlorophyll b (Chlb), Total Chlorophyll (TC) and Total Carotenoid (C_{x+c}) Contents of Oil Palm Grown Seedlings Under Mannitol-Induced Water Deficit For One Month

<table>
<thead>
<tr>
<th>Water potential (MPa)</th>
<th>Chla (µg g(^{-1}) FW)</th>
<th>Chlb (µg g(^{-1}) FW)</th>
<th>TC (µg g(^{-1}) FW)</th>
<th>( C_{x+c} ) (µg g(^{-1}) FW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.238 (control)</td>
<td>257.1a</td>
<td>108.1a</td>
<td>365.2a</td>
<td>65.7a</td>
</tr>
<tr>
<td>-0.392</td>
<td>192.8ab</td>
<td>79.2b</td>
<td>272.0b</td>
<td>59.1b</td>
</tr>
<tr>
<td>-0.674</td>
<td>176.5b</td>
<td>70.7b</td>
<td>247.2b</td>
<td>55.1bc</td>
</tr>
<tr>
<td>-0.939</td>
<td>160.2bc</td>
<td>62.6b</td>
<td>222.8bc</td>
<td>51.4c</td>
</tr>
<tr>
<td>-1.205</td>
<td>105.2c</td>
<td>39.7bc</td>
<td>144.9c</td>
<td>43.3d</td>
</tr>
</tbody>
</table>

ANOVA ** ** ** **

Note: values bearing different letters in each column show significant differences at \( p \leq 0.01 \) (**) according to Duncan’s New Multiple Range Test (DMRT).

FW – fresh weight.
MANNITOL-INDUCED WATER DEFICIT STRESS IN OIL PALM (*Elaeis guineensis* Jacq.) SEEDLINGS

TABLE 2. MAXIMUM QUANTUM YIELD OF PSII (Fv/Fm), PHOTON YIELD OF PSII ($\Phi_{\text{PSII}}$), NON-PHOTOCHEMICAL QUENCHING (NPQ) AND NET PHOTOSYNTHETIC RATE (Pn) OF OIL PALM SEEDLINGS GROWN UNDER MANNITOL-INDUCED WATER DEFICIT FOR ONE MONTH

<table>
<thead>
<tr>
<th>Water potential (MPa)</th>
<th>Fv/Fm</th>
<th>$\Phi_{\text{PSII}}$</th>
<th>NPQ</th>
<th>Pn (µmol m$^{-2}$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.238 (control)</td>
<td>0.875a</td>
<td>0.637a</td>
<td>0.012c</td>
<td>0.99a</td>
</tr>
<tr>
<td>-0.392</td>
<td>0.854b</td>
<td>0.575b</td>
<td>0.024bc</td>
<td>0.75b</td>
</tr>
<tr>
<td>-0.674</td>
<td>0.839bc</td>
<td>0.527bc</td>
<td>0.033bc</td>
<td>0.64b</td>
</tr>
<tr>
<td>-0.939</td>
<td>0.824c</td>
<td>0.486c</td>
<td>0.041b</td>
<td>0.46c</td>
</tr>
<tr>
<td>-1.205</td>
<td>0.777d</td>
<td>0.397d</td>
<td>0.099a</td>
<td>0.22d</td>
</tr>
</tbody>
</table>

ANOVA ** ** ** **

Note: values bearing different letters in each column show significant differences at $p \leq 0.01$ (**) according to Duncan’s New Multiple Range Test (DMRT).

FIGURE 3. Relationships between total chlorophyll content and quantum efficiency of PSII ($\Phi_{\text{PSII}}$), and between $\Phi_{\text{PSII}}$ and net photosynthetic rate of oil palm seedlings grown under mannitol-induced water deficit for one month. Error bars represent ±SE.

TABLE 3. CORRELATION COEFFICIENTS BETWEEN PHYSIOLOGICAL AND BIO-CHEMICAL PARAMETERS OF OIL PALM SEEDLINGS GROWN UNDER MANNITOL-INDUCED WATER DEFICIT FOR ONE MONTH

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Chl$_a$</th>
<th>Chl$_b$</th>
<th>TC</th>
<th>C$_{car}$</th>
<th>PRO</th>
<th>Fv/Fm</th>
<th>$\Phi_{\text{PSII}}$</th>
<th>Pn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chl$_a$</td>
<td>-</td>
<td>0.984**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chl$_b$</td>
<td>0.999**</td>
<td>0.937**</td>
<td>0.903**</td>
<td>0.937**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TC</td>
<td>0.999**</td>
<td>0.927**</td>
<td>0.937**</td>
<td>0.937**</td>
<td>0.937**</td>
<td>0.937**</td>
<td>0.937**</td>
<td>0.937**</td>
</tr>
<tr>
<td>C$_{car}$</td>
<td>-0.765**</td>
<td>-0.824**</td>
<td>-0.785**</td>
<td>-0.785**</td>
<td>-0.785**</td>
<td>-0.785**</td>
<td>-0.785**</td>
<td>-0.785**</td>
</tr>
<tr>
<td>PRO</td>
<td>0.885**</td>
<td>0.895**</td>
<td>0.859**</td>
<td>0.859**</td>
<td>0.859**</td>
<td>0.859**</td>
<td>0.859**</td>
<td>0.859**</td>
</tr>
<tr>
<td>Fv/Fm</td>
<td>0.891**</td>
<td>0.933**</td>
<td>0.907**</td>
<td>0.907**</td>
<td>0.907**</td>
<td>0.907**</td>
<td>0.907**</td>
<td>0.907**</td>
</tr>
<tr>
<td>$\Phi_{\text{PSII}}$</td>
<td>0.924**</td>
<td>0.856**</td>
<td>0.936**</td>
<td>0.936**</td>
<td>0.936**</td>
<td>0.936**</td>
<td>0.936**</td>
<td>0.936**</td>
</tr>
</tbody>
</table>

Note: highly significant level at $p \leq 0.01$ is represented by ** using Pearson’s correlation coefficients.

TC – total chlorophyll.

Pn – net photosynthetic rate.
(Ψ_w = -0.392 MPa) were maintained, but dropped significantly under high levels of water deficit at -0.674 MPa and -0.939 MPa (Table 4). Under extreme water deficit (Ψ_w = -1.205 MPa), SH, RL, LA, FW and DW were reduced by 28.30%, 57.47%, 73.01%, 71.59% and 64.00% when compared to the control. In addition, LA was decreased by 35.5%, 53.5%, 64.9% and 73.0% when subjected to -0.392, -0.674, -0.939 and -1.205 MPa mannitol-induced water deficit, respectively. Similarly, DW was reduced by 27.5%, 42.5%, 55.0% and 64.0%, respectively, when subjected to -0.392, -0.674, -0.939 and -1.205 MPa water deficit. A similar trend of reduction in all growth characters was demonstrated in relation to the strength of the mannitol-induced water deficit in the culture media.

Data presented above demonstrated that the proline content in the leaf tissues of oil palm seedlings increased depending on the degree and duration of the stress treatments. Proline accumulation in higher plants has been well established as a good indicator of stress response because proline alleviates water deficit stress by means of antioxidation, osmoregulation and energy preservation. In olive trees, proline levels in both young and old leaves of plants exposed to water deficit stress were higher than in plants grown under well-irrigated conditions (Ahmed et al., 2009). Proline content in mature leaves of drought-stressed sugar beet was 1.5 times higher than in well-irrigated plants (Chaitanya et al., 2006). In addition, ornithine-δ-aminotransferase (δ-OAT), glutamate dehydrogenase (GDH) and proline-5-carboxylase reductase (P5CR) activities of the proline biosynthesis pathway in drought-stressed mulberry (Chaitanya et al., 2009) and Sesuvium portulacastrum (Slama et al., 2006) increased in relation to the contents of proline. The levels of proline accumulation changed depending on the degree of water deficit (Chaitanya et al., 2009), exposure period (Slama et al., 2006) and specific plant organs (Choiuj et al., 2008; Ahmed et al., 2009).

In this study, we observed that relative membrane leakage in oil palm seedlings grown under mannitol-induced water deficit increased in a similar trend as that of proline accumulation. Relative membrane leakage of different plant species in response to water deficit stress has been shown to increase depending on the degree of stress (Beltrano and Ronco, 2008), genotype (Sayar et al., 2008; Hu et al., 2010) and exposure period (Hu et al., 2010). In the case of bermudagrass grown under water deficit conditions, relative membrane leakage in drought-sensitive cultivars, C299 and Tifeagle, was greater than in drought-tolerant cultivars (Tifway, Kan 1, Sportbermuda, H10 and H19) (Hu et al., 2010).

The photosynthetic pigments, Chl_a, Chl_b, TC and C_{x+c}, in the leaf tissues of oil palm seedlings were degraded, leading to a decrease in F_v/F_m, Φ_{PSII} and P_n in response to water deficit stress, especially under severe water deficit (Ψ_w = -1.205 MPa). Although the decrease in Chl content in response to water deficit is well-known, different effects on C_{x+c} have been reported for coconut (Gomes et al., 2008) and olive (Ahmed et al., 2009; Guerfel et al., 2009). The C_{x+c} levels in water deficit stressed olive plants decreased significantly (Ahmed et al., 2009), while they were maintained in coconut (Gomes et al., 2008). The C_{x+c} is believed to play an important role in protection against photo-oxidative damage, as represented by low NPQ (Müller et al., 2001; Omasa and Takayama, 2003). In the case of oil palm, C_{x+c} in the severe water deficit conditions was significantly degraded which may have caused the NPQ enrichment. In oil palm, the degree of degradation of the photosynthetic pigments and the CO₂ assimilation rate in response to severe water deficit were closely correlated to F_v/F_m, Φ_{PSII} and P_n reduction. Similar results have been reported in coconut (Gomes et al., 2008), perennial grass (Xu et al., 2009), maize (Li et al., 2009) and olive (Boussad et al., 2008). In addition, P_n in coconut palms was reduced significantly in both the Una and Jiqi cultivars by 37.28% and 43.09%, when

<table>
<thead>
<tr>
<th>Water potential (MPa)</th>
<th>SH (cm)</th>
<th>RL (cm)</th>
<th>LA (cm²)</th>
<th>FW (mg)</th>
<th>DW (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.238 (control)</td>
<td>20.64a</td>
<td>10.58a</td>
<td>41.02a</td>
<td>1 179a</td>
<td>200a</td>
</tr>
<tr>
<td>-0.392</td>
<td>19.56a</td>
<td>9.04ab</td>
<td>26.46b</td>
<td>728b</td>
<td>145b</td>
</tr>
<tr>
<td>-0.674</td>
<td>16.16bc</td>
<td>7.16ab</td>
<td>19.06c</td>
<td>477c</td>
<td>115bc</td>
</tr>
<tr>
<td>-0.939</td>
<td>15.52bc</td>
<td>5.10b</td>
<td>14.41cd</td>
<td>437c</td>
<td>90c</td>
</tr>
<tr>
<td>-1.205</td>
<td>14.80c</td>
<td>4.50b</td>
<td>11.07d</td>
<td>335c</td>
<td>72c</td>
</tr>
</tbody>
</table>

ANOVA

Note: values bearing different letters in each column show significant differences at p ≤ 0.01 (***) and p ≤ 0.05 (*) according to Duncan’s New Multiple Range Test (DMRT).
exposed to water deficit stress (Gomes et al., 2008), in order to limit the CO₂ assimilation rate through the stomatal apertures (Cornic, 2000). Limited CO₂ assimilation through stomatal pores of water-deficit stressed plants leads to low Pₚ (Chaves, 1991; van Heerden et al., 2007; Dias and Brüggemann, 2010). Biomass production in higher plants is achieved by the plant’s photosynthetic ability, which is inhibited by water deficit. The growth characters, i.e. SH, RL, LA, FW and DW, of oil palm seedlings were retarded in response to water shortage. Inhibition of plant growth when subjected to water deficit conditions has also been demonstrated in perennial grass (Xu et al., 2009), olive (Guerfel et al., 2009), Sesuvium portulacastrum (Slama et al., 2006) and Dianthus (Álvarez et al., 2009).

In conclusion, relative membrane leakage in oil palm seedlings increased in response to water deficit, leading to damage to the photosynthetic pigments. This in turn diminished the photosynthetic ability and reduced the growth performance of the seedlings grown under short-term water shortage conditions. The physiological and growth characters of oil palm seedlings also decreased significantly, depending on the degree of water deficit and the exposure period. These data provide the basis for the establishment for multivariate criteria for water deficit tolerance screening in oil palm breeding programmes.

ACKNOWLEDGEMENT

The authors are grateful to Jonathan Shore for grammatical proofing and Suksumboon Palm Co. Ltd for providing the oil palm seeds. This experiment was funded by the National Centre for Genetic Engineering and Biotechnology (BIOTEC), Thailand (grant number BT-B-02-PG-BC-5102).

REFERENCES


GUERFEL, M; BACCOURI, O; BOUJNAH, D; CHAÏBI, W and ZARROUK, M (2009). Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (Olea europaea L.) cultivars. Sci Hortic., 119: 257-263.


KALLARACKAL, J; JEYAKUMAR, P and GEORGE, S J (2004). Water use of irrigated oil palm at three different arid locations in peninsular India. J. Oil Palm Research Vol. 16: 45-53.


MANNITOL-INDUCED WATER DEFICIT STRESS IN OIL PALM (Elaeis guineensis Jacq.) SEEDLINGS


