Physiological Plant Stress and Responses in Oil Palm

Mohd Roslan Md Noor*; Mohd Haniff Harun* and Nur Maisarah Jantan*

ABSTRACT

Physiological plant stress, particularly water stress, is discussed in this article. Observations made on oil palm seedlings and in the field are included. Assessment of plant water status was done through observations for stress symptoms and measurements on canopy temperature. Physiological responses of oil palm under different soil conditions, seasonal drought and different planting materials were also discussed. Important aspects of respiration are also included in this article.

INTRODUCTION

Detecting and estimating plant stress at the whole crop level is difficult, mainly because of the need to integrate an estimate based on the whole plant canopy. Water stress is one of the major limiting factors in oil palm growth and productivity because this is a rain-fed crop. Hence, water is essential for plant growth as it helps the opening of the stomata to enable gaseous exchange during photosynthesis. Plants also transpire water which they obtain from the soil and, in the process, translocate the nutrients absorbed by the roots to the above-ground plant components. Trees affect the amount and spatial distribution of rainfall that reaches the soil, with most of the area beneath tree crown receiving less than the open areas. This is because the tree crown intercepts some of the rainfall, which evaporates directly back to the atmosphere, whereas the rest reaches the soil either as through fall or stem flow. Several direct measurements can be performed on single plants to assess their water status, stress status, water deficit and their physiological consequences. At the whole plant level, important aspects of water deficit are its effects on plant appearance, development stage, growth, carbon assimilation, assimilate partitioning, and on the plant reproductive processes.

In field planting, water stress often occurs simultaneously with high light intensity and heat, which expose the plants to photo-inhibition and lead to a decrease in mesophyll photosynthesis. Soil water content affects the growth rate of wheat plants through its effects on the hardness of the soil, even when the soil water potential is high (Passiou- ra and Gardner, 1990). When the soil dries, many changes take place within it that could affect root behaviour and could induce the roots to send inhibitory signals to the leaves. Elongation of roots is strongly affected by the hardness of the soil. Plants may respond to water stress differently through varying degrees of drought tolerance whereby all mechanisms tend to maintain plant survival or productivity under drought conditions. In most cases, drought tolerance does not necessarily relate to high productivity. These mechanisms include stress avoidance, tolerance to water deficits and the presence of efficiency mechanisms. Davies and Zhang (1991) found that soil drying reduces both the expansion of individual leaves and the initiation of

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new leaves. Shading also improves transpiration efficiency by reducing heat stress that unshaded crops frequently experience in areas of high incident radiation and temperature (Ong et al., 2000). One of the major effects of the tree crown is to intercept radiation and thus reduce the energy reaching the soil or the crops beneath. This can reduce evaporation of water from the bare soil under the tree. In oil palm particularly, light interception increases with palm age which is an advantage under dry conditions.

In oil palm, Villalobos et al. (1991) found that the stomata close early in the dry season and remain closed for a short period that can vary over several weeks, depending on the severity of the drought and the water-holding capacity of the soil. They also found that stressed palms in Costa Rica have higher leaf water potential (LWP) and relative water content (RWC) than the irrigated palms. The effects of soil water deficit which are mediated via a reduction in leaf water potential during drought are small in oil palm as compared to other species (Henson and Chang, 1989). Abscisic acid levels increase markedly in leaves of nursery palms facing imposed drought (Henson et al., 1992) as does proline level (Mohd Haniff, 1997), but these responses are less evident in palms in the field (Henson and Chang, 1989).

Leaf gas exchange and chlorophyll fluorescence technology have helped greatly in understanding the responses of plants to environmental stresses. The increase in photosynthesis induced by CO₂ enrichment is associated with increased foliar concentrations of glucose, fructose and starch (but no change in sucrose) in the new growth. Light-driven chlorophyll ‘a’ fluorescence intensity instruments are commonly used to measure the photo-chemical activity of photosystem II (PSII) after heat and light stress. Pea plants grown at 22°C showed a decrease in the activity of PSII when exposed to high temperatures (above 40°C). High light intensifies the damage of PSII when exposed to high temperature, but low light strongly affects the response of the photosystem, acting as an efficient protector of the photochemical activity against its inactivation by heat. Heat protection is also triggered by exposing the leaves to a moderately elevated temperature, e.g. conditioning at 30°C, before exposing them to a high temperature of 40°C. Photo-inhibition resistance can be induced by exposing the leaves to high temperature for 15 min before exposing them to high light intensity. The experimental results show the existence of an adaptive mechanism in land plants to protect themselves against heat and strong light that usually change during the diurnal cycle of the day. Aquatic higher plants respond differently. Some are able to protect themselves at low light against heat stress.

In a water-stressed seedling experiment using two oil palm planting materials, seedlings under both wet and dry soil treatments were significantly different in their steady state chlorophyll fluorescence values, (Fₛ), at day 1 and day 10 after soil drying (Table 1). Seedlings experiencing soil drying had Fₛ values reduced to one-third after 10 days of soil drying. Although the watered seedlings showed stress, their PSII values were about double those of seedlings experiencing soil drying. Watered seedlings also experienced stress as indicated by PSII values < 0.80. This can be attributed to the high temperature and vapour pressure deficit (VPD) in the rain shelter during the day as recorded by the relative humidity (RH) and temperature sensors (Mohd Roslan, 2006).

**Drought Resistance and Crop Yield**

Crop breeding for drought resistance is very important for plants grown under dry or seasonally dry conditions. Research and breeding programmes on various crops have developed selection criteria for varieties with better yield and drought tolerance.

An important factor in yield stability is the ability to cope with drought and other abiotic plant stresses. Subsequently, yield-based selection programmes through the monitoring and mitigation of stress environments, followed by the development of physiological selection criteria for stress resistance, have been designed. More recently, molecular methods, such as marker-assisted selection, are being adopted to facilitate more efficient selection for distinct components of stress resistance. Lately, biotechnology is experimenting with genetic transformation to breed crops having drought resistance.

Crop survival is the ability of a crop to survive drought and to produce some yield (Passioura, 2002). Yield and water use are related in the model postulated by Arnold and de Wit (1976), which in its simple form can be expressed as:

\[
\text{Yield} = T \times \text{WUE} \times \text{HI},
\]

where \( T \) = total seasonal crop transpiration, \( \text{WUE} \) = crop water-use efficiency and \( \text{HI} \) = crop harvest index (the ratio of economic yield to the total above-ground biomass).

\( T \) is a component of ET (crop evapotranspiration), where evaporation denotes direct water loss from the soil.
Plant Development and Size

Plant size, expressed mainly in terms of a single plant’s leaf area or leaf area index (LAI), has major control over water use. Small plants and reduced leaf area are generally conducive to low productivity while they limit water use. Although such plants can withstand drought very well, their growth rate and biomass are relatively low.

The Root

The most important control of plant water status is by the root system, while the roots are associated with transpiration demand. The most important dimension is root depth, which facilitates deep soil moisture extraction where such moisture is available. This is a primary component of drought resistance. The development of lateral roots at very shallow soil depth may have a role in capturing small amounts of intermittent rainfall.

Another scenario of seasonal soil moisture status is when the crop is grown on stored soil moisture and there is little effective rainfall during the growing season. Under such conditions, the main consideration is to manage seasonal soil moisture use so that sufficient moisture will remain for growing the crop to maturity. The shoot/root mass ratio continuously decreases under drought stress, which is a universal expression of adaptation. The ratio changes mainly due to the reduction in shoot mass. Plant senescence is a genetically programmed process, accelerated by environmental stress such as drought, heat and nitrogen deficiency. The primary expression of leaf senescence is the breakdown of chlorophyll and the subsequent collapse of photosynthesis. This is shown by the yellowing of the lower fronds in oil palm.

Photosynthetic Systems and Water-use Efficiency

The C4- in contrast to the C3-type photosynthetic metabolism is intimately associated with superior adaptation to set conditions of environmental stress. As such, C4 plants are more efficient under certain stress conditions as compared to C3 plants. The C4-type metabolism results in greater heat tolerance for photosynthesis in that photosynthesis is optimized at close to 35ºC-40ºC. This is because of the ratio of oxygenase to carboxylase in the C3 plant, and the limitation imposed by intracellular CO2 concentration increase with temperature. In the C4 plant, the oxygenation and the intracellular CO2 limitation are avoided.

As water deficit develops, various solutes accumulate in the cells, and subsequently tissue osmotic potential (OA) is reduced. OA can be reduced merely by the concentration of cellular solution due to water loss. OA is probably one of the most crucial components of crop adaptation to drought stress. It helps maintain cellular turgor at a given leaf water potential, and thus delays wilting. Abscisic acid (ABA) accumulates in various plant parts when a plant is subjected to desiccation. ABA-responsive

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Progeny</th>
<th>Day of</th>
<th>Fluorescence at steady state (F&lt;sub&gt;s&lt;/sub&gt;)</th>
<th>Quantum efficiency (PSII)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>DxP</td>
<td>1</td>
<td>649.33 ±41.1a*</td>
<td>0.65 ±0.02a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>312.92 ±35.9b</td>
<td>0.53 ±0.03a</td>
</tr>
<tr>
<td>PS1.1</td>
<td></td>
<td>1</td>
<td>590.20 ±12.95a</td>
<td>0.69 ±0.01a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>396 ±61.2b</td>
<td>0.48 ±0.07b</td>
</tr>
<tr>
<td>Dry</td>
<td>DxP</td>
<td>1</td>
<td>645.67 ±28.27a</td>
<td>0.71 ±0.009a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>218.25 ±19.2b</td>
<td>0.21 ±0.02b</td>
</tr>
<tr>
<td>PS1.1</td>
<td></td>
<td>1</td>
<td>527.50 ±26.22a</td>
<td>0.61 ±0.02a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>229.92 ±21.2b</td>
<td>0.36 ±0.06b</td>
</tr>
</tbody>
</table>

Note: *means in the same column followed by the same letter are not significantly different using t-test at p=0.05.
genes are often assumed to be stress adaptive. The rationale is that if plants under stress consistently respond by producing ABA in the leaves and roots, then ABA must be important for coping with stress. The most prominent effect of ABA accumulation in the plant is stomatal closure that reduces transpirational water loss. Drought resistance is strongly dependent on genotype, and the ability to maintain high water status or high turgidity is very important.

**SELECTION FOR DROUGHT RESISTANCE BY ASSESSING PLANT WATER STATUS**

**Stress Symptoms**

When a plant’s water status is reduced, it loses its turgidity under stress by displaying various and sometimes very distinct symptoms. The most common symptom is leaf wilting, but this is not obvious in oil palm. Stress symptoms can also be expressed by delayed flowering if the stress occurs before the normal flowering time. In oil palm, water stress may induce an increase in male inflorescence production and hence lower the sex ratio. Water deficit can also cause reproductive failure. In oil palm, water stress may increase abortion of the female inflorescences and bunch failure. This is due to limited assimilates as a result of inhibition of current photosynthesis during stress. If current photosynthesis is not enough to support bunch development, reserves in the trunk that are below the crown are used up.

**Canopy Temperature**

As water deficit develops, canopy temperature differences among genotypes increase, and plant water status becomes the main source of this variation. Canopy temperature has been used to develop a crop water stress index as a tool for crop management. Canopy temperature measured by an infra-red thermometer during drought stress has also been developed as a rapid field screening method for the monitoring of plant water status under such stress conditions.

When pointed at the canopy, the instrument measures long-wave infra-red radiation emitted from the target in view. This radiation is proportional to the target body temperature. The first consideration in using the infra-red thermometer is having a legitimate target area which does not consist of anything besides the leaf canopy, such as the woody stems or the soil surface. Secondly, work which involves the comparison of the canopy temperatures of many genotypes may change with ambient conditions, therefore such work must be done under fairly stable atmospheric conditions.

Mohd Haniff and Mohd Roslan (2006) found that oil palms infected with *Ganoderma* basal stem rot experienced a diminishing supply of water and nutrients to the leaves due to necrosis at the base of the stems that affected the vascular transport system. Thus, the infected palms were under water stress and could be expected to have higher differences in temperature (ΔT) values than healthy palms (Figure 1).

**Soil Conditions**

A better understanding of the ecophysiology of plants in sandy soils will facilitate the prediction of the community succession (Niu et al., 2006). In general, soil erosion and sand deposition will influence soil quality and crop productivity.

A comparison was done on the performance of oil palms on well-drained and water-logged areas, the latter representing stress (Mohd Roslan et al., 2009b) (Figures 2 and 3). Based on the gas exchange measurements, the palms on sandy soil (well-drained) had a 115% higher CO₂ assimilation rate as compared to the palms on clayey soil (Table 2). This was attributed to a 12.4% higher leaf chlorophyll content and lower specific leaf area (SLA) which indicates thicker leaves in palms on sandy soil (Table 3). The water-use efficiency (WUE) of these palms was about 21% higher indicating a better water-saving mechanism.

**Seasonally Dry Area**

A water stress study was carried out at ESPEK Tanjung Genting, Sintok located in north Kedah, Malaysia (Mohd Roslan et al., 2009a). The site was chosen because of the seasonal dry period that occurs, beginning at the end of December and ending in March of the following year. The VPD during the seasonal dry period may reach up to 3.5 kPa (Figure 4). Comparisons of physiological responses were...
between photosynthetic rate and the internal CO₂. Carlson and Bazzaz (1980) reported similar observations to those depicted in Figures 5 to 7. WUE was found to be low in the irrigated palms in the fourth year of planting (Table 4). There was a significant difference in spear leaf extension rate between the two treatments, with the irrigated palms showing about double the extension rate as compared to the non-irrigated control palms (Figure 6).

**Soil Respiration**

In terms of soil respiration, it was found from an oil palm replanting and newly planted areas on drained peat that the respiration rate was affected by soil moisture. Soil moisture in turn influenced the soil respiration directly through the physiological processes of roots and microorganisms, and indirectly via the diffusion of substrate and oxygen, which were influenced by drainage and water level (Nur Maisarah *et al.*, 2009). The study found that the soil respiration rate was 50% higher in the newly developed peat area as compared to the replanted peat area. Meanwhile, the soil moisture content in the replanted peat area was 39% higher compared to the newly developed peat area.

Drier soil consists of more air spaces which facilitate the aerobic respiration of roots and microorganisms as compared to a water-logged soil that promotes anaerobic respiration. In an extreme environment, drier soils can affect soil respiration. A common concept is that CO₂ efflux is low under dry conditions, is maximum at intermediate soil moisture level, and is decreased when soil moisture

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**TABLE 2. GAS EXCHANGE MEASUREMENTS AT SG MANIK, PERAK**

<table>
<thead>
<tr>
<th>Site</th>
<th>Photosynthetic rate (μmol m⁻² s⁻¹)</th>
<th>Stomatal conductance (mmol m⁻² s⁻¹)</th>
<th>Intercellular CO₂ (ppm)</th>
<th>Evapotranspiration rate (mmol m⁻² s⁻¹)</th>
<th>WUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>10.55±0.55a</td>
<td>0.28±0.02a</td>
<td>309.20±3.16a</td>
<td>3.19±0.18a</td>
<td>3.19±0.14a</td>
</tr>
<tr>
<td>Clayey</td>
<td>4.90±0.66b</td>
<td>0.10±0.01a</td>
<td>307.68±9.81a</td>
<td>2.64±0.20a</td>
<td>2.64±0.30b</td>
</tr>
<tr>
<td>% difference</td>
<td>+115.00</td>
<td>+64.29</td>
<td>+0.49</td>
<td>+17.24</td>
<td>+20.80</td>
</tr>
</tbody>
</table>

Note: *means in the same column followed by the same letter are not significantly different using *t*-test at *p*=0.05. CO₂ – carbon dioxide. WUE – water-use efficiency.

**TABLE 3. OIL PALM LEAF CHARACTERISTICS AT SG MANIK, PERAK**

<table>
<thead>
<tr>
<th>Site</th>
<th>Specific leaf area (cm² g⁻¹)</th>
<th>Specific leaf dry weight (g cm⁻²)</th>
<th>Leaf moisture content (%)</th>
<th>Relative water content</th>
<th>Leaf chlorophyll content (SPAD unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>140.98±3.25a</td>
<td>0.007±0.00016a</td>
<td>69.39±0.85a</td>
<td>0.84±0.02a</td>
<td>67.31±1.19a</td>
</tr>
<tr>
<td>Clayey</td>
<td>142.70±5.40a</td>
<td>0.007±0.00025a</td>
<td>68.71±1.00a</td>
<td>0.86±0.240a</td>
<td>59.88±1.18b</td>
</tr>
</tbody>
</table>

Note: *means in the same column followed by the same letter are not significantly different using *t*-test at *p*=0.05.
is high because of depressed aerobic activity in the soil (Luo and Zhou, 2006).

Water stress in the soil also affects microbial growth by inducing dormancy of the spores produced by soil microorganisms (Schjöning et al., 2003). This limitation is also affected by the physical properties of the dry soil in that water-filled pores are too small to permit passage of gases. Water in the soil pores at high water content affects gaseous exchanges at the site of microbial and root activities (Luo and Zhou, 2006). The relationships between CO₂ efflux and soil water content are complex and involve numerous mechanisms which have to be understood as to how water stress can affect oil palm physiology and soil CO₂ efflux exchange. Thus, more studies should be conducted to investigate other factors such as soil temperature and biological conditions.

**CONCLUSION**

Physiological stress in oil palm may exist due to many factors. However, water has a great influence in oil palm growth as well as on the reproductive stage. Efforts to determine the exact contributing factors and to counteract these in a proper and ideal manner are crucial to enhance the continuous production of fresh fruit bunches throughout the economic life of the oil palm.
Figure 5. ACi curves at Tanjung Genting.

Figure 6. Spear leaf extension rate of palms at Tanjung Genting.

Figure 7. Water-use efficiency (WUE) of oil palms at Tanjung Genting.
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