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Changes in photosynthetic activity in five common hybrids of oil palm (*Elaeis guineensis* Jacq.) seedlings under water deficit

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Abstract

The leaf water potential, gas-exchange parameters and chlorophyll fluorescence were evaluated in five common oil palm (*Elaeis guineensis* Jacq.) *tenera* hybrids 913X1988, 1425X2277, 748X1988, 7418X1988, and 690X1988 under water deficit with an aim to identify hybrids which can cope up better under such conditions and understand possible differences among hybrids in relation to the physiological mechanisms triggered by water deficit. Our findings indicate oil palm hybrids 913X1988, 1425X2277, and 7418X1988 maintained higher leaf water potentials than the other hybrids. Hybrids 7418X1988 and 1425X2277 recorded lower stomatal conductance after water deficit, which resulted in higher intrinsic water-use efficiency. The excess light energy produced due to decreased photosynthesis in 7418X1988 and 690X1988 hybrids under water deficit was dissipated as heat by higher nonphotochemical quenching. The maximum efficiency of photosystem II was not affected, even after withholding water for 24 days, suggesting an increased efficiency of photoprotection mechanisms in all these oil palm hybrids.

Additional key words: drought; *Elaeis guineensis* Jacq.; gas exchange; stomatal conductance; water deficit.

Introduction

Oil palm (*Elaeis guineensis* Jacq.), a high-oil-yielding crop, has been introduced into India in order to meet the vegetable oil demand of its huge population. Accordingly, an area of about 800,000 ha in different provinces in India has been given over to this crop. Water in the form of irrigation has been considered as one of the most critical inputs for realizing higher yields of oil palm, as water deficit not only leads to reduced growth but also affects plant physiology. The effect of water deficit on plants is a function of its intensity and duration, as well as of the genetically determined capacity of a given species to cope with environmental constraints (Chaves *et al.* 2002). Water deficit during growth of oil palm not only causes a general reduction in size but also exhibits characteristic modifications in structure, particularly leaves with reduced area. In such situations, stomata close early and in turn reduce photosynthesis leading to decreased yields (Rees 1961, Corley *et al.* 1973, Suresh and Nagamani 2006, Suresh *et al.* 2010). Tang *et al.* (2002) suggested that a combination of stomatal and nonstomatal effects on photosynthesis exists depending on the extent of water deficit. There is a big controversy as to whether water deficit mainly limits photosynthesis by stomatal closure (Flexas *et al.* 2006) or metabolic damage (Lawlor and Cornic 2002). Stomatal regulation in oil palm is delicate and enables plant to minimize water loss in the event of water deficit. Decrease in stomatal conductance is one of the initial responses of plants to water deficit. Reduction in stomatal conductance is one of the strategies used by plants during water deficit for reducing transpiration and maintaining turgor (Eckstein and Robinson 1996), while transpiration loss becomes less due to stomatal closure, it also reduces photosynthesis (de Souza *et al.* 2001). The net photosynthetic

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Abbreviations: C_i – intercellular CO_2 concentration, Chl – chlorophyll; E – transpiration rate; ETR – apparent rate of photochemical transport of electrons through PSII; F_m – maximum fluorescence of dark-adapted state; F_m' – maximum fluorescence yield acclimated to irradiated light; F_o – minimum fluorescence of dark-adapted state; F_0' – initial fluorescence in leaves acclimated to irradiating light; F_p – chlorophyll fluorescence intensity at peak of continuous fluorescence inductive curve; F_s – steady-state fluorescence in leaves acclimated to irradiating light; F_v – variable part of chlorophyll fluorescence; F_v/F_m – maximum quantum efficiency of PSII primary photochemistry; g_s – stomatal conductance; NPQ – nonphotochemical quenching; PAR – incident photosynthetically active radiation in leaf; P_N – net photosynthetic rate; PSI – photosystem I; PSII – photosystem II; Q_L – coefficient of photochemical quenching; WUE – instantaneous water-use efficiency; Ψ_w – leaf water potential; Φ_{PSII} – effective quantum yield of PSII.

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rate and stomatal conductance of attached leaves of sunflower decreased as leaf water potential declined (Tezara *et al.* 2008). The factors limiting photosynthesis recovery after water- and salt stress seem to be multiple, and strongly dependent on the species and conditions analyzed (Chaves *et al.* 2009).

Oil palm as a tropical plant is exposed to high irradiance which may cause disturbance in the photosynthetic apparatus under water deficit. The dissipation of available energy through processes other than photosynthetic carbon metabolism is a vital defense mechanism under water deficit (Chaves *et al.* 2002). High photosynthetic photon flux density combined with environmental stressors like high temperature and drought intensifies photodamage to the assimilatory apparatus, thereby inhibiting photosynthesis (Ohashi *et al.* 2006). Chlorophyll fluorescence analysis helps in characterization of light utilization under stress conditions (Flexas *et al.* 2002, Kitao *et al.* 2003). Nonphotochemical quenching is one of the mechanisms in plants used to prevent or alleviate damage caused by excessive light energy reaching the photosynthetic apparatus (Maxwell and Johnson 2000). Water deficit also causes alterations in photochemical reactions resulting in stomatal and nonstomatal limitations with damage to reaction centres of photosystems I and II (Angelopoulos *et al.* 1996). New evidence shows that reactive oxygen species damage ATP synthase, offering an explanation of the observations of decreased ATP synthase levels and therefore ATP content under water-deficit conditions (Lawlor and Tezara 2009). Suresh *et al.* (2010) reported that water deficit did not irreversibly affect gas-exchange parameters and quantum efficiency of photosystem II until the 24th day of withholding water as before this oil palm seedling exhibited total recovery of photosynthesis. Pinheiro and Chaves (2011) discussed the interplay of sugars, reactive oxygen species and hormones with photosynthetic responses to drought involving many metabolic events.

This study was undertaken to evaluate the responses of leaf water potential, gas-exchange parameters and chlorophyll fluorescence to water deficit in five high-yielding common oil palm hybrids subjected to water deficit at the nursery stage. The possible differences between hybrids in relation to physiological mechanisms triggered by water deficit are discussed.

Materials and methods

The study was conducted at the Directorate of Oil Palm Research, Pedavegi which is situated in West Godavari district of Andhra Pradesh province in India. The experimental site (Pedavegi) is located at 16º43'N and 81º09'E with a mean altitude of 13.41 m a.s.l. The average rainfall is 1,221 mm. Five oil palm *tenera* hybrids, namely 913X1988, 1425X2277, 748X1988, 7418X1988, and 690X1988 were used for the study.

The five hybrids taken up for the study are developed indigenously through reciprocal recurrent selection. These hybrids are high-yielding (25–30 t ha^{-1} y^{-1}) and are being grown under different agroclimatic regions of India. Seedlings, which were approximately 10 months old, were selected according to their uniformity in size. The plants (one per bag) were grown in plastic bags (size 45 × 50 cm) containing a mixture of sand, soil, and farm yard manure (1:3:1, v/v/v) and subjected to a period of 30 d of acclimitization to light and temperature under greenhouse conditions [mean temperature: 26/19°C (day/night), relative humidity: 75–85%, photon flux density: 700–800 µmol m^{-2} s^{-1}]. During this period, all bags were irrigated daily to maintain field capacity (water saturation). The field capacity was considered reached when water percolated through the bag to the ground under it and the soil was saturated. After acclimatization, plants were separated into two groups of 20 plants each. One group continued to receive daily irrigation which was the control and the other was subjected to water deficit by withholding irrigation. Gas-exchange parameters, leaf water potential and chlorophyll (Chl) fluorescence were measured every 4th d throughout the study. On the 24th d, when the photosynthetic rate was close to zero, it was assumed that stomatal closure was complete and water-deficit seedlings were rewatered. Recovery of gas-exchange parameters, at least in some hybrids, was observed after 12 d of rehydration.

Morphological observations such as plant height, girth, and number of leaves were recorded both in the controls and water-deficit-treated oil palm hybrids used in this study.

Gas-exchange parameters, such as net photosynthetic rate (P_N), intercellular CO_2 concentration (C_i) and stomatal conductance (g_s), were recorded using a portable photosynthesis system (*LCA-4, ADC*, Hertfordshire, UK) connected to a *PLC 4* (6.25 cm^2) leaf chamber. During measurements, photon flux density was 800 µmol m^{-2} s^{-1} (photosynthetically active radiation), leaf temperature 25°C and ambient CO_2 concentration 380 µmol mol^{-1}. The vapor pressure deficit in the chamber was maintained below 2.5 kPa to prevent stomatal closure due to low air humidity effect. The measurements were made on a fully opened healthy leaf (3rd leaf from top) under bright sunlight between 10:00 and 11:00 h. Instantaneous water-use efficiency (WUE) was determined by the ratio of P_N to E.

Leaf water potential (Ψ_w) was measured every 4th d after initiation of water deficit and during subsequent rehydration. Leaf discs (6 mm in diameter) were sampled and placed in a *C-52-SF* sample chamber (*Wescor Inc.*, Logan, UT, USA). The samples were allowed to equilibrate and then measured with a dew point microvoltmeter (*Model HR-33T, Wescor Inc*., Logan, UT, USA). Five leaf samples from a fully opened healthy leaf (3rd leaf from the top) were taken at each sampling. All observations were made between 10:00 and 11:00 h.

Chl fluorescence parameters were measured using a photosynthesis yield analyzer (*Mini-Pam, Walz*, Effeltrich, Germany). The minimal fluorescence (F_0) was measured in 30-min dark-adapted leaves using weak modulated irradiance (<0.1 µmol m^{-2} s^{-1}). A 600-ms saturating flash (>7,000 µmol m^{-2} s^{-1}) was applied to determine the maximum fluorescence (F_m) and photochemical efficiency of photosytem II (PSII) (F_v/F_m). Then the leaves were continuously irradiated with white actinic light (800 µmol m^{-2} s^{-1}) in order to measure the steady state fluorescence yield (F_s) and maximum fluorescence yield (F_m') of irradiated leaves. The following Chl fluorescence parameters were calculated: maximum quantum efficiency of PSII primary photochemistry (F_v/F_m), as per Van Kooten and Snel (1990); effective quantum yield of PSII [Φ_{PSII} = (F_m'– F_s)/F_m'], according to Genty *et al.* (1989); apparent rate of photochemical transport of electrons through PSII [ETR = Φ_{PSII} × PAR × 0.5 × 0.84], as per Schultz (1996). The coefficient of photochemical quenching (according to the lake model) [Q_L = (F_m' – F_s) F_0'/(F_m' – F_0') F_s] was determined as per Kramer *et al.* (2004) and the coefficient of nonphotochemical quenching of excitation energy [NPQ = (F_m – F_m')/F_m'] according to Schreiber *et al.* (1994), where F_0 – initial fluorescence in leaves subjected to dark; F_m – maximum fluorescence in leaves acclimated to dark; F_v – variable fluorescence in leaves acclimated to dark [F_v = F_m – F_0]; F_0' – initial fluorescence in leaves acclimated to irradiated light; F_m' – maximum fluorescence in leaves acclimated to irradiated light; F_s – steady state fluorescence in leaves acclimated to irradiated light; PAR – incident photosynthetically active radiation in leaf; 0.5 corresponds to the proportion of absorbed quanta used by PSII reaction centres; and 0.84 represents the proportion of incident irradiance absorbed by leaf. The F_0' was calculated by the instrument software.

Experimental design and statistical analysis: The experiment was laid out in a completely randomized block design with twenty replicates. Each plant (seedling) was considered as a replication. Statistical analysis was done using *MSTAT* statistical software (*MSTAT,* developed by Dr. Russel Freed, Crop and Soil Sciences Department of Michigan State University, USA). Data was subjected to analysis of variance (*ANOVA*) by factorial randomized design, and *F* values and least significant differences (LSD) were calculated. Only data obtained at maximum water deficit (24th d of witholding water) and after recovery (12th d after rehydration) are shown in the figures.

Results

Morphological observations: The plant height, girth, and number of leaves were recorded in five oil palm hybrids in the control and water deficit treatments and results after the 24th d are depicted in Table 1. The plant height varied from 135.20 to 144.50 cm in control and water deficit treatments in the different oil palm hybrids. The palm girth ranged from 29.2 to 32.7 cm and number of leaves were between 16.5 to 18.0. Though small differences were observed in these parameters, there was no significant effect on plant height, girth and number of leaves after 24 d of water deficit, in any of the oil palm hybrids.

Leaf water potential in irrigated plants of five oil palm hybrid seedlings ranged from –1.7 to –2.0 MPa and did not differ significantly among them (Fig. 1*A,B*). Significant differences in Ψ_w were observed among different hybrids under water deficit. Highest Ψ_w was observed in 913X1988 which did not differ significantly with that of 1425X2277 and 7418X1988. The other two hybrids viz., 748X1988, and 690X1988 recorded Ψ_w lower than –4.0 MPa (Fig. 1*A*). The lower Ψ_w in all hybrids at 24th d of imposition of water deficit was associated with lower photosynthetic rates due to stomatal closure. The Ψ_w of water-deficit seedlings of all hybrids reached to the values observed in well watered plants after 12 d of rehydration (Fig. 1*B*).

Gas-exchange parameters: P_N in different oil palm hybrids ranged from 5.4 to 6.2 µmol m^{-2} s^{-1} and decreased as the intensity of the water deficit increased (Fig. 1*C*). Higher P_N were observed in 913X1988 and 748X1988, which did not differ significantly between them. Compared to well watered plants, P_N was reduced by 21 and 26 percent in 913X1988 and 1425X2277, while 748X1988, 7418X1988, and 690X1988 had reductions varying between 29 to 35 % at 8 d of water deficit (data not shown). There was a larger reduction in P_N in all hybrids after 12 d of water deficit, with the exception of 748X1988.

g_s in all the hybrids under irrigated conditions ranged from 0.3 to 0.5 mol m^{-2} s^{-1}. The lowest g_s was recorded in 7418X1988 which, by the 24th day of water deficit, but this did not differ significantly with the other hybrids (Fig. 1*E*). However, 7418X1988 was the hybrid which was least able to recover under rehydration (Fig. 1*E*). There was a steep reduction of g_s in all hybrids except 913X1988 after the 8th day of imposition of water deficit (data not shown).

The C_i/C_a ratio increased under water deficit as

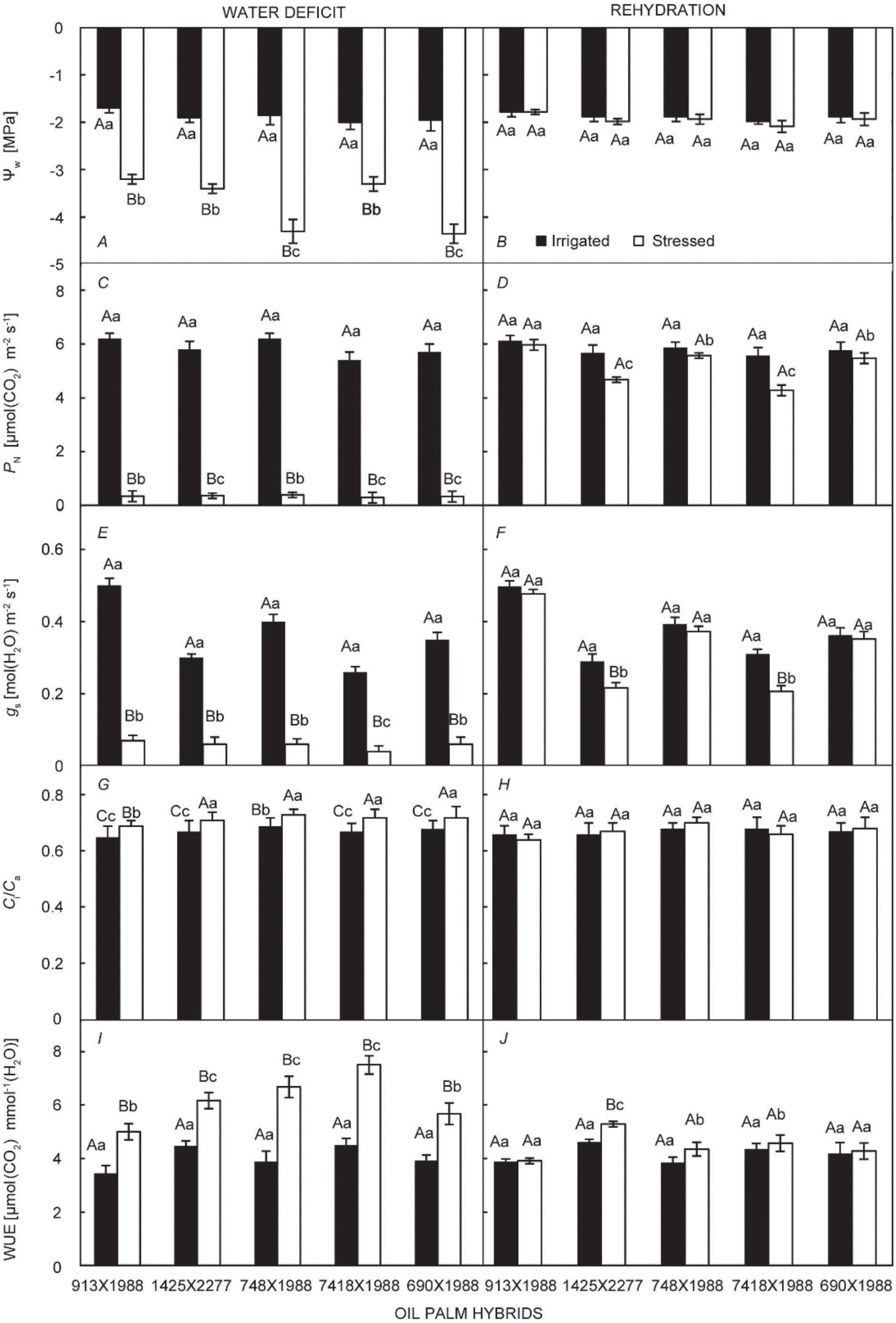

Fig. 1. Leaf water potential (Ψ_w – *A,B*), net photosynthetic rate (P_N – *C,D*) stomatal conductance (g_s – *E,F*), ratio of intercellular to atmospheric CO_2 concentration (C_i/C_a – *G,H*) and instantaneous water-use efficiency (WUE – *I,J*) in five oil palm hybrids at 24 d of imposition of water deficit and 12 d of rehydration. Vertical bars represent means ± SE for $n = 20$. *Capital letters* mean statistical difference between well watered and water-deficit conditions whereas *small letters* mean difference between hybrids ($p<0.05$).

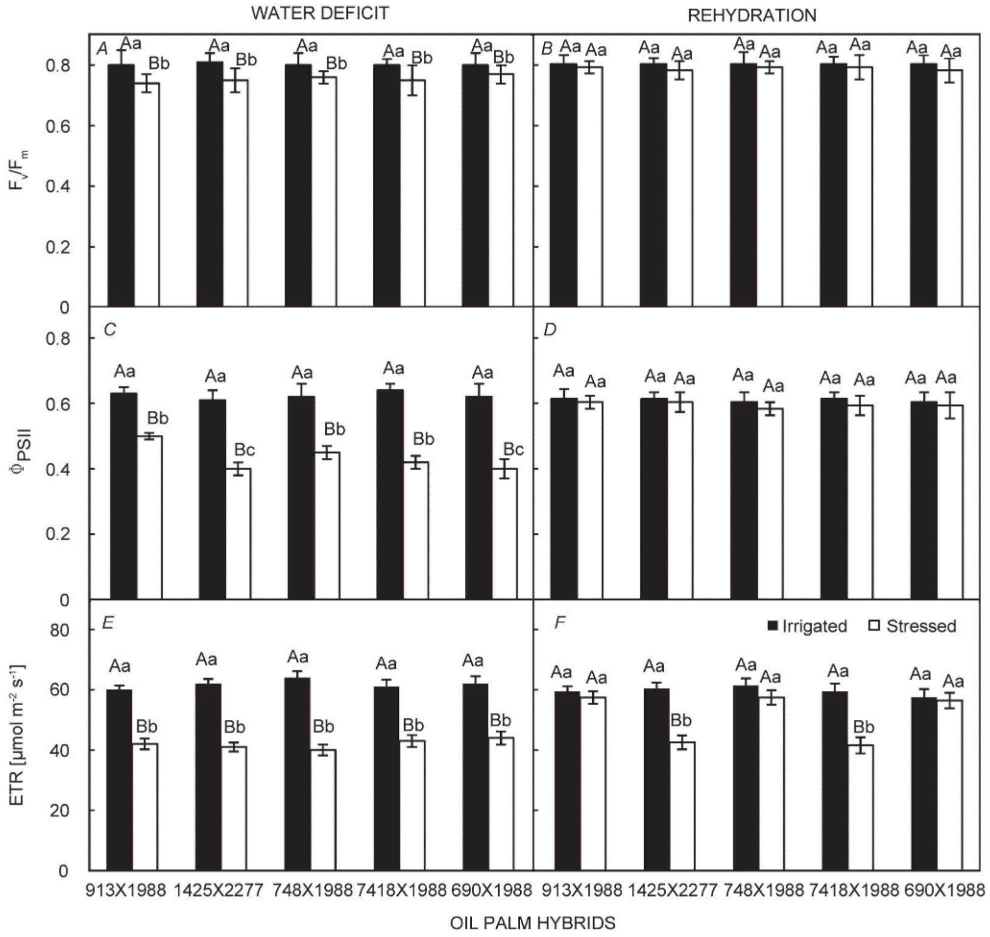

Fig. 2. Maximum quantum efficiency of PSII primary photochemistry (F_v/F_m – *A,B*), effective quantum yield of PSII (Φ_{PSII} – *C,D*) and apparent photochemical electron transport rate (ETR – *E,F*) in five oil palm hybrids at 24 d of imposition of water deficit and 12 d of rehydration. Vertical bars represent means ± SE for $n = 20$. *Capital letters* mean statistical difference between well watered and water-deficit conditions whereas *small letters* mean difference between hybrids ($p<0.05$).

compared with the control in all the oil palm hybrids. Differences in C_i/C_a ratio among oil palm hybrids under water deficit, although significant, were quite small (Fig. 1*G*). On rehydration, there were no significant differences among the oil palm hybrids in control and water-deficit treatments (Fig. 1*H*). Also the 913X1988 hybrid did not show significant differences in P_N and C_i between water deficit and well watered treatments till 8 d of water deficit. The lowest P_N and g_s was recorded between the 20th d (7418X1988 and 1425X2277) and the 24th d (913X1988, 690X1988, and 748X1988) of deficit. On rehydration, 913X1988 and 748X1988 hybrids showed the faster recovery as by the 8th d, they reached similar P_N and g_s values as that of well watered seedlings. 7418X1988 and 1425X2277 hybrids did not show similar values of P_N and g_s after 12 d of rehydration indicating their greater sensitivity to water deficit compared to the other hybrids (Fig. 1*D*,*F*).

Higher values of WUE were observed in all hybrids under water deficit compared to that of irrigated conditions (Fig. 1*I*). Highest WUE under water deficit was observed in 7418X1988 followed by 748X1988 and 1425X2277. The WUE increased from 8th d of withholding water in all the hybrids except 913X1988 and 690X1988, which showed an increase in WUE from 12th d of water deficit (data not shown). Hybrid 7418X1988 does not show a significantly different WUE value from the rest after the 12th d of rehydration (Fig. 1*J*).

Chl fluorescence: The maximum quantum efficiency of PSII (F_v/F_m) decreased from ~0.8 in the control plants to lower values (0.74–0.77) in all hybrids by the 24th d of imposition of water deficit (Fig. 2*A*). In general, there was no significant difference between the F_v/F_m ratio of irrigated and water-deficit-treated plants until the 12th d and thereafter significantly lower values were observed. On rehydration the F_v/F_m in water deficit seedlings was on par with the control after 12th d (Fig. 2*B*) except for 913X1988 which recovered by the 8th d (data not shown). The Φ_{PSII} in irrigated hybrids ranged from 0.61 to 0.64,

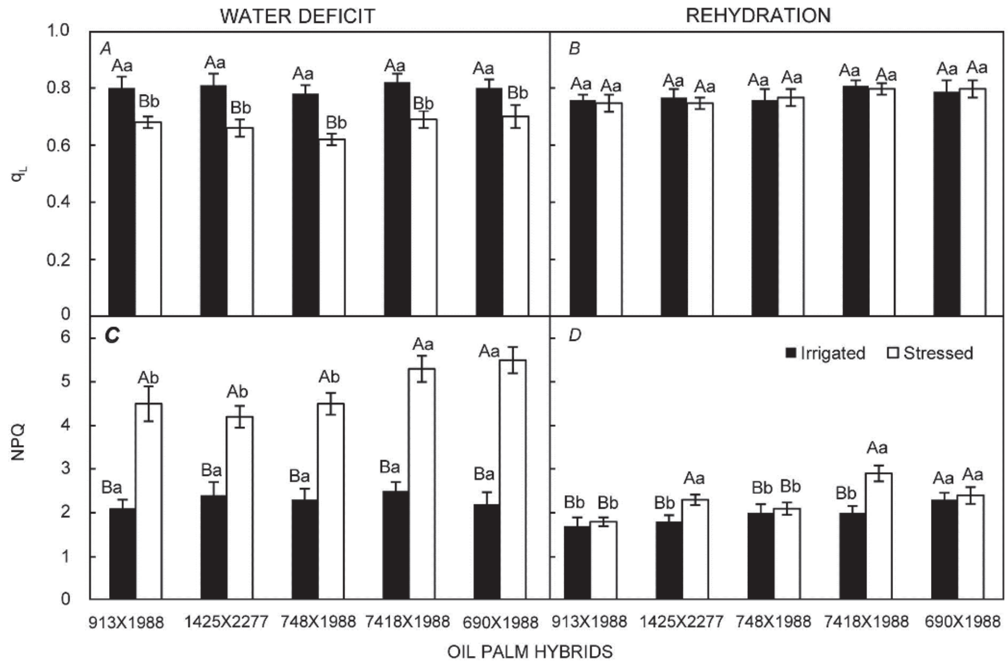

Fig. 3. Photochemical quenching of excitation energy (Q_L – *A,B*) and nonphotochemical quenching of excitation energy (NPQ – *C,D*) in five oil palm hybrids at 24 d of imposition of water deficit and 12 d of rehydration. Vertical bars represent means ± SE for $n = 20$. *Capital letters* mean statistical difference between well watered and water-deficit conditions whereas *small letters* mean difference between hybrids ($p<0.05$).

while it was 0.50, 0.40, 0.45, 0.42, and 0.40 in 913X1988, 1425X2277, 748X1988, 7418X1988, and 690X1988 respectively at the 24th d of water deficit (Fig. 2*C*). A significant decrease in Φ_{PSII} was observed in all hybrids from the 16th d of imposition of water deficit with the exception of 1425X2277 that decreased from the 12th d (data not shown). All the hybrids showed full recovery of Φ_{PSII} values after 12 d of rehydration (Fig. 2*D*).

In general, ETR in different hybrids under water deficit decreased as the number of days of withholding water increased. The ETR in different hybrids ranged from 40–44 μmol m^{-2} s^{-1} at 24th d of water deficit with 748X1988 recording lowest value (Fig. 2*E*). The photosynthetic rate of the oil palm hybrid 1425X2277 and 7418X1988 did not show full recovery after rehydration which is in agreement with diminished ETR values. The reduction in ETR in 1425X2277 under water deficit suggests its lesser tolerance. The decline in ETR among different hybrids under water deficit compared to that of the control was lowest in 748X1988 (62.5 %) followed by 1425X2277 (66 %) at 24 d of imposition of water deficit (Fig. 2*F*). However, hybrids 1425X2277 and 7418X1988 did not show full recovery of ETR values after 12 d of rehydration. The Q_L values in different hybrids ranged from 0.62 to 0.70 at 24 d of imposition of water deficit. Significantly lower Q_L values were recorded in water-deficit seedlings of all hybrids compared to that of control (Fig. 3*A*). The Q_L values of all rehydrated seedlings of different hybrids reached similar values to that of control at 12th d of recovery (Fig. 3*B*). The NPQ values in water deficit seedlings of all hybrids ranged from 4.2 to 5.5 at 24th d of imposition of water deficit (Fig. 3*C*). Highest NPQ was recorded in 690X1988 which did not differ significantly with that of 7418X1988 at 24th d of water deficit. After rehydration, NPQ values were on par with control in all hybrids except 7418X1988 and 1425X2277 (Fig. 3*D*).

Discussion

Morphological parameters like girth, height and number of leaves recorded during the study indicated that very little change in morphology occurred during the time of water-deficit treatment although there was a consistent but statistically insignificant decrease in all the measurements. Most of the parameters measured were more or less fully reversible on rehydration.

Distinct patterns were observed among the five oil palm hybrids subjected to water deficit. Hybrids 913X1988, 7418X1988 and 1425X2277 differed from others in maintaining a relatively high Ψ_w even after 24 d of water deficit. Similar findings have been reported in *Malphighia emarginata* tree species (Nogueira *et al.* 2001). In sunflower, P_N and g_s decreased as Ψ_w declined

(Tezara *et al.* 2008). Since water deficit strongly impairs gas-exchange parameters in oil palm (Suresh *et al.* 2010), maintenance of high Ψ_w by these hybrids may alleviate the undesirable effect of drought on photosynthesis.

A combination of stomatal and nonstomatal effects on photosynthesis exists depending on the extent of water deficit (Tezara *et al.*1999, Chaves *et al.* 2002, 2009, Lawlor and Tezara 2009, Pinheiro and Chaves 2011). Among the oil palm hybrids tested, 7418X1988 and 1425X2277 showed the earliest sensitivity to water deficit by greater reduction of P_N and g_s on 8 d of water deficit itself and recording higher leaf water potentials at 24th d of imposition of water deficit. Also these two hybrids 7418X1988 and 1425X2277 did not show full recovery of P_N after rehydration. Similar reports of decline in g_s and P_N with increasing water deficit have been reported by Ni and Pallardy (1992) and Flexas *et al.* 2006. P_N in plants under water deficit were different compared to that of fully watered plants even after the recovery of g_s and Ψ_w, it can be inferred that 7418X1988 and 1425X2277 hybrids have greater sensitivity to water deficit in relation to its photosynthetic machinery compared to that of other hybrids. Tang *et al.* 2002 has reported that photosynthesis can be inhibited even when stomatal influence is eliminated implying that factors other than low CO_2 availability can affect photosynthesis. The decrease in P_N is related to closure of stomata under water deficit (Chaves *et al.* 2002) with no indication of damage to chloroplast reactions. P_N is also limited by lower ATP content caused by reduction in ATP synthase (Tezara *et al.* 1999).

Osmond *et al.* 1980 have reported that the first effect of reduction in g_s is an increase in WUE. In general, WUE in hybrids was increased due to reduced g_s leading to a decline in P_N. Similar findings have been reported in oil palm (Suresh *et al.* 2010) and *Styphnodendron adstringens* (Rocha and Moraes 1997). Better stomatal control in 7418X1988 hybrid has increased WUE under water deficit. Hybrids 690X1988 and 913X1988 recorded significantly lower WUE at 24 d water deficit, caused by a large reduction in P_N. In addition to it, 690X1988 showed the lowest Ψ_w at 24 d water deficit. In addition to g_s, leaf area, plant hydraulic conductivity and cuticular transpiration may increase water loss by leaves by reducing $\Psi_{w.}$ (Kramer and Boyer 1995). Hormonal balance plays an important role in gas-exchange characteristics of plants under water deficits by accumulation of abscisic acid and decreased cytokinins leading to stomatal closure (Pospisilova *et al.* 2000).

In general, electron transport rate can be considered as an overall measurement of photochemical activity and data reveals that it was reduced at 24 d of water deficit. There was a larger reduction in P_N in all hybrids after 12 d of water deficit, with the exception of 748X1988 due to lower g_s. Subsequently stomatal and nonstomatal factors could reduce P_N from 12th to 24th d of water deficit. The causes of decline in P_N could not be distinguished either by stomatal closure or impairment of photochemical or biochemical reactions. P_N of 7418X1988 and 1425X2277 hybrids did not show full recovery at 12th d of rehydration, which may be due to decreased ETR values. Probably, the greater stomatal control of 7418X1988 hybrid in maintaining higher leaf water potential caused a higher photoinhibitory effect due to a sharp reduction in C_i. On the contrary, hybrids 913X1988 and 748X1988 recorded full recovery of P_N values at 12 d after rehydration.

In our study, the Chl fluorescence measurements revealed that water deficit did not promote extensive photoinhibition as the F_v/F_m ratio was always more than 0.74 after 24 d of water deficit. The small but significant decrease in the F_v/F_m ratio in all hybrids under water deficit is probably due to some inactive PSII reaction centres in which some degradation of the D1 protein, responsible for transfer of water electrons to Chl *a* associated with PSII centres, has occurred (Lazár 1999). The progressive decrease in Φ_{PSII} and ETR in all hybrids at 24 d of water deficit might be due to the inability of the plastoquinone complex to carry out oxido-reduction reactions. The decrease in Q_L in all hybrids under water deficit indicated an increase in quinone A (Q_A) in the reduced state *i.e.* due to an increased proportion of closed PSII reaction centres (Dietz *et al.* 1985, Genty *et al.* 1989). A decrease in ETR in hybrids under water deficit can be considered as lesser tolerance to drought and an increase in NPQ in 7418X1988 hybrid may be an adaptative mechanism to counter excessive light energy when plants record lesser P_N. Yordanov *et al.* 2000 suggested that reduction in ETR might be caused by photochemical downregulation under environmental constraints.

Our findings indicate oil palm hybrids 913X1988, 1425X2277 and 7418X1988 maintained higher leaf water potentials than the other hybrids. Reduction in g_s particularly in 1425X2277 and 7418X1988 led to decreased P_N and increased WUE under water deficit. The decline in F_v/F_m during water deficit may be due to activation of protective mechanism in oil palm hybrids as rehydrated seedlings recovered their photosynthetic activity. The excess light energy produced due to decreased P_N in 7418X1988 hybrid under water deficit might be dissipated as heat by higher NPQ.

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