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Influence of different methods and levels of irrigation using crop factor on physiological responses of oil palm (*Elaeis guineensis* Jacq.) in relation to fresh fruit bunch yield

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Abstract
The present investigation was carried out on eighteen years old oil palm plantation at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh with different methods and levels of irrigation water using crop factors to find out their influence on the physiological responses in relation to yield of fresh fruit bunches. The result obtained has indicated significantly highest relative water content (97.44%), photosynthetic rate (16.46µmol m^{-2} s^{-1}) and stomatal conductance (0.307mol m^{-2} s^{-1}) with micro-jet method of irrigation, whereas, significantly highest membrane stability index (25.26%) and chlorophyll content index (112.64) were observed with drip method of irrigation. Among the levels of irrigation water using crop factor 0.7 has recorded significantly highest photosynthetic rate (16.56 µmol m^{-2} s^{-1}) and stomatal conductance (0.295mol m^{-2} s^{-1}), whereas, relative water content (95.51%), membrane stability index (27.11%) and chlorophyll content index (126.25) were found significantly highest with crop factor 0.8. Among the interaction effects, significantly highest photosynthetic rate (18.73µmol m^{-2} s^{-1}) and stomatal conductance (0.322mol m^{-2} s^{-1}) were observed with micro-jet method of irrigation using crop factor 0.7, while the relative water content (98.00%), membrane stability index (28.85%), chlorophyll content index (127.96) and fresh fruit bunch yield were found significantly highest with drip method of irrigation using crop factor 0.8.

Keywords: Membrane stability index, oil palm, photosynthetic rate, relative water content, and stomatal conductance

Introduction
Oil palm (*Elaeis guineensis* Jacq.), native of forest belt of West Coast and Central Africa, where it benefits from the abundant rainfall received during major part of the year. Oil palm has been introduced in to India, to grow under the coastal humid tropics of peninsular India as a rain fed crop with the intension of reducing the dependency of importing edible vegetable oil from the western countries. However, a limitation in the period of rainy season and prolonged period of drought situation prevailing during growth and development of the crop, particularly under the changed climatic conditions causing serious moisture deficit which interfere in the physiological and biochemical mechanisms thus leading to a reduction in the productivity of oil palm fresh fruit bunch yield. In general, plants contend with a complexity of environmental challenges such as variations in the sunlight, heat, salinity and moisture availability as the seasons change and oil palm is no exception. Although variations in these parameters are not necessarily harmful, but beyond certain limits they become source of stress in the plant which impose limitations on the normal functioning of plant systems. Under extreme conditions, these stresses could kill the plant. To survive and remain productive under stress conditions, plants have evolved certain adaptive strategies, some of which are morphological while others are physiological (Jones *et al.,* 1981; Levit, 1980; Rao *et al.,* 1993) [13, 15,]. Photosynthesis is a process of conversion of solar energy into the chemical energy (carbohydrates) through the chlorophyll pigment by utilizing the available CO_2 and water which is required for the regular dynamics of plant. So, the plant's survival and production of economic yields under stressed conditions depend upon the photosynthetic ability of the plant under harsh environmental conditions (Lauteri *et al.,* 2014; Ambavaram *et al.,* 2014) [14, 2]. In general, severe drought conditions cause a reduction in the availability of moisture which may lead to closure of

stomata as a survival mechanism of the plant, thus physiological reactions disturbed which may cause a reduction in the photosynthetic efficiency of plant (Mafakheri *et al.*, 2010) [16]. Thus, the study of photosynthetic rate in stressed plants will help to understand how plants tolerate the water deficit conditions (Graca *et al.,* 2010) [11]. Closure of stomata is considered the first line of defense mechanism against dehydration (Hopper *et al.,* 2014) [12]. Stomata are regulated based on the level of water deficit and close partially and thus allowing carbon fixation during drought conditions with improved water use efficiency (Benešova *et al.*, 2012) [3]. Partial closure of stomata is due to availability of lower content of moisture in the soil thus resulting in the retention of limited available water rather than loosing into the atmosphere in the form of transpiration. Thus, water conservation in the plant system prevents the dryness and regulates the movement of CO_2 content through several other physiological and biochemical processes and fixes more carbon through certain alternate pathways, for example stomatal adjustment (Gilbert *et al.,* 2011; Nilsen *et al.*, 2014) [10, 17]. So, the plants which possess better stomatal regulation (aperture closure/open) are considered as more drought-tolerant. Understanding the behavior of oil palm and its responses to water deprivation through different methods of irrigation in combination with different levels of irrigation based on crop factors may provide an opportunity to understand the better option/options to identify the best water use efficiency system and thus irrigation water supply can be customized for the better utilization of moisture without hampering the yield of oil palm. Information thus generated will be helpful to the farming community of the region to select the best method of irrigation system and level of irrigation water using crop factor based on the environmental conditions, especially under the sub-optimal environments.

Material and methods

The present investigation was carried out on the existing eighteen years old oil palm plantation at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh and was laid out in a split-plot design with four replications consisting of main plot treatments with two different methods of irrigation systems and three sub-plot treatments of irrigation levels using crop factors based on the rate of evapotranspiration. The level of irrigation water using crop factor was calculated as described below by Rao *et al.*, (2016) [20].

Water requirement of a crop is the quantity of water required by the crop in a given period of time for its optimum growth under field conditions. It is a function of rainfall, soil water reserves and evapotranspiration. Water requirement varies from place to place depending on climatic conditions like sunshine hours, temperature, relative humidity, wind velocity, etc... This is the best available method to estimate crop water requirement from direct measurement of evapotranspiration. In this method, pan evaporation or penman's estimate of evaporation is multiplied by an appropriate crop factor. Water use of crop is very closely related to evaporation. In fact, crop water use is composed of evaporation of water from the soil surface and transpiration of water through the leaves. Combined together these two factors are named as evapotranspiration. While evaporation is easily measured, transpiration is not. Therefore, it is much simpler to relate the crop evapotranspiration to daily evaporation via a crop factor. A crop factor is related to the percent of ground covered by the crop canopy and therefore will vary depending on the crop stage. For an adult oil palm 0.7 is considered as crop factor. The following simple method of calculation has been devised based on the evaporation rates prevailing in the area especially during summer months.

Evaporation from pan evaporimeter: 6.70 mm (for example)

Crop factor: 0.7

Potential evapotranspiration (PE) = Pan evaporation × Crop factor

PE = 6.07 × 0.7 = 4.69 mm/day

46,900 L/day/ha as 1 mm of rainfall is equal to 1 L m^{-2}

Since 143 palms are accommodated in one hectare area, the quantity of water per palm per day works out to be 328 litres.

Water holding capacity at not less than 70% of the field capacity is acceptable and will not affect the FFB yield of oil palm significantly.

Therefore the minimum quantity of water to be applied will be:

4.69 mm × 70% = 3.283 mm/day or 32,830 L/ha/day or 220 L/palm/day.

The two methods of irrigation systems adopted were micro-jet and drip, while the three irrigation levels used were based on Crop Factors (CF) 0.6, 0.7 and 0.8. The treatments were: T_1: Micro-jet method of irrigation system using irrigation level crop factor 0.6; T_2: Micro-jet method of irrigation system using irrigation level crop factor 0.7; T_3: Micro-jet method of irrigation system using irrigation level crop factor 0.8; T_4: Drip method of irrigation system using irrigation level crop factor 0.6; T_5: Drip method of irrigation system using irrigation level crop factor 0.7; T_6: Drip method of irrigation system using irrigation level crop factor 0.8.

All the other physiological and yield parameters were recorded as per the time schedule framed mainly during the month of April where plants experience severe water deficit. Chlorophyll content index value of oil palm leaves was measured by using a hand held chlorophyll content meter *CCM*-200 (Opti-Sciences, Inc., Hudson, USA) in the present study. The instrument has 0.71 cm^2 measurement area and calculated as chlorophyll content index value based on absorbance measurements at 653 and 931 nm. Five measurements with hand held meter were recorded on each leaf disc of 500 cm^2 and mean of these values was used for analysis. The result was expressed as ‘Chlorophyll value’. Net photosynthetic rate (P_N) and Stomatal conductance (g_s) were recorded by using a portable Photosynthesis System (*LCA-4, ADC*, Hertfordshire, UK) which is also called infra red gas analyzer (IRGA) connected to a *PLC-4* (6.25 cm^2) leaf chamber, which works on the principle of heteroatomic molecules absorb infrared light at specific wave lengths. The measurements were made on a fully opened healthy leaf (3rd leaf from top) under bright sunshine between 10:00 AM to 11:00 AM hours. Measurement of water content in a tissue is expressed either on fresh weight or dry weight basis, has been recently replaced by the measurement based on maximum amount of water a tissue can hold. These measurements were referred to as relative water content. The method used was as per the procedure outlined by Catsky (1974) [4]. Membrane Stability Index of plant tissue was measured as per the procedure explained by Sairam *et al*. (2002) [23]. Average yield of fresh fruit bunches per palm in each treatment was multiplied with number of palms planted per hectare (143 palms) and expressed in tonnes. The data thus arrived was subjected to statistical analysis as per the procedure outlined by Panse and Sukhatme (1985).

Results and discussion

The data pertaining to chlorophyll content index of oil palm leaves (Table 1) has indicated non-significant differences with different methods of irrigation. Significant differences were observed in the chlorophyll content index of oil palm leaves with different levels of irrigation using crop factors. Among the levels of irrigation using crop factor 0.8 has recorded significantly highest chlorophyll content index value (126.25), whereas, level of irrigation using crop factor 0.6 has recorded significantly lowest chlorophyll content index value (94.68). Interaction effect between methods of irrigation and levels of irrigation using crop factors was found non-significant. However, application of irrigation water using crop factor 0.8 through drip method of irrigation recorded significantly highest chlorophyll content index (127.96), while, significantly lowest chlorophyll content index (93.88) was observed in the treatment of application of irrigation water using crop factor 0.6 through micro-jet method of irrigation. The data arrived has indicated an increase in the level of irrigation water has increased the chlorophyll content index but no significant differences were observed between the methods of irrigation. Similar kind of result was reported earlier by Sumesh *et al.* (2014) [25] in transgenic *Hevea* lines and is found in agreement with the present result.

The data pertaining to photosynthetic rate (Table 1) has recorded significant differences between the methods of irrigation, levels of irrigation water and their interactions. Significantly highest photosynthetic rate (16.46 µmol m^{-2} s^{-1}) was observed in the leaves of oil palm irrigated with micro-jet method of irrigation, whereas, significantly lowest photosynthetic rate (12.97 µmol m^{-2} s^{-1}) was observed with drip method of irrigation. Among the irrigation levels, significantly highest photosynthetic rate (16.56 µmol m^{-2} s^{-1}) was observed in the leaves of oil palm by application of irrigation water using crop factor 0.7 and was found at par with the application of irrigation water using crop factor 0.8 (15.85 µmol m^{-2} s^{-1}). Application of irrigation water using crop factor 0.6 has recorded significantly the lowest (11.75 µmol m^{-2} s^{-1}) photosynthetic rate. Interaction effect between the methods and levels of irrigation water was also found significant with regard to the photosynthetic rate. Significantly highest photosynthetic rate (18.73 µmol m^{-2} s^{-1}) was observed with micro-jet method of irrigation using crop factor 0.7 and was found at par with the application of irrigation water through micro-jet method of irrigation using crop factor 0.8 (18.53 µmol m^{-2} s^{-1}). Significantly lowest photosynthetic rate (11.36 µmol m^{-2} s^{-1}) was observed by application of irrigation water through drip method of irrigation using crop factor 0.6. Water applied through micro-jet method of irrigation recorded significantly higher rate of photosynthetic activity in comparison to drip method of irrigation irrespective of the crop factor. Water stress conditions observed during growth of oil palm not only causes a general reduction in size but also exhibits a characteristic modification in the leaves *i.e.*, reduced leaf area. Such type of condition generally leads to early closing of stomata which may lead to a reduction in the gaseous exchange between the plant and external atmosphere thereby a decreased rate of photosynthesis observed which is ultimately related to yield loss (Rees, 1961; Corley *et al*. 1973; Suresh and Nagamani, 2006) [19, 5, 27] in crop plants. However, there is a big controversy over this issue, whether water deficit limits the rate of photosynthesis by stomatal closure or the metabolic damage occurred in the cell. The canopy of oil palm posses older leaves at the base and is always shaded by the upper leaves. Under such conditions, the ability of palms to have a better photosynthetic rate at low irradiance assumes greater significance. Leaves of many species show a steady increase in their photosynthetic rate during leaf expansion (Šesták, 1985) [24], but the oil palm leaflets remain tightly folded against the rachis during the expansion phase hence, photosynthesis might have not taken place.

Significant differences were observed in the stomatal conductance (Table 1) of oil palm leaves with different methods of irrigation and in the interaction effect. Significantly highest stomatal conductance (0.307 mol m^{-2} s^{-1}) was observed in the leaves of oil palm by application of irrigation water through micro-jet method of irrigation than drip method (0.241 mol m^{-2} s^{-1}) of irrigation. Stomatal conductance was observed non-significant among levels of irrigation water using crop factors. Significant differences were observed in the interaction effect of stomatal conductance between methods of irrigation and levels of irrigation water using crop factors. Significantly highest stomatal conductance (0.322 mol m^{-2} s^{-1}) was observed with micro-jet method of irrigation using crop factor 0.7 and was found at par with micro-jet method of irrigation using crop factor 0.8 and 0.6. Significantly lower stomatal conductivity was observed in the oil palm leaves applied irrigation water through drip method of irrigation. Significantly lowest stomatal conductance (0.216 mol m^{-2} s^{-1}) was observed with drip method of irrigation using crop factor 0.8. Stomatal regulation in oil palm is delicate and enables the plant to minimize the water losses in the event of water stress. A reduction in the stomatal conductance is one of the initial responses used by plants during the period of water stress for decreasing the rate of transpiration and turgor maintenance (Eckstein and Robison 1996). When the rate of transpiration is reduced due to stomatal closure, it will also reduce the rate of photosynthesis (*de* Souza *et al*., 2001) [6]. The net photosynthetic rate and stomatal conductance of attached leaves of sunflower decreased as leaf water potential declined (Tezara *et al*. 2008) [28]. Flexas *et al*. (2006) [8] reported a decrease in the rate of stomatal conductance and photosynthetic rate as the plants were subjected to increased water stress.

Significant differences were observed in the relative water content (Table 1) of leaves with different methods and levels of irrigation. Significantly highest relative water content (97.44%) in the leaves was observed with drip method of irrigation than micro-jet method of (91.71%) of irrigation. Among the irrigation levels, significantly highest relative water content (95.51%) was observed by application of irrigation water using crop factor 0.8. Interaction effect of RWC between methods and levels of irrigation water using crop factor was found non-significant. However, highest relative water content (98.00%) of leaves was observed with drip method of irrigation using crop factor 0.8, whereas, lowest (90.82%) RWC was observed with micro-jet method of irrigation using crop factor 0.7. Relative water content in the leaves of oil palm irrigated with micro-jet or drip method of irrigation has shown no definite trend with the amount of irrigation level increased. Maintenance of normal physiological processes under stress conditions require sufficient cell turgidity or relative water content with less injury to the cell membrane. A small quantity of water loss should therefore cause a shift in turgor so that the leaves tend to maintain high relative water content to retain a high symplast volume which indicates that under water deficit conditions the maintenance of high relative water content is more important in conferring the drought tolerance in the palms. Sun *et al.*, (2011) [26] reported that relative water content in the leaves is integrated with physiological traits regulated by water stress.

Significant differences were observed in the membrane stability index (Table 1) of oil palm leaves with different methods and levels of irrigation. Significantly highest membrane stability index (25.26%) of the leaves was observed with drip method of irrigation than micro-jet method of (19.75%) of irrigation. Among the levels of irrigation, significantly highest membrane stability index (27.11%) was observed by application of irrigation water using crop factor 0.8, whereas, significantly lowest membrane stability index (17.25%) was observed by application of irrigation water using crop factor 0.6. Interaction effect between methods of irrigation and levels of irrigation water using crop factors on membrane stability index was found significant. Significantly highest membrane stability index (28.85%) was observed by application of irrigation water using crop factor 0.8 through drip method of irrigation, whereas, significantly lowest membrane stability index (13.01%) was recorded by application of irrigation water using crop factor 0.6 through micro-jet method of irrigation. Abbas (2012) [1] reported that drought, salinity, high and low temperatures damage the structure of cell membrane thereby leading to an increase in the membrane permeability and thus resulting in the leakage of intracellular contents. Maintenance of membrane structure and integrity is the key factor in the water stress tolerance. Membrane integrity is usually determined by reducing the leakage of solutes (electrolytes, sugars, amino acids, organic acids and hormones) from cells. The capacity of stem for mobilization or translocation of reserves appears to be related to drought tolerance or resistance which could be due to accumulation of ABA in response to water stress.

The data pertaining to yield of fresh fruit bunches per palm per year (Table 1) has recorded non-significant differences between the methods of irrigation. However, application of different levels of irrigation water based on crop factors have recorded significant differences with regard to yield of fresh fruit bunches per palm per year. Among the levels of irrigation, significantly highest annual yield of fresh fruit bunches (19.83 t/ha) was observed by application of irrigation water using crop factor 0.7 and was found at par with the application of irrigation water using crop factor 0.8. Significantly lowest annual yield of fresh fruit bunches per palm per year was observed by application of irrigation water using crop factor 0.6 (17.57 t/ha). Interaction effect between methods of irrigation and levels of irrigation using crop factors on the annual yield of fresh fruit bunches was found non-significant. However, highest annual yield of fresh fruit bunches (21.23 t/ha) was recorded by drip method of irrigation using crop factor 0.8 followed by micro-jet method of irrigation using crop factor 0.8 (19.68 t/ha). Lowest annual yield of fresh fruit bunches (16.51 t/ha) was observed with drip method of irrigation using crop factor 0.6. Number of fresh fruit bunch production in oil palm depends upon the number of productive female inflorescences produced. A small reduction in the number of leaves produced due to shortage of water showed an amplification of inhibitory effect on the number of female inflorescences produced thereby a reduction was observed in the number of fresh fruit bunches per palm per year which ultimately led to a reduction in the annual yield of fresh fruit bunches. A small shortage in the application of irrigation water to the palms showed a reduction in the number of female inflorescences produced accordingly the number of fresh fruit bunches produced was influenced which led to a reduction in the annual yield of fresh fruit bunches per palm per year. Gawankar *et al.* (2003) and Rao (2009) [22] also reported similar kind of observations in their earlier studies on oil palm which supports the present investigation.

Table 1: Effect of methods of irrigation and levels of irrigation using crop factors on physiological response to yield of oil palm

Treatments	Chlorophyll content index	Photosynthetic rate (μmol m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})	Relative water content (%)	Membrane stability index (%)	Yield of fresh fruit bunches (t/ha)
Irrigation methods (M)						
M_1 (Micro-jet)	111.76	16.46	0.307	91.71	19.75	19.84
M_2 (Drip)	112.64	12.97	0.241	97.44	25.26	18.17
LSD (p = 0.05)	NS	1.190	0.042	0.917	1.222	NS
Irrigation levels (L)						
(L_1) Crop factor 0.6	94.68	11.75	0.262	94.54	17.25	17.57
(L_2) Crop factor 0.7	115.67	16.56	0.295	93.67	23.15	19.83
(L_3) Crop factor 0.8	126.25	15.85	0.266	95.51	27.11	19.61
LSD (p = 0.05)	4.217	1.330	NS	0.956	1.796	1.944
Interaction of M x L						
M_1L_1	93.88	12.13	0.284	91.29	13.01	18.62
M_1L_2	116.85	18.73	0.322	90.82	20.87	19.55
M_1L_3	124.55	18.53	0.316	93.01	25.38	19.68
M_2L_1	95.48	11.36	0.239	97.78	21.48	16.51
M_2L_2	114.48	14.39	0.267	96.52	25.44	18.44
M_2L_3	127.96	13.17	0.216	98.00	28.85	21.23
LSD (p = 0.05)	NS	1.450	0.049	NS	2.709	NS

Based on the results obtained, it could be observed that several of the physiological parameters were influenced by supplemental irrigation water applied at different levels based on the crop factors rather than the method of irrigation during the critical periods of growth and development, which ultimately influenced the final output in terms of FFB yield. An increase in the level of irrigation water led to better maintenance of relative water content and membrane stability index in the plant, which favored opening of stomata thus taking gaseous exchange which ultimately favored accumulation of more photo-assimilates which contributed for better growth and development in terms of fresh fruit bunches.

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